

ENGINEERING SCIENCES

Programme Code: ENGG00

Programme Outcome:

Designed to orient students to take up the challenging assignments relating to front end and back end of Nuclear Fuel Cycle across all units of DAE, reactor design and development aimed at peaceful use of nuclear power for power generation, isotope production for medical, health, agricultural and food irradiation and support maintenance and operation of existing reactor systems.

DETAILED COURSE STRUCTURE

COURSE STRUCTURE - MECHANICAL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502-503	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Nuclear Fuel Cycle Technology	EN508	35	2	150
5	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
6	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			220+15	15	875

CORE ENGINEERING (MECHANICAL)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Code design for Process Equipment	EN610	30	2	125
2	Computational Fluid Dynamics & Heat Transfer	EN611	50	3	200
3	Code design for Nuclear Pressure Vessels & Piping	EN614	30	2	125
4	Advanced Machine Design	EN617	25+5	2	100
5	Finite Element Method	EN621	30	2	125
6	Fracture Mechanics	EN622	20	1	75
7	Mechanics of Solids	EN624	40+5	3	150
CORE TOTAL			225+10	15	900

ELECTIVES (MECHANICAL - Any 3 Courses - 9 Credits)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	2	100
2	Advanced Fracture Mechanics	EN704	30	2	100
3	Fluid Power Technology	EN709	25+5	2	100
4	Material Science in Nuclear Engineering - ME	EN712	25+5	2	100
5	Multi-scale material Modeling	EN715	30	2	100
6	Emergency Preparedness & Response	EN716	29+1	2	100
7	Reliability Engineering - ME	EN718	30	2	100
8	Vibrations	EN721	25+5	2	100
9	Radiation Damage of Metals and Alloys	EN724	25+5	2	100
ELECTIVE TOTAL			90+21	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

COURSE STRUCTURE - CHEMICAL ENGINEERING**NUCLEAR ENGINEERING (FOUNDATION COURSES)**

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502-503	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Nuclear Fuel Cycle Technology	EN508	35	2	150
5	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
6	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			220+15	15	875

CORE ENGINEERING (CHEMICAL)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Chemical Reaction Engineering	EN601	25+5	2	100
2	Advanced Mass Transfer	EN604	25+5	2	100
3	Code design for Process Equipment	EN610	30	2	125
4	Computational Fluid Dynamics & Heat Transfer	EN611	50	3	200
5	Nuclear Chemical Engineering	EN628	35	2	150
6	Advanced Process Instrumentation & Control	EN634	45	3	200
7	Process Modeling, Simulation and Optimization	EN635	45	3	200
CORE TOTAL			225	17	1075

ELECTIVES (CHEMICAL) - Any 3 Courses

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	2	100
2	Fluid Power Technology	EN709	25+5	2	100
3	Material Science in Nuclear Engineering-ME	EN712	25+5	2	100
4	Membrane Technology	EN714	25+5	2	100
5	Molecular Engineering	EN725	20+5	2	100
ELECTIVE TOTAL			80+20	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

Total Contact Hrs: 555; Total Credits: 42; Total Marks: 2825

COURSE STRUCTURE – METALLURGY**NUCLEAR ENGINEERING (FOUNDATION COURSES)**

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502-503	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Nuclear Fuel Cycle Technology	EN508	35	2	150
5	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
6	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			220+15	15	875

CORE ENGINEERING (METALLURGY)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Corrosion	EN615	15	1	75
2	Extractive Metallurgy of Less Common Metals	EN620	40+5	3	150
3	Mechanical Metallurgy	EN623	40+5	3	150
4	Nuclear Materials	EN629	50	3	200
5	Nuclear Metallurgy	EN630	30	2	125
6	Physical Metallurgy	EN631	40+5	3	150
7	Process Control & Instrumentation (MT)	EN632	25+5	2	100
CORE TOTAL			230+20	17	950

ELECTIVES (METALLURGY) - Any 3 Courses - 6 Credits

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Computational Techniques	EN701	30	2	100
2	Materials Characterization	EN713	30	2	100
3	Multi scale Material Modeling	EN715	30	2	100
4	Emergency Preparedness & Response	EN716	29+1	2	100
5	Welding Science & Technology	EN723	25+5	2	100
6	Radiation Damage of Metals and Alloys	EN724	25+5	2	100
7	Molecular Engineering	EN725	20+10	2	100
ELECTIVE TOTAL			85+21	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

Total Contact Hrs: 535+56; Total Credits: 41-42; Total Marks: 2725

COURSE STRUCTURE - CIVIL ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502-503	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Nuclear Fuel Cycle Technology	EN508	35	2	150
5	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
6	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			220+15	15	875

CORE ENGINEERING (CIVIL)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Civil Engg Design of Concrete & Steel Strcts I	EN608.1	30	2	125
2	Civil Engg Design of Concrete & Steel Strcts II	EN608.2	30	2	125
3	Design Basis Hazards & Geotechnical Engg	EN626	40+5	3	150
4	Earthquake Engineering & Structural Dynamics	EN609	45	3	200
5	Finite Element Method	EN621	30	2	125
6	Mechanics of Solids	EN624	40+5	3	150
CORE TOTAL			215+10	15	875

ELECTIVES (CIVIL) - Any 3 Courses

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Construction Materials, Management & Quality Assurance	EN708	30	2	100
2	Project Management	EN717	25+5	2	100
3	Safety & Reliability of Civil Engineering Structures (Mandatory)	EN722	25+5	2	100
4	Service Life Estimation and Retrofitting of Concrete Structures	EN710	25+5	2	100
5	Beyond Design Basis Events: Concepts and Assessment of Civil Structures	EN711	25+5	2	100
ELECTIVE TOTAL			80+20	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

Total Contact Hrs: 515; Total Credits: 40; Total Marks: 2650

COURSE STRUCTURE - ELECTRICAL ENGINEERING
NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502, 505	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Material Science in Nuclear Engineering	EN507	20	1	75
5	Nuclear Fuel Cycle Technology	EN508	35	2	150
6	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
7	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			240+15	16	950

CORE ENGINEERING (ELECTRICAL)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design I	EN602	25+5	2	75
2	Computer Based System Design	EN612	35	2	150
3	Electrical Systems for Nuclear Power Plants and Facilities	EN618	35	2	125
4	Modern Control Systems Design and Simulation	EN625	35	2	150
5	Process Instrumentation & Control	EN633	30	2	125
6	Reactor Control Engineering & Instrumentation	EN637,638	45	3	150
7	Reliability Engineering (EE)	EN639	25+5	2	75
CORE TOTAL			230+10	15	850

ELECTIVES (ELECTRICAL) - Any 3 Courses

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electrical Engg. Design-II	EN702	25+5	2	100
2	Artificial Intelligence, Machine Learning & Applications	EN703	30	2	100
3	Digital Signal Processing, Image Processing & Applications	EN706	30	2	100
4	Embedded Electronics Software and System Security	EN707	25+5	2	100
5	Signal Conditioning, Recovery and EMI Aspects	EN719	30	2	100
6	Software Engineering	EN720	25+5	2	100
ELECTIVE TOTAL			80+15	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

Total Contact Hrs: 550; Total Credits: 41 ; Total Marks: 2700

COURSE STRUCTURE - ELECTRONICS ENGINEERING**NUCLEAR ENGINEERING (FOUNDATION COURSES)**

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502, 505	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Material Science in Nuclear Engineering	EN507	20	1	75
5	Nuclear Fuel Cycle Technology	EN508	35	2	150
6	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
7	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			240+15	16	950

CORE ENGINEERING (ELECTRONICS)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Electronic Circuit Design Techniques	EN603	30	2	125
2	Advanced Nuclear Instrumentation	EN605	40+5	3	150
3	Embedded & Computer Based Sys. Design	EN619	40+5	3	200
4	Process Instrumentation & Control	EN633	30	2	125
5	Reactor Control Engineering & Instrumentation	EN637-8	45	3	150
6	Reliability Engineering (EE)	EN639	25+5	2	75
CORE TOTAL			210+15	15	825

ELECTIVES (ELECTRONICS) - Any 3 Courses

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence, Machine Learning & Applications	EN703	30	2	100
2	Digital Signal Processing, Image Processing & Applications	EN706	30	2	100
3	Embedded Electronics Software and System Security	EN707	25+5	2	100
4	Signal Conditioning, Recovery and EMI Aspects	EN719	30	2	100
5	Software Engineering	EN720	25+5	2	100
ELECTIVE TOTAL			90+10	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

Total Contact Hrs: 540 ; Total Credits: 41 ; Total Marks: 2675

COURSE STRUCTURE - INSTRUMENTATION ENGINEERING

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502, 505	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Material Science in Nuclear Engineering	EN507	20	1	75
5	Nuclear Fuel Cycle Technology	EN508	35	2	150
6	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
7	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			240+15	16	950

CORE ENGINEERING (INSTRUMENTATION)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Applied Process Instrumentation	EN607	40+5	3	150
2	Computer Based System Design	EN612	35	2	150
3	Modern Control Systems Design and Simulation	EN625	35	2	150
4	Reactor C&I and Human Machine Interface	EN636	35	2	150
5	Reactor Control Engineering & Instrumentation	EN637-8	45	3	150
6	Reliability Engineering	EN639	25+5	2	75
CORE TOTAL			215+10	14	825

ELECTIVES (INSTRUMENTATION) - Any 3 Courses

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence, Machine Learning & Applications	EN703	30	2	100
2	Digital Signal Processing, Image Processing & Applications	EN706	30	2	100
3	Embedded Electronics Software and System Security	EN707	25+5	2	100
4	Signal Conditioning, Recovery and EMI Aspects	EN719	30	2	100
5	Software Engineering	EN720	25+5	2	100
ELECTIVE TOTAL			90+10	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

Total Contact Hrs: 535 ; Total Credits: 40 ; Total Marks: 2675

COURSE STRUCTURE - COMPUTER SCIENCE

NUCLEAR ENGINEERING (FOUNDATION COURSES)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Accelerator Physics and Technology	EN501	40+5	3	150
2	Engineering Mathematics	EN502, 505	30	2	125
3	Health Physics and Rad & Indl Safety	EN506	20	1	75
4	Material Science in Nuclear Engineering	EN507	20	1	75
5	Nuclear Fuel Cycle Technology	EN508	35	2	150
6	NPP & Advanced Reactor Concepts	EN509	40+5	3	150
7	Reactor Physics and Engineering	EN510	55+5	4	225
FOUNDATION TOTAL			240+15	16	950

CORE ENGINEERING (COMPUTER SCIENCE AND ENGINEERING)

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Advanced Operating Systems	EN606	25+5	2	75
2	Computer Graphics & Visualisation	EN613	25+5	2	75
3	Distributed Computing	EN616	25+5	2	75
4	Network & Information Security	EN627	45	3	200
5	Reactor Control Engineering & Instrumentation-1	EN637	25+5	2	75
6	Reliability Engineering	EN639	25+5	2	75
7	Software Design Practices & Formal Method	EN640	40+5	3	75
8	Machine Learning and Big Data Analytics	EN641	25+5	2	75
CORE TOTAL			230+35	18	725

ELECTIVES (COMP. SCIENCE AND ENGINEERING) - Any 3 Courses

Sr. No	Subject Title	Course Code	Hours	Credits	Marks
1	Artificial Intelligence, Machine Learning & Applications	EN703	30	2	100
2	Data Base Management System & Web Technology	EN705	30	2	100
3	Digital Signal Processing, Image Processing & Machine Vision	EN706	30	2	100
4	Embedded Electronics Software and System Security	EN707	25+5	2	100
ELECTIVE TOTAL			85+5	6	300

SKILL ENHANCEMENT & ASSESSMENT

Sr. No	Subject Title	Course Code	Credits	Marks
1	Viva Voce (I & II)	EN591	NA	200
2	Practicals	EN592	NA	100
3	Mini Project	EN593	4	300
TOTAL			4	600

Total Contact Hrs: 555 ; Total Credits: 44 ; Total Marks: 2575

FOUNDATION COURSES COORDINATOR

Course	Coordinators	Contact
EN501: Accelerator Physics and Technology	Dr. K Rajesh	krajesh@barc.gov.in
EN502: Engineering Maths-I (All Engg)	Dr. K. P. Singh	kpsingh@barc.gov.in
EN503: Engineering Maths-II (ME Group)	Dr. K. P. Singh	kpsingh@barc.gov.in
EN504: Engineering Maths-II (MT)	Dr. K. P. Singh	kpsingh@barc.gov.in
EN505: Engineering Maths-II (EE Group)	Dr. K. P. Singh	kpsingh@barc.gov.in
EN506: Health Physics and Radiological & Industrial Safety	Dr. M K Sureshkumar	smk@barc.gov.in
EN507: Material Science in Nuclear Engineering (EE)	Dr. Supratik Roychowdhury	supratik@barc.gov.in
EN508: Nuclear Fuel Cycle Technology	Dr. (Smt) Tessy Vincent	tessyv@barc.gov.in
EN509: Nuclear Power Plants Engineering & Advanced Reactor Concepts	Shri D. Naga Sivayya Shri Santanu Pahari Dr. Naveen Kumar	dnsiva@igcar.gov spahari@npcil.co.in nkumar@hbni.ac.in
EN510: Reactor Physics & Engineering	Dr. Anurag Gupta Shri. M. V. Gathibandhe, RPD	anurag@barc.gov.in manoharg@barc.gov.in

CORE COURSES COORDINATOR

Course	Coordinators	Contact
EN601: Advanced Chemical Reaction Engineering	Dr. K. K. Singh	kksingh@barc.gov.in
EN602: Advanced Electrical Engineering Design-I	Shri S. Malhotra	sanjaym@barc.gov.in
EN603: Advanced Electronic Circuit Design Techniques	Shri C. P. Kulkarni	cpkulk@barc.gov.in
EN604: Advanced Mass Transfer	Dr. G. Sugilal	gsugilal@barc.gov.in
EN605: Advanced Nuclear Instrumentation	Shri S. P. Borkar	bsuhas@barc.gov.in
EN606: Advanced Operating Systems	Shri K. Rajesh	rajesh@barc.gov.in
EN607: Applied Process Instrumentation	Shri Partha Das	parthad@barc.gov.in
EN608.1 Civil Engineering Design of Concrete and Steel Structures-I	Dr. Praveen Kumar	praveen@barc.gov.in
EN608.2 Civil Engineering Design of Concrete and Steel Structures-II	Dr. (Smt) Y. A. Prulekar Dr. A. Mondal	yogitap@barc.gov.in apurba@npcil.co.in
EN609 Earthquake Engineering and Structural Dynamics	Dr. (Smt) Y. A. Parulekar Dr. A. Mondal	yogitap@barc.gov.in apurba@npcil.co.in
EN610 Code design for Process Equipment	Dr. J. Chattopadhyay	jchatt@barc.gov.in
EN611: Computational Fluid Dynamics & Heat Transfer	Dr. Naveen Kumar	nkumar@hbni.ac.in
EN612: Computer Based System Design	Shri S. K. Lalwani	skl@barc.gov.in
EN613: Computer Graphics and Visualization	Shri Dinesh Sarode	dinesh@barc.gov.in
EN614: Code design of Nuclear Pressure Vessels & Piping	Dr. J. Chattopadhyay	jchatt@barc.gov.in
EN 615: Corrosion	Dr. Supratik Roychowdhury	supratik@barc.gov.in
EN616: Distributed Computing	Shri K. Rajesh	rajesh@barc.gov.in
EN 617: Advanced Machine Design	Shri K.J. Thomas Dr. I.A Khan	imran@barc.gov.in
EN618: Electrical Systems for Nuclear Power Plants and Facilities	Dr. Shakti Prasad Panda	sppanda@npcil.co.in
EN 619: Embedded & Computer Based System Design	Shri. S. K. Lalwani	skl@barc.gov.in
EN620: Extractive Metallurgy	Dr. A. Awasthi	aawasthi@barc.gov.in

EN 621: Finite Element Method	Dr. A. K. Dureja	akdureja@barc.gov.in
EN622: Fracture Mechanics	Dr. Chattopadhyaya	jchatt@barc.gov.in
EN623: Mechanical Metallurgy	R. N. Singh	rnsingh@barc.gov.in
EN624: Mechanics of Solids	Dr. Suneel K. Gupta	suneelkg@barc.gov.in
EN625: Modern Control Systems Design and Simulation	Dr. S. R. Shimjith	srshim@barc.gov.in
EN626 Design Basis Hazards and Geotechnical Engineering	Shri. A. D. Roshan Dr. V. S. Phanikant	phani@barc.gov.in
EN627: Network and Information Security	Shri. Gigi Joseph	gigi@barc.gov.in
EN628: Nuclear Chemical Engineering	Shri. M. S. Deshpande	msd@barc.gov.in
EN629: Nuclear Materials	Dr. T. Mahata	tsmahata@barc.gov.in
EN630: Nuclear Metallurgy	Dr. Sudhir Mishra	sudhir@barc.gov.in
EN631: Physical Metallurgy	Dr. S. Neogy	neosuman@barc.gov.in
EN632: Process Control and Instrumentation (MT)	Smt. Rajalakshmi R	rajlaxmi@barc.gov.in
EN633: Process Instrumentation & Control (EE)	Shri Partha Das	parthad@barc.gov.in
EN634: Advanced Process Instrumentation & Control	Dr. Shimjith	srshim@barc.gov.in
EN635: Process Modelling, Simulation & Optimization	Dr. K. K. SinghS	kksingh@barc.gov.in
EN636: Reactor Control & Instrumentation and Human Machine Interface	Shri. D. A. Roy	daroy@barc.gov.in
EN637: Reactor Control Engineering & Instrumentation-I	Smt. Ratna Bhamra	rbhamra@barc.gov.in
EN638: Reactor Control Engineering & Instrumentation-II	Shri. P. V. Bhatnagar Smt. Ratna Bharma	pvbhat@barc.gov.in rbhamra@barc.gov.in
EN639: Reliability Engineering (EE)	Dr. (Smt) Gopika Vinod	vgopika@barc.gov.in
EN640: Software Design Practices and Formal Method	Dr. Ajith K. John	ajith@barc.gov.in
EN641: Machine Learning and Big Data Analytics	Shri. Gigi JosephS	gigi@barc.gov.in

ELECTIVES COURSES COORDINATOR

Course	Coordinators	Contact
EN701: Advanced Computational Techniques	Shri. K. Rajesh	rajesh@barc.gov.in
EN702: Advanced Electrical Engineering Design-II	Shri. S. Malhotra	sanjaym@barc.gov.in
EN703: Artificial Intelligence, Machine Learning & Applications	Shri. Dinesh Sarode	dinesh@barc.gov.in
EN704 Advanced Fracture Mechanics	Dr. Suneel Gupta	suneelkg@barc.gov.in
EN705: Data Base Management System and Web Technology	Shri. J. J. Kulkarni	jjk@barc.gov.in
EN706: Digital Signal Processing, Image Processing & Applications	Shri. M. Padmanabhan	mpadmana@barc.gov.in
EN707: Embedded Electronics Software and Embedded System Security	Dr Amol Wakankar	amolk@barc.gov.in
EN708: Construction Materials, Management and Quality Assurance	Dr. M. K. Pradhan	mpradhan@barc.gov.in
EN709: Fluid Power Technology	Shri. P. K. Limaye	pklimaye@barc.gov.in
EN710: Service Life Estimation and Retrofitting of Concrete Structures	Dr. Yogita Parulekar Dr. Praveen Kumar	yogitap@barc.gov.in praveen@barc.gov.in
EN711: Beyond Design Basis Events: Concepts and Assessment of Civil Structures	Dr. Ajai S Pisharady Dr. Rajiv Ranjan	aspisharady@aerb.gov.in rranjan@npcil.co.in
EN712: Material Science in Nuclear Engineering-ME	Dr. Supratik Roychowdhury	supratik@barc.gov.in
EN713: Materials Characterisation	Dr. B. Vishwanadh	bvisu@barc.gov.in
EN714: Membrane Technology	Dr. A. K. Ghosh	akghosh@barc.gov.in
EN715: Multi-Scale Material Modeling	Dr. M. K. Samal	mksamal@barc.gov.in
EN716: Emergency Preparedness and Response	Shri Probal Chaudhury	probal@barc.gov.in
EN717: Project Management	Shri. Arindam Pal	apal@npcil.co.in
EN718: Reliability Engineering (ME)	Dr. (Smt) Gopika Vinod	vgopika@barc.gov.in
EN719: Signal Conditioning, Recovery & EMI Aspects	Dr. Sanjay Malhotra	sanjaym@barc.gov.in
EN720: Software Engineering	Dr. Ajith John	ajith@barc.gov.in
EN721: Vibrations	Shri. M. K. Agarwal	mkagra@barc.gov.in
EN722: Safety and Reliability of Civil Engineering Structures	Dr. K. Bhargava	kapil_66@barc.gov.in
EN723: Welding Science and Technology (MT)	Dr. A.Laik	laik@barc.gov.in
EN724: Radiation Damage of Metals and	Dr. S. Neogy	neosuman@barc.gov.in

Alloys (ME & MT)		
EN725: Molecular Engineering (CH & MT)	Dr. S. K. Musharaf Ali	musharaf@barc.gov.in

FOUNDATION COURSES

EN501: Accelerator Physics and Technology (40 Lecture Hrs)

Coordinator: Dr. K Rajesh
(krajesh@barc.gov.in)

Course Details:

- **Basic Accelerator Physics**

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

- **RF Linacs**

- **Introduction to Linacs**

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

- **Proton Linac**

- Linac structures: Radiofrequency Quadrupole linac, DTL, CCDTL, CCL, IH linac, CH linac.

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- RF superconductivity & introduction of superconducting RF structures, effects of RF frequency selection, Advantages of SC systems over room temperature ones, Breakdown mechanisms in superconducting cavities.
 - Introduction to Space charge effects.
 - Beam diagnostics for measurement of beam current, position, profile, energy and emittance.
 - Accelerator Driven Systems & RF electron accelerators
 - Electron beam generation, propagation and applications in generation of microwaves. RF electron accelerators.
- **Accelerator Technology**
 - **General**
 - Material selection for Accelerator components
 - Mechanical Design and fabrication issues; tolerances, surface finish, etc
 - Thermal management in accelerator systems
 - Alignment requirements of accelerator magnets and RF structures, method and instruments for alignment and surveying in accelerators.
 - **Ultra High Vacuum Systems**
 - **Basic concepts in Vacuum**
 - The ideal gas law, Throughput and pumping speed, Leak rate, Outgassing, Adsorption, Desorption, Mean free path, Gas flow regimes, Conductance.
 - Pumps: Oil sealed rotary vane type pump, Diaphragm pump, Roots pump, Cryosorption pump, Oil diffusion pump, Hydrocarbon free vacuum, Turbomolecular pump, Sputter ion pump, Cryopump, Getter Pumps
 - Basics of low-pressure measurement techniques, McLeod Gauge, Thermocouple gauge, Pirani gauge, Cold-cathode/Hot-cathode gauge. Leak rate, Real leak, Virtual leak, Helium mass spectrometer, leak test, sealing materials and lubricants, Pump fluids and sorbents, Special materials, Outgassing rates of materials, Stainless steel, OFHC Copper, Aluminum, Glasses, Ceramic, Sealing materials, Diffusion pump fluids.
 - **Cryogenics Systems**
 - **Introduction to Cryogenic Engineering**
 - General and basics, Cryogenic properties, Basic cycles
 - Large Cryogenic Systems for Accelerators
 - **Cryogenic Equipments**
 - Process compressor, High speed Turboexpanders, Compact high effectiveness, Heat Exchangers, Cold Box and Piping, Dewars and Storage Vessels, Vacuum Systems, Cryomodules, Cryogenic Instrumentation and Control systems.

Course Outcomes:

This course will introduce the students to the domain of accelerator physics, accelerator technology and cryogenics. The course will give exposure to linacs technology and cryogenic equipment.

References .

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

EN502: Engineering Maths-I (15 Lecture Hrs) (All Engg)

Coordinator: Dr. K. P. Singh
(kpsingh@barc.gov.in)

Course Details:

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

Course Outcomes:

This course will introduce the students to the fundamentals of error analysis, numerical methods for solving linear and non-linear equation/s, ODE and Fourier transformation. The course will expose the students to data analysis techniques.

References:

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

16. Rajsekaran S., "Numerical Method for Initial and Boundary Value Problems", Wheeler, 1987.
17. Rajsekaran S., "Numerical Method in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
18. Jain M.K., "Numerical Method for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
19. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN503: Engineering Maths-II (15 Lecture Hrs) (ME Group)

Coordinator: Dr. K. P. Singh
(kpsingh@barc.gov.in)

Course Details:

- **Introduction to Numerical Discretization Techniques (7 lectures)**

- Classification of Partial Differential Equations (PDEs), Initial value Problems and Boundary Value Problems, and different types of Boundary conditions.
- Introduction to discretization method and approximate solution of differential equations (FDM, FEM and FVM), Finite Difference Approximations in 1-D, Solution of steady and unsteady heat conduction equations.
- Approximate solution of differential equations – Weighted residual method, collocation, least squares and Galerkin's method, Piecewise approximations. assembly concept.
- Solution of steady and unsteady heat conduction equations with finite element method, Implicit and explicit method.
- Finite element formulations of convection dominated problems using classical Galerkin methodology and need for alternate trial functions and upwinding.

- **Probability Distribution and its applications (3 lectures)**

- Continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.
- Response Surface method
- Monte Carlo Method

- **Vector Calculus and functional analysis (5 lectures)**

- Differentiation of compositions of functions, Mean Value theorem for vector valued functions, Calculus for matrix-valued maps, Invertibility of Maps, Banach's fixed point theorem, Local invertibility, Variational proof of the inverse function theorem, Gateaux and Frechet differentials, Measurable functions and Lebesgue's integral.
- Holomorphic primitives and line integrals, Conservative Fields and Potentials, Closed forms and irrotational fields, Elementary domains and Goursat's theorem, Removable singularities, poles and essential singularities, Singularities at infinity, Singular points at boundary and radius of convergence, Calculus of residues, Definite integrals by the residue method

Course Outcomes:

This course will introduce the students to the fundamental of FDM, FEM and FVM techniques for solving PDEs. The course will also expose the students to theory of probability, vector calculus and functional analysis.

References:

1. Issacson E., Keller H.B., "Analysis of Numerical Method", Wiley, 1966.
2. Todd R.J., "Survey of Numerical Analysis", McGraw Hill, 1962.
3. Sastry S.S., "Introductory Method of Numerical Analysis", Prentice Hall, 1981.
4. Scheid F., "Numerical Analysis: Schaum Outline Series", McGraw-Hill Book Co., 1983.
5. Rajaraman V., "Computer Oriented Numerical Method", Prentice Hall, 1971.

6. Williams P.W., "Numerical Computation", Nelson, 1972.
7. Bajpai A.C., "Numerical Method for Engineers and Scientists: A Students' Course Book", London, Taylor and Francis, 1975.
8. Chapra S.C., "Numerical Method for Engineers: International Edition", McGraw Hill, 1989.
9. Scarborough J.B., "Numerical Mathematical Analysis", Calcutta, Oxford and IBH Publishers, 1968.
10. Conte S.D., "Elementary Numerical Analysis: An Algorithmic Approach", Tokyo, McGraw Hill, 1972.
11. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
12. Salvatori M.G., "Numerical Method in Engineering", New Delhi, Prentice Hall, 1952.
13. Gerald C.F., "Applied Numerical Analysis", Addison Wesley, 1984.
14. Rajsekaran S., "Numerical Method for Initial and Boundary Value Problems", Wheeler, 1987.
15. Rajsekaran S., "Numerical Method in Science and Engineering: A Practical Approach", Allahabad, Wheeler, 1987.
16. Jain M.K., "Numerical Method for Scientific and Engineering Computation", Wiley Eastern, 2nd Edition, 1991.
17. Krishnamurthy E.V., "Computer Based Numerical Algorithms", East West Press, 1976.

EN504: Engineering Maths-II (20 Lecture Hrs) (MT)

Coordinator: Dr. K. P. Singh
(kpsingh@barc.gov.in)

Course Details:

• Applications in Materials Science

- Use of matrix in crystallography. Stereographic analysis, Crystallography and Crystal Defects: Crystal Structure, Lattices, Point groups and Space groups Reciprocal lattice and Structure factor, Stereographic projection, Common Crystal structures.
- Tensor analysis in phase transformation and deformation studies.

Course Outcomes:

This course will introduce the students to the field of application of mathematics in crystallography and lattice studies. The course will be imparted basics of tensor analysis with special emphasis on its application to phase transformation and deformation studies

References:

1. Press W.H., "Numerical Recipes: The Art of Scientific Computing", Cambridge University Press, 1986.
2. Space group for scientists, Burns and Glazer, Aedamic Press, UK, 2013
3. Solid State Physics, Mermin and Ashcroft Salvatori M.G. "Numerical Method in Engineering", New Delhi, PrenticeHall, 1952.
4. Solid State Physics, C. Kittel, Willey Press, 2012

EN505: Engineering Maths-II (15 Lecture Hrs) (EE Group)**Coordinator: Dr. K. P. Singh**
(kpsingh@barc.gov.in)***Course Details:***

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

Course Outcomes:

This course will introduce the students to fundamentals of transforms and its application to solution of differential equations, error analysis use of statistical tools for error analysis.

References:

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

EN506: Health Physics and Radiological & Industrial Safety (20 Lecture Hrs)

Coordinator: Dr. M K Sureshkumar
(smk@barc.gov.in)

Course Details:**• Health Physics****▪ Introduction**

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

▪ Biological effects, Radiation Protection and Regulation

- Human body: Cells, tissues and organs, structure of cell, cellular effects.
- Factors, which influence the damage of cell. Interaction of radiation with biological matter.
- Radiation effects: stochastic and deterministic.
- Acute and delayed effects.
- Types of exposure (natural, occupational, medical and public).
- National and International regulatory bodies, their role and responsibilities.
- Dose limits stipulated by these bodies.
- Dose limits observed in India.
- Principles of radiation protection, concept of ALI & DAC (with suitable problems).
- Changes in latest ICRP recommendations.
- Nature of duties and responsibilities of Radiation Safety Officer/Health Physicist.

▪ Principles of radiation detection and monitoring

- Basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors.
- Type of Radiation monitors/Radioactivity measurement method adopted for radiation protection should be taught.
- Thermo Luminescence Detectors (TLD), Pocket dosimeters

▪ Radiation protection and measurement (External and Internal)

- Control of external exposures (with problems in each case).
- General Shielding Principles, Routes of intake of radioactive material, Fundamentals of radioactive waste management.
- Personnel monitoring, area monitoring, air monitoring, contamination monitoring, Bioassay, whole body counting techniques.
- Environmental Monitoring.

- **Radiation Protection procedures**
 - Procedures followed in radiation work places, work permits, zoning concept, contamination control method, and rubber areas.
 - Decontamination techniques. Precautions during radioactive source storage and handling, Protective equipment's.
 - Criticality hazards and control.
 - Safety during transportation of radioactive materials.
- **Nuclear Accidents, Emergency Preparedness and Management**
 - Reasons for accidents, classifications of accidents, International Nuclear Events Scale. Types of emergencies, emergency preparedness.
- **INDUSTRIAL SAFETY ASPECTS (10)**
 - **Introduction**
 - Recognition of Workplace Hazards: Chemical Agents, Physical Agents, Biological Agents, Ergonomic Factors, Mechanical hazards: Safe working with machines, Tools and equipment, Electrical hazards, Accident prevention techniques
 - Hazards due to physical agents:
 - UV and IR radiation, Lasers, Microwave radiation; noise, heat
 - Chemicals hazards:
 - Classification of chemicals, fire and explosion hazards, health hazards: airborne chemical contaminants, routes of entry, types of exposures, harmful effects of toxic substances – pneumoconiosis, irritants, asphyxiants, anaesthetics and narcotics, systemic poisons and cancer-causing chemicals, National Fire Protection Association (NFPA) symbol, Transport Code for Chemical, Emergency Action Code.
 - **Evaluation**
 - Instrumental method, air sampling method, liquid effluent monitoring.
 - **Occupational exposure limits**
 - Threshold Limit Values- TLV-TWA, TLV-STEL, TLV-Ceiling; IDLH, LD50/LC50
 - **Handling, storage and control**
 - Engineering control measures and safety features.
 - Safety management techniques such as safety audit, Personal/ administrative control, and medical control.
 - **Fire and explosion hazards**
 - Fire pyramid, classification of fires, hazardous operations, explosion hazards - dusts, flammable liquids - explosive limits.
 - USNFPA Classification of Flammable/combustible liquids: flammable gases.
 - Engineering safety for prevention of fire and explosion.
 - Hazard area classification, selection of equipment, detection and extinguishing systems.

▪ Hazard identification, assessment and control

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

▪ Management of major hazard Installations

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

▪ Personal Protective Equipment

- Need; Classification of Non-Respiratory Protective Equipment: Head Protection - Eye and Face Protection - Ear Protection - Arm and Hand Protection - Leg and Foot Protection - Protective Clothing - Safety Belts; Respiratory Protective Equipment - Classification of Hazards - Classification of Respiratory Protective Equipment - Selection of Respiratory Protective Equipment - Protection Factors - Safety in the Use of Respirators; Testing and quality assurance; Training in Use, Care and Maintenance.

Course Outcomes:

This course will introduce the students to the fundamentals of radiation and industrial safety, dosimetry, radiation detection and protection. The course will learn the procedures involved in emergency preparedness and management of nuclear accidents and fire. At the completion of the course, the students will know about the exposure limits for occupation workers and public. A basic understanding of hazard analysis, hazard management and personal protection equipment will be imparted.

References:

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

EN507: Material Science in Nuclear Engineering (EE) (20 Hrs)

Coordinator: Dr. Supratik Roychowdhury
(supratik@barc.gov.in)

Course Details:

- Materials classifications in terms of structure, electronic configuration, nature of bonding, type of disorder and dimensionality (nanostructured materials).
- Free electron theory, MB and FD statistics, electrons in periodic potential,
- Bloch's theorem, Basics of electron band structure, density of states and Fermi surface.
- Crystal structure and symmetry, Bravais lattice, Reciprocal lattice, Bragg's Law,
- Diffraction method --- X-rays, Electron and Neutron scattering.
- Electronic processes in solids, Bonds and Bands in semiconductors, ANB8-N compounds, basics of intrinsic and extrinsic semiconductors (donor and acceptor levels, carrier generation and recombination, mobility, drift and diffusion, etc.)
- Hall effect, physics of p-n junction, semiconductor heterostructures and Superlattices. Superconductivity, Type-I and Type-II Superconductors, Josephson junctions, SQUIDS
- Microstructure-property relationship, thermodynamics and phase diagram (binary) of materials.
- Dielectric, optical, magnetic and superconducting materials and properties
- Dielectrics, piezoelectrics, ferroelectrics
- Optical and Non-linear optical materials, laser materials, fiber optics
- Ferromagnetic, Antiferromagnetic, Ferrimagnetic materials
- Nano-technology, MEMS and nano-phase materials, sensor technology and applications.
- Nuclear Materials and processing
- Introduction to Reactor core materials for PHWR, PWR, BWR, CHTR, MSBR and Fusion reactors
- Introduction to Nuclear fuels: Metallic, ceramic (Oxides, MOX and Carbide fuels)

Course Outcomes:

This course will introduce the students to the domain of material science, classification of materials, crystal structures and its relationship with material properties. The course will expose the students to different types of materials used in nuclear reactor systems and their desirable properties.

References:

1. "Introduction to Solid State Physics", Charles Kittel (Wiley Eastern)
2. "Band theory of metals", Simon Altman (Pergamon Press)
3. "Solid State Physics", Adrianus Dekker (Macmillan Press)
4. "Electrons in Metals and Semiconductors", R.G. Chambers (Chapman and Hall)
5. "The Physics and Chemistry of Materials", Joel Gersten and Fiedenick Smith (Wiley, Canada)
6. "Electronic Processes in Matters", Leonid Azaroff and Janes Brophy (McGraw Hill)
7. "Physical Metallurgy: Principles and Practice", V. Raghavan (Prentice Hall)
8. "Introduction to Materials Science for Engineers", James Shackelford (Maxwell Macmillan)
9. "Fundamentals of Materials Science and Engineering", D. Callister (Wiley, Europe)
10. "Principles of Electronic Ceramics", L.L. Hench and J.K. West, John Wiley & Sons, Singapore(90)
11. High Temperature Solid Oxide Fuel Cell: Fundamentals, Design and Applications - S.C. Singhal, K. Kendall (Eds.), Elsevier Science (2003)
12. Thermoelectric Handbook: Micro to Nano, D.M. Rowe (Ed.), Taylor & Francis (2006)
13. "Materials in Nuclear Applications", C.K. Gupta (CRC Press)
14. "Nuclear Materials Science", Karl Whittle, IOP Publishing Bristol UK

EN508: Nuclear Fuel Cycle Technology (35 Lecture Hrs)

Coordinator: Dr. (Smt) Tessy Vincent
(tessyv@barc.gov.in)

Course Details:**• Introduction to Nuclear Fuel Cycle**

- Overview of nuclear fuel cycle, Open vs closed fuel cycle, Drivers for the choice of national back-end strategy

• FRONT END**▪ Mining, Milling and Associated Processing of Indian Uranium Resources**

- Uranium Resources and Mining Technology
- Processing Concepts –(a) Mineralogy, (b) Leaching, (c) Solid-liquid Separation, (d) Solution Purification, (e) Product recovery, (f) Waste management.
- Uranium Purification using Hydro-Metallurgical Processes: Process, Equipment, Quality control
- Case Studies: Jaduguda and Tummalapalle
- Metal Production by Metallothermic Reduction Processes

▪ Fuel Fabrication

- Overall significance and technology for advanced fuel fabrication
- Fuel for fast reactor (mixed carbide, mixed oxide and metallic)
- Fuels for thermal reactors; Fuels with enriched uranium (APSARA, HFRR, LWR etc.)

• BACK END**▪ Reprocessing**

- Spent fuel characteristics from different types of Indian nuclear reactors, Objectives of reprocessing, Special features of radiochemical plants
- Reprocessing by PUREX: Overall process description and a few safety scenarios including red oil and criticality: how to control
- Thorium utilization – Indian perspective, Comparison between U and Th fuel cycle, Reprocessing by THOREX, AHWR fuel reprocessing
- Overview of reprocessing of spent FBR fuel including Pyro-reprocessing, and other non aqueous reprocessing technologies

▪ Waste Management

- Nuclear Waste Vs Chemical waste, Sources of radioactive waste, National frame work for management of radioactive waste, Objectives of radioactive waste management, Basic principles of radioactive waste management
- Solid waste Management: Sources; Overview of Treatment processes, NSDF, Disposal Modules; Surveillance of NSDF, Multibarrier disposal concept at NSDF
- High Level Liquid waste: Definition, Source, Major components, three step management programme, Vitrification – Glass as matrix, Concept of Interim Storage and Geological Disposal Facility, Multibarrier concept of Geological Disposal facility, Overall design of back-end facility including transfer devices (Alps, Steam jets, special pumps) etc.

- Partitioning Technology including recovery of useful radionuclides from waste for societal applications
- Vitrification – melter technology and associated challenges; Overall design basis of industrial melters as adopted in the plants.
- **Mechanical Design Aspects of Back-end Technologies**
 - Spent fuel transportation- shipping cask design and regulatory requirement.
 - Spent fuel storage. Spent fuel charging and chopping system. Hull transfer and disposal system.
 - Remote viewing and remote handling system in reprocessing and vitrification plants.
 - Mechanical design aspects of dissolver, thermo-syphon evaporator, feed clarifier and pulse column.
 - Sampling system. Remote Head Metering Pumping system and remote valves for radiochemical plants
 - Layout considerations and design philosophy for backend including civil design aspects. Control of radiation exposure including shielding and barriers. Ventilation aspects and Off gas handling and treatment. Utilities requirement for backend.
- **Electrical Systems & Instrumentation for Back-end Facilities**
 - Introduction to Instrumentation & plants in general
 - Functions of Instrumentation, Measurement Method for Level , Density, Pressure, &Temp for In-cell equipment
 - Instrumentation for Transfer modes like Steam Jets, ALPs etc.
 - Instrumentation for Important equipment like Pulsed Column, TSE, Tanks, Joule Melter
 - PLC/SCADA, Control Room Systems
 - Introduction to Radiation Monitoring System (RMS), Functions of RMS, various Nuclear instruments like, AGM, CAMs, Stack Monitor, Criticality Alarm system etc., CRPC, DRPC
 - Electrical System: Objective of electrical system, Types of power supply system, Design safety features, Motors/ starters/ CBs.
 - Earthing system, Lighting System, Building lightning protection system, Electrical power supply system for Joule Melter, Typical sub-station layout.
- **Design aspects of back end technology facilities**
 - Design classification and seismic categorization, considerations for external events, Standards/codes for design

Course Outcomes: This course will introduce the students to the domain of nuclear fuel cycle and processes involved at front and back end of fuel cycle. The course will impart students the knowledge about nuclear waste generation, its handling, processing and storage. The students will learn about fuel fabrication techniques, technological challenges at Front and Back end of Nuclear Fuel cycle.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd Ed.
2. Uranium Extraction Technology, Tech. Rep. Series, IAEA, Vienna 1993
3. J. T. Long, Engineering for Nuclear Fuel Reprocessing, Gordon & Breach Science Publishers Ltd (1967)
4. M. F. Simpson, J. D. Law, Nuclear Fuel Reprocessing, In: Encyclopedia of Sustainability Science & Technology Series, Springer, New York (2018)

5. R. Taylor, *Reprocessing and Recycling of Spent Nuclear Fuel*, Woodhead Publishing Series in Energy: Number 79, Elsevier, New York (2015)
6. M. I. Ojovan, W. E. Lee, *New developments in glassy nuclear wastefoms*, Nova Science Publishers, Inc, New York, 2007
7. M. I. Ojovan, W. E. Lee, *An introduction to nuclear waste immobilization*, Elsevier, OXFORD, UK, 2005.

EN509: Nuclear Power Plants Engineering & Advanced Reactor Concepts (40 Lecture Hrs)

Coordinator: [Shri D. Naga Sivayya\(dnsiva@igcar.gov\)](mailto:dnsiva@igcar.gov)
[Shri Santanu Pahari\(spahari@npcil.co.in\)](mailto:spahari@npcil.co.in)
[Dr. Naveen Kumar\(nkumar@hbni.ac.in\)](mailto:nkumar@hbni.ac.in)

Course Details:

• Module 1: Thermal Reactors (22)

- Description of schematic of NPP: site requirements; Layout of Nuclear Power plant-Zoning requirements, layout within Reactor Building: Reactor components / systems: Calandria, End shield, Coolant Channel and End fitting.
- Reactivity control mechanisms: Zone control / Regulating rods, Absorbers, Shut down System.
- Primary Heat Transport System including Steam Generators, Shut Down Cooling, Emergency Core Cooling System, Moderator System.
- Auxiliary systems: Ventilation, Annulus gas, Process water & Fire water systems.
- Secondary System: Description of flow sheet and major components, comparison of operating conditions; Thermal Cycles and Major components of thermal and nuclear units.
- SGPC and ΔT correlation, base load operation. Control and protection channels with typical examples.
- Electrical Systems: Electrical power systems for a nuclear power plant with relevant definitions; Key single line diagram for various classes of power supply system.
- Nuclear Power Plant Safety: Design principles for providing nuclear safety: Basic Principles (Reliability, Single failure, Redundancy and Diversity), Process systems, Safety Systems and Support Systems, Defence in depth approach, Design basis accidents, Beyond DBA.
- Safety Evaluation and Safety Criteria: Description of Deterministic and Probabilistic approaches.
- Safety Monitoring of Operating Plants: IAEA Classification, NUSS Codes, Safety systems, Description of role of defence in depth, Exclusion zone, Design Principles - Reliability, Single Failure, Redundancy, Diversity.
- PWR Module: PWR core & important design parameters, core components, major primary system components, safety philosophy for handling LOCA / station black out etc.

References:

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

• Module 2: Fast Breeder Reactors (12)

- Fast Reactor Physics: Characteristics of fast reactor, breeding ratio, internal / external breeding, doubling time. Reactivity coefficients, concepts of fuel expansion and bowing, core slumping, sodium void and Doppler effects
- Fast Reactor Core Design: Requirement of core materials: Coolant, structural material and fuel. Design: Specific power, linear rating, burn up, fluence, operating conditions, constraints, maximum temperatures of clad and coolant, coolant velocity, pressure drop in core, core height / diameter ratio,

blanket thickness. Fuel pin diameter, number of pins per subassembly and reactivity worth of subassembly

- Heat Transport System: Coolant: Requirements of fast reactor coolant, comparison of various coolants & choice of sodium as coolant, properties of sodium, purification & purity control, corrosion and mass transport. Heat transfer in liquid metal. Primary sodium circuit, secondary sodium circuit and inert gas system. Sodium pumps: Mechanical pump and electromagnetic pump. Intermediate heat exchanger and steam generator. Safety: Decay heat removal, steam generator tube leak detection and sodium water reaction discharge circuit
- Fuel Handling System: On-line Vs Off-line refueling, salient features & safety requirements, In-vessel & Ex- vessel handling & storage, Sodium cleaning and decontamination.

Course Outcomes: This course will introduce the students to different types of nuclear systems for power generation, their fundamental components, design aspects and safe operation. The students will learn about the process and safety systems of NPPs in general with special focus on IPHWR and PFBR. The course will also expose the students to the need of advanced nuclear systems, their desirable features and roadmap for their development.

References:

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

• **Module 3: Advanced Reactor Concepts (6)**

▪ **Introduction**

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

▪ **Directions of Development in the World (1)**

- GIF and other advanced reactor concepts
- Indian Programme on Advanced Reactors and Associated Challenges (2)
- AHWR
- AHWR-LEU
- CHTR, IHTR, IMSBR etc.
- Reactor Physics Design Challenges (1) ADS and applications (1)

EN510: Reactor Physics & Engineering (55 Lecture Hrs)

**Coordinators: Dr. Anurag Gupta(anurag@barc.gov.in)
Shri. M. V. Gathibandhe, RPD(manoharg@barc.gov.in)**

Course Details:**• Module 1: Nuclear Reactor Physics (33)****▪ Properties of Nuclei**

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

▪ Fission Process

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

▪ Interaction of Neutrons with Matter

- Production of neutrons

▪ Concept of microscopic cross section:

- Inelastic and elastic scattering

▪ Variation of cross-section with energy

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

▪ Diffusion of Neutrons

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

▪ Chain Reaction

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

▪ Slowing Down Process

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

▪ Heterogeneous Reactors

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

▪ Reactor Kinetics

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

▪ Core Burn Up

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

▪ Neutron Poisons

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

▪ Reactivity Coefficients

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

• Module 2: Reactor Engineering & Radiation Shielding (22)**▪ Reactor Engineering (14)**

- Introduction to reactor system & Indian Nuclear power programme.
- Station schematic line diagram to indicate interlinks between reactor, turbine, generator, grid & auxiliary systems.

- Classification of reactors, characteristics of research, test & power reactors with examples. Core configuration & cycle diagrams thermal reactors (BWR, PWR, PHWR).
 - Fast reactors.
 - Research reactors (DHRUVA) characteristics, selection criteria & comparison of different reactor materials & structural materials for reactor internals.
 - Basic principles of heat generation, heat sources and distribution; Steps involved in heat removal from reactor systems.
 - Heat flow & temperature distribution in solid cylindrical, fuel elements; temperature distribution in clad for the above type of fuel elements and assessment of film drop temperature in each case with a solved example in each case; significance of KdT with example; Axial clad surface & coolant temperature distribution in fuel channel; maximum clad surface temperature and its location with a solved example.
 - Brief description of various types of fuel; metallic (DHRUVA) Oxide (PWR, BWR, PHWR, AHWR) & Coated Fuel (HTGR); Design requirements & limitations for various types of fuel element design.
 - Economic comparison of different coolants based on pumping & heat removal capability; Boiling in reactor system critical heat flux & Burnout phenomena in water reactors; Heat transfer coefficient & assessment in reactor systems; Brief data of coolant (pressure, temp) in various reactors.
- **Nuclear Fuel Cycle (2)**
- Concept of Nuclear Fuel Cycle $\frac{3}{4}$ open and closed fuel cycles.
 - Global options of fuel cycles; Issues related to Resources, Proliferation, and Advanced Technologies.
 - Mineral resources and nuclear fuel cycle strategies of Indian Nuclear Power Programme, 3-stage nuclear fuel cycle,
 - Advanced fuel cycles
- **Radiation Shielding (6)**
- Source of various neutron & Gamma radiation within the reactor system
 - Attenuation of neutrons & gamma rays
 - Dose rates for gamma rays for various source geometries
 - Buildup factors for homogeneous & multiple layer shields
 - Removal diffusion theory for neutron attenuation
 - Coolant activation, heat generation

Course Outcomes: This course will introduce the students to fundamentals of reactor physics. The students will learn about the fission process and interaction of nuclei with neutrons, diffusion of neutrons through different media and its effect on neutron life cycle. The course will expose the students to the field of reactor kinetics and its application to design of control systems for sustainable chain reaction. The students will also learn about fundamentals of techniques of heat transfer from fuel to coolant and its transport to steam generation system for electricity generation. Reactor engineering principles will be taught in detail with emphasis on safe and sustainable harnessing of nuclear power.

Streaming of radiation through gaps & void in the shield

CORE COURSES

EN601: Advanced Chemical Reaction Engineering (25 Lecture Hrs)

Coordinator: Dr. K. K. Singh
(kksingh@barc.gov.in)

Course Details:

- Review of basic concepts of reaction engineering
- Non ideal flow in reactors, distribution of residence times, experimental RTD studies, RTD Modelling, applications. Zero parameter, one parameter and two parameter models of non-ideal reactors. RTD of laminar flow reactor and falling film reactor.
- Reactors with heat effects, dynamic behaviour of chemical reactors, steady state multiplicity and oscillations
- Combustion, Reaction mechanism of Hypergolic reactions: H₂-O₂ and H₂-F₂.
- High temperature chemical reactors (HTCR) namely chemical flame reactors and thermal plasma reactors. Application of HTCR in DAE.
- Characterization of shape indices for irregular shape particles, non-catalytic heterogeneous fluid-solid reactions: governing models and design equations; identification of the controlling resistance in gas-solid reaction; gas-solid reactor design.
- CFD modeling approach for gas-solid reactor.
- Heterogeneous catalytic reactions, transport and heat effects, design equations based on species balance, momentum balance and energy balance; effect of pressure drop and condensing vapour on reactor design; mass transfer limited reactions in packed beds.
- Reactor design: counter-current moving bed reactors.
- Advanced topics in reaction engineering: three phase reactors, photochemical reactors, electrochemical reactors, integral reactor-separators (reactive distillation, membrane reactors), complex systems, micro-reactors
- Examples from chemical and nuclear industry.

Course Outcomes:

This course will introduce the students to the fundamentals of non-ideal reactors and residence time distribution (RTD) studies, including non-isothermal effects and dynamic behavior. The course will also expose the students to heterogeneous reactions and advanced approaches in reaction engineering and reactor design.

References:

1. Coulson and Richardson's Chemical Engineering (Vol-3A). Butterworth-Heinemann, 4th edition, 2017.
2. Westerterp, K.R.; Van Swaaij, Van W. P. M.; Beenackers, A.A.C.M. Chemical Reactor Design and Operations, 2nd Edition, Wiley and Sons, 1991.
3. Fogler, H.S. Elements of Chemical Reaction Engineering, 4th Edition, Pearson Education India, 2015.
4. Elnashaie, S.S.E.H. Modeling, Simulation, and Optimization of Industrial Fixed Bed Catalytic Reactors, CRC Press, 1994.
5. Froment, G.F.; Bischoff, K.B.; De Wilde, J. Chemical Reactor Analysis and Design, 3rd Edition, Wiley, 2010.
6. Scott, K. Electrochemical Reaction Engineering, Academic Press Inc., 1991.
7. Smidtt, L.D. The Engineering of Chemical Reactions, 2nd Edition Oxford University Press, 2004.

8. Levenspiel, O. Chemical Reaction Engineering, 3rd Edition, Wiley Students Edition, 2006.
9. Galkin, N.P.; Sudarikov, B.N. Technology of Uranium, Israel Program for Scientific Translations, Jerosalem, 1966.
10. Glassman, I.; Yetter, R.A.; Glumac, N.G. Combustion, 5th Edition, Academic Press, 2014.

11. Katz, J.J.; Rabinowitch, E. The Chemistry of Uranium, Part-1: The Element, Its Binary and Related Compounds, Literary Licensing LLC, 2013.
12. Lewis B.; von Elbe, G. Combustion, Flames and Explosions of Gases, 3rd Edition, Academic Press, 1987.
13. Smith, J.M. Chemical Engineering Kinetics, 3rd Edition, McGraw Hill Education, 2013.
14. Strehlow, R.A. Combustion fundamentals, Reprint Edition, Krieger Pub Co., 1993.
15. Szekely, J.; Evans, J.W.; Sohn, S.Y. Gas-Solid Reactions, Academic Press, 1976.

EN602: Advanced Electrical Engineering Design-I (25 Lecture Hrs)

Coordinator: Shri S. Malhotra
(sanjaym@barc.gov.in)

Course Details:

- Materials: Soft Magnetic Materials and their properties and applications, Permanent Magnetic Materials and their properties and applications, Super conducting Materials and their properties and applications. (5)
- Special Electrical Machines and their applications: Servo motors, their design and application in control rod mechanisms, Hysteresis motors, Switched Reluctance motors, Canned motors, High speed motors (5)
- Control Machines: Conventional control, Vector control (5)
- Special Techniques of Magnetic Circuit Design: Finite Difference Method, Finite Element Method, Their applications, design of machines and Transformer, chokes and other Electromechanical Equipment.
- NDT Method: MFL Technique, Eddy current Technique, Remote Field eddy current Method. (5)
- Power Electronics (5 lectures, course to include concepts on Semiconductor power devices, firing circuits, protection, rectifiers/inverters, SMPS, LMPS etc..to be finalized along with course coordinator)

Course Outcomes:

This course will introduce the students to materials and electrical properties, non-destructive testing techniques including MFL, and superconducting properties. The course will also expose the students to control techniques of electrical motors and electronics, along with FEM and its engineering applications.

References:

(Reference materials will be provided during the course)

EN603: Advanced Electronic Circuit Design Techniques (30 Lecture Hrs)**Coordinator: Shri C. P. Kulkarni**
(cpkulk@barc.gov.in)**Course Details:**

- Silicon Processing: Various steps involved in fabrication of Silicon devices (2)
- Semiconductor Detectors: Theory, design, fabrication and applications (2)
- Micro-Electro-Mechanical Systems (MEMS): Theory, design, fabrication and applications (2)
- Hardware description method: VHDL language structure, data objects, types, design units, balanced and priority logic, replicated logic using functions, procedures, loops and components, hierarchical design, delay models and other language details (6)
- Digital circuit design using VHDL: Design of sequential and combinational circuits, memories, finite state machines, behavioral and structural description, concepts of test-bench, simulation, design methodologies, optimization for speed, area and power, synthesis considerations (4)
- Programmable Logic Devices: CPLD and FPGA technologies, architecture, comparison, device selection, programming method, basic design flow (4)
- RF Electronics: RF system for particle accelerator (1)
- RF System Components: Transmission lines, waveguides, circulators, resonators, power couplers (3)
- RF Power Amplifiers: Theory, design (2)
- RF Signal Processing: Low level RF controls, beam diagnostics, measurement and protection (4)

Course Outcomes:

This course will introduce the students to materials and electrical properties, non-destructive testing techniques including MFL, and superconducting properties. The course will also expose the students to control techniques of electrical motors and electronics, along with FEM and its engineering applications.

References:

1. VLSI Technology by S. M. Sze, McGraw-Hill, 1988
2. VLSI Fabrication Principles by S. K. Gandhi, Wiley International Publication, 1994
3. Fundamentals of Microfabrication by Marc J. Madou, CRC Press
4. Fundamentals of Digital Logic with VHDL Design, 2nd edition, by Stephen Brown and Zvonko Vranesic, Published by Tata McGraw-Hill.
5. VHDL for Programmable Logic, 2008 edition by Kevin Skahill, Published by Pearson Education.
6. HDL Coding Style Guide
7. Microwave Devices and Circuits by Samuel L. Liao, Published by Prentice Hall
8. RF Circuit Design by Reinhold Ludwig and Pavel Bretchko Published by Person Education
9. Proceedings of CERN Accelerator School 2005-003, Topic- RF Engineering Editor- Miles
10. Proceedings of CERN Accelerator School 2009-005, Topic- Beam Diagnostics Editor- D. Brandt

EN604: Advanced Mass Transfer (25 Lecture Hrs)**Coordinator: Dr. G. Sugilal**
(gsugilal@barc.gov.in)**Course Details:**

- Principles of steady state and transient mass transfer - a theoretical perspective
- Theories of mass transfer with and without chemical reaction with examples from gas-liquid, liquid-liquid, and liquid-solid systems;
- Interfacial phenomenon in liquid – liquid systems (drop breakage, coalescence, Marangoni effect, effect of surfactant)
- Approaches for design: equilibrium and rate based
- Application of equilibrium and rate-based design approaches to gas-liquid and liquid-liquid contactors.
- Design basis of extraction equipment: mixer settlers (PMMS, CAL-MIX, slurry extractors), annular centrifugal contactors, ARDC and pulsed extractors.
- Adsorption and ion exchange equipment: Design and scale-up aspects with applications.
- Process intensification approaches and equipment (hollow fibers, supercritical extraction, microfluidic extractors, sonochemical reactors).

Course Outcomes:

This course will introduce the students to mass transfer with and without chemical reactions, including rate-based design approaches. The course will also expose the students to selection and design of contacting equipment and process intensification techniques.

References

1. L. K. Doraiswamy and M. M. Sharma, Heterogeneous reactions: analysis, examples, and reactor design, John Wiley and Sons, New York, 1984.
2. G.S. Laddha and A.E. Degaleesan, Transport phenomena in liquid extraction. McGraw-Hill Companies, 1978.
3. P.V. Danckwerts, Insights into chemical engineering: selected papers of PV Danckwerts. Elsevier, 2013.
4. A. Rice, D. Herzog and W. Connelly, Handbook of membrane separations: chemical, pharmaceutical, food, and biotechnological applications, 2010.
5. R. W. Baker, Membrane technology and applications, 2nd Edition, John Wiley and Sons Ltd.
6. E. L. Cussler, Diffusion - Mass transfer in fluid systems, Cambridge University Press, New York, NY, 1984.
7. C.A. Miller and P. Neogi, Interfacial phenomena: equilibrium and dynamic effects. 2nd Edition, CRC Press.

EN605: Advanced Nuclear Instrumentation (40 Lecture Hrs)**Coordinator: Shri S. P. Borkar**
(bsuhas@barc.gov.in)**Course Details:**

- High Resolution Energy Spectroscopy: Types of Pre-Amplifiers, Noise in Pre-Amplifier, Optimum time constant, Resolution, Cooled detector Pre-Amplifier, Spectroscopy Amplifier, Gated Integrator, Triangular Shaping Amplifier, Pulse peak stretcher, Different types of Nuclear ADC's, Multi Channel Analyzers and their different modes. Particle identification by pulse shape analysis, DSP techniques for nuclear pulse spectroscopy.
- Timing Spectroscopy: Walk, Jitter, and method of time pick-off, Resolving Time and Coincidence units, Timing single channel Analyzer, Experimental set-up for measurement of Absolute activities using coincidence, Time to digital converter, Time to amplitude converter and biased amplifier.
- Nuclear Laboratory Instruments: Isotope Calibrator, Low level alpha, beta and gamma counting systems, Liquid scintillation counting systems, Nuclear medical instruments, Gamma Camera Spect.
- Miscellaneous Topics: Accelerator Instrumentation, Introduction to CAMAC, Application of CAMAC and VME for Beam-line and Control Instrumentation, Application of Nuclear Instrumentation in different fields.
- **Reactor Instrumentation:**
 - Fundamental Considerations / Philosophies, requirements, and scope.
 - Measurement ranges of reactor neutron flux and considerations
 - Types of neutron detectors FC, 10B, BF₃, CIC and SPND for in-core and out-of-core use.
 - Signal processing blocks in Pulse, Campbell, DC range of measurement and generation of various signals (LCR, LR, Lin, LinR and ρ)

Course Outcomes:

This course will introduce the students to electronics used in spectroscopy design and nuclear instrumentation, including alpha, beta, and gamma detectors and scintillation counters. The course will also expose the students to accelerator instrumentation, reactor neutronic instruments, and associated signal processing techniques.

References

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

EN606: Advanced Operating Systems (25 Lecture Hrs)**Coordinator: Shri K. Rajesh**
(rajesh@barc.gov.in)**Course Details:**

- General Overview: Basic Components, Structures, Comparison between Unix & Windows NT, Security
- File Subsystem: File System Data Structures, Concepts of NFS / VFS / NTFS
- Process Subsystem: Processes & Threads, System calls for creating and managing processes & threads, Signal handling, Scheduling
- Memory & I/O Subsystem: Memory Management Policies, Virtual Memory, I/O System Structure, Synchronous & Asynchronous I/O, Device drivers, Kernel I/O data structures, Plug & Play I/O [1][4]
- Multiprocessing: Fundamentals, Symmetric and asymmetric multiprocessing,
- Design of Linux OS
- Linux File System
- Process Control
- Process Scheduling
- Swapping
- Demand Paging
- Device Drivers
- Inter Process Communication

Course Outcomes:

This course will introduce the students to inter-process communication (IPC) calls, shell programming, and system calls. The course will also expose the students to distributed file systems and practical applications of system calls

References:

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

EN607: Applied Process Instrumentation (40 Lecture Hrs)**Coordinators: Shri Partha Das(parthad@barc.gov.in)****Course Details:**

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

symbols, typical loop diagrams, typical instrument hook up diagrams.

- Introduction to MEMS sensors and applications

Course Outcomes:

This course will introduce the students to flow, pressure, level, and temperature measurement techniques and analytical instrumentation. The course will also expose the students to control valves and sizing calculations, P/I and I/P converters, impulse tubing, and interpretation of P&ID diagrams and design guides

References:

1. "Instrument Engineer's Handbook", Vol I & II, Bela G. Liptak; CRC Press
2. "Process/ Industrial Instruments and Control Handbook" - Gregory K. Mcmillan, Douglas Considine; McGraw Hill Publication
3. "Jones' Instrument Technology", Vol 1–5, Nolting B E; Elsevier Publication
4. "Measurement Systems", Ernest O Doebelin; McGrawHill Publication
5. "Principles and Practice of Flow meter Engineering" - L.K. Spink; Foxboro Company
6. "Fluid Meters - Their theory and Application", H.S. Bean. ASME Publications
7. "Instrumentation for Process Measurement and Control", Norman A. Anderson, CRC Press
8. "Process Control Systems: Application Design and Tuning". F.G. Shinskey, McGrawHill.
9. "Automatic Process Control", Donald P Eckman; Wiley India Pvt Ltd
10. "Process Control Instrumentation Technology", C. D. Johnson; Prentice Hall
11. "Control Valve Handbook", Emerson Process Management, Fisher Controls International
12. ANSI/ISA 5.1, Instrumentation Symbols and Identification;
13. ISA 5.4- Instrument Loop Diagrams;
14. ASME PTC 19.3 TW – 2016, Thermowells
15. BS EN ISO 5167, Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full
16. ANSI/ ISA75.01, Control Valve Sizing Equations;
17. ANSI/ISA 75.02: Control Valve Capacity Test procedures

EN608 Civil Engineering Design of Concrete and Steel Structures

EN608.1 Civil Engineering Design of Concrete and Steel Structures-I (30 Lecture Hrs)

Coordinator: Dr. Praveen Kumar
(praveen@barc.gov.in)

Course Details:

- **Introduction to various structures of nuclear facilities Classification of structure and design basis:** Radiation protection objectives, defense in depth, safety functions, safety classification, seismic classification, quality classification, design classification, design for natural and man induced events.
- **Design Loads**
 - Normal Loads: Dead Load, liveload, equipment load, test pressure and test temperature load, prestress load, operational thermal and pressure load, earth pressure loads, hydrostatic pressure loads, estimation of temperature variation in structures due to solar radiation.
 - Abnormal Load: Hydrostatic load due to internal flooding, design accident pressure, design accident temperature.
 - Severe Environmental Loads: operating basis earthquake, severe wind including gust effect and aerodynamic instability, design basis flood load, tsunami.
 - Extreme Environmental Loads: Safe Shutdown Earthquake, cyclone, extreme wind loads, wind-induced missile
- **Design of RC structures**
 - Design of RC structures as per IS456, AERB standards (AERB/SS/CSE-1), ACI 318/ ACI 349 design load combinations, design of beam, column, slab, walls etc., design of plates & shell structures, Wood's criteria, serviceability design checks of crack width and deflection, case studies
- **Design for shrinkage, creep & heat of hydration:** Shrinkage & heat of hydration, different types of shrinkage, codal aspects, case studies.
- **Foundation design**
 - Engineering layout and selection of type of foundation, foundation stability, safety against bearing, overturning, sliding & uplift; shallow foundations, Winkler model, pile foundation.
 - Machine Foundation - Introduction, evaluation of design parameters, analysis and design of block foundations and frame foundations, foundations for misc. machines, vibration isolation, and construction details of machine foundations, turbo generator foundations.
 - Fracture mechanics approach- Introduction to fracture mechanics concepts in RCC structural design

Course Outcomes:

This course will introduce the students to structural systems of nuclear facilities, including safety, seismic, and quality classifications. The course will also expose the students to design loads and combinations as per BIS, ACI, and AERB standards, RC structural design concepts including fracture mechanics, and shallow, deep, and machine foundation design.

EN608.2 Civil Engineering Design of Concrete and Steel Structures-II (30 Lecture Hrs)**Coordinators: Dr. (Smt) Y. A. Prulekar (yogitap@barc.gov.in)****Dr. A. Mondal (apurba@npcil.co.in)****Course Details:**

- **Introduction to Prestressed Concrete structures:** Introduction to prestressed concrete structures, Design of pre-tensioned and post-tension prestressed concrete structures, losses in prestress – short term and long term.
- **Design of lined and unlined containment structures:** Lined RC and prestressed containment, Introduction to various codes viz. - RCC-G/BPEL/BAEL, ASME Section-3 Div-2, load combinations, allowable stresses, design criteria against limit state of serviceability and ultimate limit state, case study of design of RB inner/outer containment structure, case studies.
- **Design of steel structures of nuclear facility:** Design of truss and framed structures as per IS 800: 2007, AERB standards, AISC standards etc., design of connections, design of embedded parts and anchor bolts as per AERB and ACI standards, case studies.
- **Design of water-retaining structures:** Design of overhead and underground tanks using un-cracked section, design for static and hydrodynamic load, serviceability checks, case studies.
- **Design of cooling towers:** Estimation of waste heat for power plants, once through & closed loop water circulation system, selection of design parameters for cooling requirements, Introduction to thermal and structural design of Natural Draft Cooling Tower (NDCT), case studies.

Course Outcomes:

This course will introduce the students to the design of prestressed concrete structures and reactor containment structures using RCC-G, BPEL, BAEL, and ASME codes. The course will also expose the students to steel structure design as per BIS, AERB, and AISC standards, and the design of water retaining structures and natural draft cooling towers.

References

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

EN609 Earthquake Engineering and Structural Dynamics (45 Lecture Hrs)

Coordinators: Dr. (Smt) Y. A. Parulekar (yogitap@barc.gov.in)
Dr. A. Mondal (apurba@npcil.co.in)

Course Details:

- **Introduction to Seismology**
 - Structure of the earth, plate tectonics and faults, seismic waves & wave propagation, seismograph, locations of earthquake, intensity, magnitude, iso-seismal curves, attenuation, identification of capable fault, estimation of magnitude potential, determination of Peak Ground Acceleration (PGA), Design Basis Earthquake, Concept of Response spectrum, Generation of Artificial Time History, Power Spectral Density, IS 1893 Response Spectra
 - Seismic instrumentation for micro-earthquake and strong motions.
- **Structural Dynamics**
 - Introduction to dynamic loading, different types of dynamic loadings, concept of damping, derivation of equations of motion, effect of gravity/static loads on equation of motion, equation of motion for support excitation
 - Single degree of freedom of system (SDOF)–undamped & damped system, free & forced vibration; Response to harmonic and impulse loading, concept of transmissibility and vibration isolation, estimation of damping of structural system using free & forced vibration approach; response to impulse loading-shock spectra, response to general dynamic loading using Duhamel Integral.
 - Numerical procedure to determine dynamic response of SDOF, acceleration-impulse extrapolation, evaluation of dynamic response by direct integration
 - Multi degree of freedom system (MDOF) – Equations of motion for lumped mass system, evaluation of Eigen values (natural frequencies) & eigenvectors (mode shapes), orthogonality property of normal modes, response to ground motion, Fourier analysis and response to generalized periodic loading
 - Introduction to dynamics of continuous system
- **Seismic Response Analysis of Structures**
 - Seismic response analysis using response spectrum and time history approach
 - Modal superposition method, Modal combinations and spatial combinations, missing mass correction
 - Time history analysis using direct time integration,
 - Accidental torsion, soil-structure interaction, fluid structure interaction, equipment structure interaction
- **Random vibrations:** Fourier analysis and evaluation of power spectral density function, response of structures in frequency domain.
- **Special Seismic Design Considerations**
 - Failure of structures during earthquake, Layout and irregularities of structures, Concept of ductility-strain,
 - curvature and displacement ductility, design guidelines for achieving ductility in reinforced concrete structures; Seismic Design Optimization, Principles of performance-based design, dynamic response control techniques such as base isolation, dampers etc.
- **Seismic Requalification of Existing Installations**
 - Need and methodology for seismic requalification, seismic walkdown, health assessment, data collection,

- review basis ground motion, evaluation of seismic margin capacity, retrofitting.
- **Case Studies:** Dynamic analysis of a typical RC and steel structures, requalification and retrofitting of safety related nuclear Installments.

Course Outcomes:

This course will introduce the students to seismic waves, wave propagation, response spectra, time history methods, and seismic instrumentation. The course will also expose the students to dynamic loading and response of SDOF and MDOF systems, soil–structure and fluid–structure interaction, frequency-domain analysis, and seismic requalification and retrofitting techniques

References

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

EN610 Code design for Process Equipment (30 Lecture Hrs)

Coordinator: Dr. J. Chattopadhyay
(jchatt@barc.gov.in)

Course Details:

- **Part-1: Design of non-nuclear pressure vessels & heads under internal/external pressure**
 - General introduction to ASME Code. Salient differences between Sec. VIII Div.1 and Div.2. Membrane theory for thin shells, stresses and dilation in cylindrical, spherical and conical Shells. General theory of membrane stresses in vessel under internal pressure and its application to ellipsoidal and torispherical end closures.
 - Thick cylinder and sphere and derivation of Lamé's equations. Derivation of ASME Sec. VIII Div.1 and Div. 2. Thickness equations for cylindrical/ spherical shell and conical, ellipsoidal and torispherical end closures.
 - Bending of circular plates and determination of stresses in simply supported and clamped circular plate. Basis of ASME equation for flat closures.
 - Openings, nozzles and external loading. Stress concentration in plate having circular hole due to bi-axial loading. Theory of reinforced opening and reinforcement limits. Beam on elastic foundation and its application to thin-walled pressure vessels. Extent and significance of load deformation on pressure vessel. Reinforcement Rules for ASME, Sec.VIII Div.1. Local Stresses in shells due to external loadings from nozzles and lugs etc.
 - Buckling of vessels under external pressure. Elastic buckling of long cylinders, buckling modes, buckling(collapse) coefficients. ASME procedure for design of vessels under external pressure. Design of stiffening rings. Design of shells for axial compression.
 - Design consideration for pressure vessel. Design pressure and temperature, Allowable stresses, Impact toughness requirement as per ASME Sec.VIII Div.1. Non-destructive Examination (NDE) of welds as per ASME Sec.VIII, Div.1. Requirements for Hydro and pneumatic testing of pressure vessels.
 - Design and analysis of cryogenic vessels. Material selection and design aspects at low service temperature.
- **Part-2: Design of vessel supports, flange joints, tube sheet and power piping (10 lectures)**
 - Bolted Flange joints. Types of flange joints. Types of Gaskets and their selection. Gasket seating force calculations. Bolting design. Flange loads and moments. Design of flange as per ASME Boiler and Pressure Vessel and B31.3 Code.
 - Supports for vertical and horizontal vessels. Design of skirt, lugs, saddle supports and anchor bolt.
 - Design of tube sheet as per TEMA guidelines and its comparison with ASME design rules.
 - Design of piping as per ANSI/ASME B31.1 code (power piping). Pipe sizing, flexibility factor and stress intensification factor, piping support.
 - Case Studies/Tutorials

Course Outcomes:

This course will introduce the students to the basis of ASME Section VIII and Section III equations for pressure vessel and piping design. The course will also expose the students to nozzle opening design, external pressure considerations, ANSI/ASME B31.1 and B31.3 piping codes, and NDE examination of welds with acceptance standards.

References:

1. Jawad, M.H., and Farr, J.R., "Guidebook for the design of ASME Section VIII Pressure vessels", 2nd Edition, ASME Press, 2001.
2. Harvey J.F., "Pressure Vessel Design", CBS Publication
3. Brownell L.E., and Young E.D., "Process Equipment Design" Wiley Eastern Ltd., India
4. ASME "Pressure Vessel and Boiler Code", Sec.VIII, Div.I and Div.II, 2010
5. American Standard Code for Pressure Piping", - B31.1, 1972
6. "Standard of Tubular Exchanger Manufacturers Association", 7th Edition, 1988.

EN611: Computational Fluid Dynamics & Heat Transfer (50 Lecture Hrs)

Coordinator: Dr. Naveen Kumar
(nkumar@hbni.ac.in)

Course Details:

- **Basics of Fluid Flow, Heat Transfer and Numerical Analysis (5):**
 - Kinematics of fluid flow: Streamline, streakline and pathline; streamfunction, vorticity and deformation of a fluid element.
 - Basic equations governing heat conduction, fluid flow and mass transfer (viz. the continuity', momentum and energy' equations) with special reference to Navier-Stokes and Bernoulli equations.
 - Classification of Partial Differential Equations (PDEs) and different types of Boundary conditions.
 - Formulations of governing equations used in numerical simulation.
 - Streamfunction-temperature formulation
- **Laminar Boundary Layer and Forced Convective Heat (5):**
 - Formulation of differential equation for hydrodynamic and thermal boundary layer
 - Different analytical method of reduction of boundary layer equations and theoretical formulation of boundary layer thickness.
 - Study of jets and inlet flow and flow separation in the light of Boundary Layer Theory
 - Convective heat transfer for internal and external flows
 - Low and high Prandtl number limits and different thermal boundary conditions
- **Turbulent Flow and Heat Transfer (5):**
 - Introduction to Turbulence
 - Approaches to Turbulence Modeling
 - Reynolds decomposition for turbulence
 - Prandtl's mixing length theory, Mixing length models
 - Structure of turbulent boundary layer over flat plate and through circular cylinder
 - Calculation of friction factor and drag coefficient
 - Analytical and semi-analytical correlations for calculating heat transfer coefficients
 - Analogy between heat and momentum transfer
 - Reynolds analogy, von Karman-Prandtl analogy, Martenelli analogy, Lyons analogy
 - Turbulence Modeling:
 - Eddy diffusivity models: k - ϵ and k - ω) models, RNG based k - ϵ model
- **Natural Convection (3):**
 - Basic Equations of natural convection
 - Boussinesq approximation
 - Derivation of Dimensionless groups from basic equations
 - Analytical approximations
 - Integral solution for laminar flow over a flat plate
- **Numerical Solution of Complete Fluid Flow and Energy Equation (10):**
 - Discretization of conduction equation with Dirichlet, Neumann and periodic boundary conditions, by ADI and TDMA Method.
 - Temporal integration: explicit, implicit scheme
 - Discretization of convection, upwinding, Streamline-Upwind Petrov Galerkin method
 - Discretization of convection-diffusion problem: exponential scheme, power-law scheme

- Streamfunction-vorticity-temperature formulation
 - Velocity-vorticity-temperature formulation: Poisson, Cauchy-Riemann and Biot-Savart form
 - Elliptic, parabolic and hyperbolic equation method
 - Primitive-Variable (P-V-T) formulation
 - Pressure velocity coupling for incompressible flow:
 - Staggered, Non-Staggered Grid (momentum interpolation, pressure-weighted interpolation)
 - Discussion on MAC, PISO, SIMPLE and SIMPLER family of method
 - Simple grid generation techniques for structured grid:
 - Numerical solution of approximate equations
 - Numerical Solution of Reduced Boundary Layer Equations: BVP, Keller box method
- **Reactor Heat Transfer**
 - Pressure drops in rod cluster fuel element friction, local acceleration and elevation pressure drop in wire-wrap & grid spacers; effect of creep and bundle misalignment on PHWR bundle pressure drop. Flow orificing objectives & method; effect of orificing in BWR.
 - Hot spot factors: Classification, basic statistical relationship, determination of subfactors, multiplicative & statistical method of combining subfactors.
 - Subchannel analysis of rod cluster mixing mechanisms, mixing parameters, introduction to computer codes.
 - low loops: Determination of operating point during forced and natural circulation; Loss of flow accident; Decay heat generation and flow coast down in primary loop. Transition to thermosyphon cooling; steady state theory of thermosyphon loops. Transient and stability behaviour of the thermosyphon loops.
 - Loss of coolant Accident; Events during blow down, description of emergency core cooling system; flooding and sputtering.
 - Radiation heat transfer in non-participating and participating media.
 - Heat transfer during severe accidents in nuclear reactors
 - **Heat Transfer with Phase Change**
 - Introduction of two-phase flow and basic relations; flow regimes in adiabatic and diabatic vertical co-current flow and in adiabatic co-current horizontal flows.
 - Basic equations of two-phase flow; Homogenous & separated flow models for two phase flow; void fraction & phase velocity ratio (Zivi's model)
 - Introduction to boiling heat transfer and bubble nucleation; Regimes in boiling heat transfer (a) pool boiling (b) flow boiling: Heat transfer correlation for pool boiling (Rohsenow's correlation) and flow boiling (Chen's correlation)
 - Condensation heat transfer: Nusselt's theory and its limitations: Jet condensation fundamentals and its application in containment cooling.
 - Critical heat flux: Various models of critical heat flux, CHF, MCHF. Critical power concept. Post dryout heat transfer: Various models available for calculation of heat transfer coefficient.
 - Critical Flow: Models for single – phase and two-phase critical flow.
 - Two-phase heat transfer and pressure drop during transition from one flow regime to another

Course Outcomes:

This course develops the fundamental understanding of fluid flow, heat transfer, and numerical methods required for computational analysis of thermal-hydraulic systems. It enables students to model single-phase and two-phase flows, reactor heat transfer phenomena, and accident scenarios using CFD-based solution techniques.

References

1. Long, C. A. (1999): Essential Heat Transfer, Pearson Education Ltd, Harlow.
2. Bird, R.B., Stewart, W.E. and Lightfoot, E.N. (1960): Transport Phenomena, John Wiley & Sons: NY.
3. Schlichting, S. (1979): Boundary Layer Theory, 7th ed., McGraw-Hill: NY.
4. Holman, J.P. (1997): Heat Transfer, 8th ed., McGraw-Hill: NY.
5. Kays, W.M. and Crawford, M.E. (1993): Convective Heat Transfer, McGraw-Hill: NY.
6. Bejan, A. (2004): Convective Heat Transfer, 3rd Ed. Wiley India.
7. Tennekes, H. and Lumley, J.L. (1972): A First Course in Turbulence, MIT Press: Cambridge.
8. Piquet, J. (1999): Turbulent Flows: Models and Physics, Springer-Verlag: Berlin.
9. Patankar, S.V. (1982): Numerical Heat Transfer and Fluid Flow, Hemisphere.
10. Versteeg, H.K. and Malalasekera, (1996): An Introduction to Computational Fluid Dynamics: the Finite.

EN612: Computer Based System Design (35 Lecture Hrs)**Coordinator: Shri S. K. Lalwani**
(skl@barc.gov.in)**Course Details:****• Hardware Design**

- Overview of microprocessors and peripherals: 8086, Digital Signal Processor (TMS320) DMA controller, serial communication controller and timer/counter.
- Personal computer architecture, memory organization, industrial PC
- Standard bus: Overview of PCI, VME bus, and cPCI bus mechanical, electrical and functional specifications. Serial buses: USB and PCIe
- Overview of combinational and sequential logic blocks, Finite State Machine
- Programmable Logic devices: Introduction to SPLD, CPLD and FPGA.
- Introduction to Hardware Description Language (VHDL) and programming using VHDL.
- System design concepts: Fault tolerance, hot standby, live insertion, triple modular redundancy and safety issues
- Case Study: Design of a single board computer with shared memory interface, analog and digital I/O board design (with emphasis on signal conditioning and isolation), computer based system

• Networking & Communication

- Asynchronous and synchronous communication
- Standards like RS232, RS422, RS485
- Encoding schemes
- Local Area Networks
- OSI7 layer model and TCP/IP reference model
- Standards like Ethernet, Token bus, Token ring, Wireless LAN and Bluetooth
- Communication Protocols: IPV4, IPV6, ARP, DHCP, UDP, TCP
- Networking hardware–cables, hub, switch, router, etc.
- Fiberoptics in communication

• Industrial networks: Field Bus standards, CAN bus, and Protocols

- Deterministic communication techniques
- Case study: various techniques used in NPP for communication and networking

Course Outcomes:

This course introduces hardware and system-level design concepts using microprocessors, programmable logic devices, and industrial communication standards. It also develops skills in embedded system architecture, networking, and fault-tolerant system design for real-time industrial applications.

References:

1. Douglas V. Hall, “Microprocessors and Its Interfacing, Programming and Hardware”
2. Yu-cheng Liu, Glenn A. Gibson, “Microcomputer Systems The 8086/8088 Family - Architecture, Programming and Design”
3. 8086 family User Manual by Intel
4. Alan Clements, “Microprocessor Systems Design 68000 Hardware, Software, and Interfacing”
5. Texas Instruments, “TMS320C20x User’s Guide”
6. VMEbus Specification Manual, Revision C.1
7. Tom Shanley and Don Anderson, “PCI System Architecture”

8. Ian Grout, "Digital Systems Design with FPGAs and CPLDs", Elsevier publication
9. Douglas L Perry, "VHDL: Programming by example", McGraw-Hill Professional publication
10. Stephen Brown and Zvonko Vranesic, "Fundamentals of Digital Logic with VHDL Design", McGraw-Hill publication
11. A VHDL Primer by Jairam Bhaskar
12. Bryan Mealy and Fabrizio Tappero, "Free Range VHDL"
13. Andrew S. Tanenbaum and David J. Wetherall, "Computer Networks", Pearson Education India
14. Douglas E. Comer & David L. Stevens, "Internetworking with TCP/IP Vol. I", Prentice Hall India Learning Private Limited
15. Douglas E. Comer & David L. Stevens, "Internetworking with TCP/IP Vol. II", Prentice Hall India Learning Private Limited
16. Forouzan, "Data Communications and Networking", McGraw Hill Education

EN613: Computer Graphics and Visualization (25 Lecture Hrs)

Coordinator: Shri Dinesh Sarode
(dinesh@barc.gov.in)

Course Details:

- Introduction to Graphics and Visualization
- Curves and Surfaces
- Structured, Unstructured and Multi Block Grid storage,
- Memory and Computational Efficiency
- Meshing Algorithms
- Color Models
- Scalar visualization techniques and algorithms
- Vector Visualization techniques and algorithms
- Volume Visualization Method
- Particle Tracing algorithms
- 2D and 3D iso-surface algorithms
- Ray tracing algorithm

Course Outcomes:

This course provides knowledge of visualization techniques for scientific and engineering data, including scalar, vector, and volume rendering methods. It enables students to design efficient meshing, surface generation, and rendering algorithms for effective data interpretation and simulation visualization.

EN614: Code design of Nuclear Pressure Vessels & Piping (30 Lecture Hrs)

Coordinator: Dr. J. Chattopadhyay
(jchatt@barc.gov.in)

Course Details:

- **Part-1: Design of nuclear pressure vessels**

- Introduction to Nuclear design code: ASME Section-III. Unique features of Sec. III vis-à-vis non-nuclear design codes, design margins, concept of Design-by-analysis (DBA), Safety classification of components and Service levels as per NCA-2140.
- Types of stresses, their significance and relevance to different failure modes of pressure vessels.
- Technical basis of Primary stress limits. Derivation of stress intensities in vessel and piping. Limit analysis of beams and cylindrical shell under pressure and moment loading.
- Technical basis of Secondary stress limits. Failure modes of Ratchetting and shakedown.
- Limits on Peak stress. Basis of Low Cycle Fatigue Design. Fatigue evaluation of vessels. Strain concentration factor 'Ke', Local strain approach: Neubar rule, Elastic and elastic-plastic fatigue analysis.
- Design rules for vessels as per NB 3300.
- Allowable stress limits for various service levels for vessels, bolts and pipings.
- Fracture Toughness requirements for materials for pressure vessels, piping and bolting. ASME Appendix G procedures.
- Design rules for Elevated Service Temp – Subsection NH

- **Part-2: Design of nuclear piping (12 lectures)**

- Design of Nuclear piping as per Sec.III Div.1 (NB-3600), Definition of B, C and K stress indices.
- Design rule for piping support-NF3600. Design rule for Plate and shell-Type of support as per NF3200, Design rule for Linear-type support-NF3300
- Pre and Post weld heat treatment requirement for vessels and pipings as per ASME code sec.III.
- NDE requirements, Examination of welds, Acceptance standard.
- Case Studies/Tutorials

Course Outcomes:

This course introduces nuclear design codes and stress-based design methodologies for pressure vessels and piping systems. It develops competence in applying ASME Section III rules for structural integrity, fatigue assessment, fracture mechanics, and nuclear piping design compliance.

References:

1. Jawad, M.H., and Farr, J.R., "Structural analysis and design of Process equipment", John Wiley & Sons, 1984.
2. Chattopadhyay, S "Pressure Vessel Design and Practice", CRC Press, 2005.
3. "Criteria of the ASME Boiler and Pressure vessel code for Design by Analysis in Section III and VIII, Division 2", ASME Press, 1968.
4. "ASME Boiler and Pressure Vessel Code – Rules for construction of nuclear facility components", Sec.III, Div.I, 2010

EN 615: Corrosion (15 Lecture Hrs)

Coordinator: **Dr. Supratik Roychowdhury**
(supratik@barc.gov.in)

Course Details:

- **Basics of corrosion:** Definition and importance of corrosion, corrosion principles; thermodynamic and electrochemical aspects; electrode potentials; polarization and corrosion rates; passivity, mixed potential theory, environmental effects: Dissolved Oxygen, temperature, pH, Velocity bacteria, dissolved salts and metallurgical variables.
- **Forms of corrosion and their control:** Uniform attack; Galvanic corrosion, pitting and crevice corrosion; selective leaching; erosion corrosion; intergranular corrosion (including low temperature sensitization, corrosion of weldments); stress corrosion cracking (SCC), irradiation assisted SCC; hydrogen damage; oxidation; microbiological induced corrosion (MIC), Corrosion testing procedures, specification tests. General principles of corrosion control – anodic and cathodic protection, inhibitors and passivators, corrosion protection by alloying, surface treatment and surface modification.
- **Corrosion in the nuclear industry:** Flow accelerated corrosion (FAC), mechanism, plant occurrences, mitigation; Corrosion in nuclear fuel reprocessing, waste management and heavy water plants. End grain corrosion; Hot conditioning; SCC of stainless steels and nickel base alloys in LWRs; Corrosion problems in steam generators; oxidation and nodular corrosion of zirconium alloys; hydrogen related problems in Zr-alloys: hydriding, DHC, hydride blistering; PCI-SCC of Zr-alloys; Effects of radiation on corrosion.

Course Outcomes:

This course provides a fundamental understanding of corrosion mechanisms, degradation modes, and mitigation techniques in industrial and nuclear environments. It equips students with the ability to analyze corrosion failures and apply material selection and protection strategies for enhanced component life.

References:

1. Corrosion Engineering – M.G. Fontanna, McGraw Hill Series in Materials, Second Ed. 1978.
2. Corrosion and Corrosion Control – H.H. Uhlig and R.W. Revie, Wiley Interscience, Third Ed. 1985.
3. Corrosion in Nuclear Applications – W.E. Berry, Wiley, London, 1971
4. ASM Handbook, 9th Ed., Vol. 13 on Corrosion, 1988.
5. Fundamentals of Electrochemical Corrosion, E.E. Stansbury and R.A. Buchanan, ASM International, First Ed., 2000.
6. Corrosion of Stainless Steels – A.J. Sedricks.
7. Principles and Prevention of Corrosion – D. A. Jones, MacMillan, 1996.

EN616: Distributed Computing (25 Lecture Hrs)

Coordinator: Shri K. Rajesh
(rajesh@barc.gov.in)

Course Details:

- **Module I: Advanced Computer Architecture:** CPU performance improvement techniques, architectural innovations in latest commercial processors, CPU microarchitectures, Advances in Memory, Memory technologies, Memory Interfacing techniques, Advances in I/O interfaces, Shared bus, Switched fabric, High Performance Interconnect technologies, Ethernet and Infiniband variants, Caching technologies and their improvements, Storage technologies and their advancements, Virtualization techniques
- **Module II: Parallel Computing:** Introduction to High Performance Computing, Need, Applications, Classifications, HPC Architectures, Pipelining, Superscalar, VLIW, EPIC, SIMD, Vector processing, MIMD and their classifications, Interconnection networks and topologies, network metrics, types of interconnection networks, Modern Parallel Architectures (NUMA, UMA, CCNUMA, Accelerators based heterogeneous architecture), Software concepts of High Performance Computing: Parallelism, Granularity, Amdahl's and Gustaffson's laws, Design of parallel algorithms, Parallel Programming Methodologies, Parallel Programming Models and Paradigms, Programming Environments, OpenMP and MPI, CUDA, OpenCL, Example Parallel Programs, benchmarking, case studies.
- **Module III: Cloud Computing:** Introduction to Grid Computing, Virtualization, Cloud Computing, Cloud Middleware, Security in Clouds, Advanced concepts in Distributed Computing.

Course Outcomes:

This course introduces advanced computer architectures, parallel computing models, and distributed computing frameworks including cloud and grid systems. It enables students to design and implement high-performance computing solutions for large-scale scientific and engineering applications.

References

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

EN 617: Advanced Machine Design (25 Lecture Hrs)

**Coordinators: Shri K.J. Thomas
Dr. I.A Khan(imran@barc.gov.in)**

Course Details:

- **Part-1: Principles of Machine Design**

- Introduction to design process, material selection, functional & strength requirements, design method for static and fluctuating loads.
- Drawing standards & practices, limits and fits, geometric & dimensional tolerances as per ISO/ANSI standards.
- Properties of lubricants and their specific applications, Hydrodynamic theory of lubrication (Reynolds' equation), modes of wear and wear-mechanism maps, tribological behaviour of contact asperities.

- **Part-2: Design of machine elements**

- Design of shafts, keyways and couplings: Stresses in shafts subjected to bending, torsional and shear loads, shafts mounting, protection against buckling and shaft whipping, design of various keys and keyways as per ISO standards, selection of rigid/flexible couplings using catalogues.
- Bearing and bearing mountings: Sliding and rolling contact type bearings, bearing materials, Speed ratings (ISO 15312) and load ratings of various contact-type bearings, statistical (Weibull) design of bearings, life predictions under variable loads (Palmgren-Miner rule), pressure development mechanism in hydrodynamic bearings, converging/diverging films, bearing performance curve, design of boundary lubricated (pV method) and hydrodynamic bearings (Raimondi & Boyd technique), design considerations in mounting of bearings.
- Gears and gear box: Force transmission in different types of gears, stress analysis of gear tooth (Lewis equation), gear design based on bending stress number (AGMA 2001–C95), Hertz contact stresses, design based on contact stress number, selection of gear materials, design of gear box.
- Belts and chain drives: Selection considerations for belts & chain drives, catalogue based design of V-belt drives, failure modes and design load ratings of chain drives.
- Threaded fasteners and screws: Introduction to various thread standards (UNS and ISO) and thread dimensions, stress analysis, critical speed & buckling considerations for power screws, catalogue based design of ball screws.

- **Part-3: Sealing Method and Advanced Manufacturing techniques**

- Introduction to static, dynamic, metallic and non-metallic seals, seal materials, selection criterion for elastomeric 'O'rings, expansion bellows, labyrinth and valve packings.
- Introduction to Precision machining, super finishing, micro-machining and laser based 3-D printing.

- **Case studies/Tutorials**

Course Outcomes:

This course develops advanced mechanical design skills for critical machine components under static and dynamic loading conditions. It also emphasizes tribology, sealing systems, and modern manufacturing methods for reliable and high-performance mechanical system design.

References:

1. "Machine elements in mechanical design" by Robert L. Mott, 4th edition, Pearson Prentice Hall
2. "Machine design – An integrated approach" by Robert L. Norton, 4th edition, Pearson Prentice Hall
3. "Mechanical Engineering Design" by Joseph E. Shigley.
4. "Machinery's HandBook" (24th edition)

5. "ISO Standards HandBook" 18.
6. "SKF Bearing Catalogue."
7. "Relevant IS standards."
8. "Friction, Wear, Lubrication, Tribology HandBook" edited by Prof. I.V. Kragelsky & V. VALisim.
9. "Gear Hand Book" by Dudley.
10. "AGMA Standards 218.01" Dec. 1982.
11. "Industrial Sealing Technology" by H. Hugo Buchter

EN618: Electrical Systems for Nuclear Power Plants and Facilities (35 Lecture Hrs)**Coordinators: Dr. Shakti Prasad Panda
(sppanda@npcil.co.in)****SCourse Details:**

- Interaction of Nuclear Power Station with The Power Grid: Overview of Indian Power grid, requirement of reliable grid and grid interaction, transmission lines for startup power and power evacuation, power system analysis - short circuit, load-flow and stability studies. Ferranti effect and reactive power compensation in line, unit size, islanding scheme and house load operation.
- EHV Switchyards in NPP: Type, voltage levels and clearances, switching schemes, comparison between different types, brief introduction to equipment in switchyard, 220kV cables, OPG and overhead conductor, lightning protection, grounding, rating, specification, test requirement and standards.
- Generator and excitation system: Rating, specifications, test requirement and standards.
- Transformers and reactors: GT, UT, SUT, shunt reactors and its accessories: Functions, selection criteria, rating, regulation, specifications, test requirements and standards
- Generator Circuit Breaker, Switchgears, MCC and Distribution Boards and its accessories: Functions, selection criteria, types, specifications, test requirements and standards.
- Motors: Types of motors and its selection criteria, radiation withstand, performance, bus transfer, energy efficiency, specifications, test requirements and standards.
- DG sets, UPS, Batteries and Chargers: Types, selection criteria, rating, regulation, specifications, test requirements and standards.
- Station Auxiliary Power Supply Systems: Class I, II, III and IV classifications, Nature of electrical loads and supply voltages, cabling, lighting, effect of voltage and frequency variation on electrical equipment and remedial measures, synchronizing schemes, autotransfer, emergency transfer and load shedding.
- Class 1E requirements: Requirements for safety related electrical equipment and systems, seismic qualification.
- Relays and Protection system: classification of relays, device numbers, protection of transmission line, switchyard bus bars, generator, transformers and reactors and motors.
- Billing, station metering, telemetry and SCADA systems.
- VFDs and Numerical Relays, Design of Ground Mat, Joule Melter Power Supplies, Harmonic analysis in Power system

Course Outcomes:

This course provides comprehensive knowledge of electrical power systems used in nuclear facilities, including generation, transmission, protection, and auxiliary power systems. It enables students to design and analyze safety-class electrical systems with emphasis on reliability, redundancy, and regulatory compliance.

References:

1. Design of Electrical Power Systems for Nuclear Power Plants – AERB safety guide No. AERB/NPP/SG/D-11
2. Electric grid reliability and interface with Nuclear Power Plants: IAEA Nuclear Energy Series no. NG-T-3.8
3. Manual on Transmission Planning Criteria: Central Electricity Authority, New Delhi
4. Installation and Operation of Meters: Central Electricity Authority Regulations
5. Manual on Layout of Substations-CBIP, New Delhi
6. Manual on Transmission Lines-Publication No. 323, CBIP, New Delhi

7. Manual on Power System Protection – Publication No. 328, CBIP, NewDelhi
8. Electrical Transmission & Distribution HandBook-Westinghouse Electrical Co., USA
9. Protective Relays-Network Protection & Automation Guide- Alstom Grid
10. Transformer Book - The J&P
11. Switchgear Book - The J&P
12. Handbook of Batteries-McGraw Hill Book Company
13. Power Electronics – Mohan, Undel and, Robbins
14. Elements of Power System Analysis-W.D. Stevenson
15. Electrical Power System – Wadhwa
16. Performance and Design of AC machines – MG Say
17. Modern Power Station Practice-Volume D - Electrical System&Equipment, British Electrical International.
18. IEEE-80-IEEE Guide for Safety in AC Substation Grounding
19. IEEE-308-Criteria for class 1E Equipment for Nuclear Power Generating Stations
20. IEEE-323-Qualifying class1E Equipment for Nuclear Power Generating Stations
21. "IEEE-519-2014: Recommended practice and Requirements for Harmonic control in Electric Power System"

EN 619: Embedded & Computer Based System Design (40 Lecture Hrs)

Coordinators: Shri. S. K. Lalwani
(skl@barc.gov.in)

Course Details:

- **Module I [20]**

- Part A - Microprocessor based Design [10]
 - 8086 Microprocessor: Hardware architecture, memory and I/O interfacing and handling of interrupts;
 - Introduction to DSP Processors and comparison with Microprocessors
- Part B[10]
 - ARM processor: architecture.
 - Board level buses: I2C and SPI
 - Introduction to USB

- **Module II [20]**

- Part A – Computer based hardware design [7]
 - Overview of PC Architecture, Industrial PC and Embedded PC, SBC architecture
 - Industry standard bus systems: PCI, VME: Mechanical, electrical, functional and procedural specifications
 - Multi processing, bus arbitration and Plug and Play
 - System design considerations: thermal, EMC and signal integrity analysis; Design accommodations for testability, reliability and maintainability.
 - Design Case Study:
 - I/O Board design, bus interface (PCI, PCIe) FIFO and shared memory interfaces.
 - Low Power Electronic system design
- Part B - Computer Communication and Networks [6]
 - Overview of asynchronous and synchronous communication standards
 - Encoding (NRZ, Manchester), Ethernet
 - Industrial networks, Field Bus, CAN bus and Protocols
 - Networking hardware: Cables, Hubs, switch and routers.
- Part C - Software development for embedded and PC based systems (7)
 - Basic RTOS concepts
 - C programming for ARM based applications
 - Programming for PC based systems.

Course Outcomes:

This course introduces embedded hardware and software design using microprocessors, ARM architectures, industrial buses, and real-time operating systems. It equips students with practical skills for developing reliable computer-based control and communication systems.

References:

1. Douglas V. Hall, “Microprocessors and Its Interfacing, Programming and Hardware”

2. Yu-cheng Liu, Glenn A. Gibson, "Microcomputer Systems The 8086/8088 Family - Architecture, Programming and Design"
3. 8086 family User Manual by Intel
4. Alan Clements, "Microprocessor Systems Design 68000 Hardware, Software, and Interfacing"
5. Texas Instruments, "TMS320C20x User's Guide"
6. VMEbus Specification Manual, Revision C.1
7. Tom Shanley and Don Anderson, "PCI System Architecture"
8. Ian Grout, "Digital Systems Design with FPGAs and CPLDs", Elsevier publication
9. Douglas L Perry, "VHDL: Programming by example", McGraw-Hill Professional publication
10. Stephen Brown and Zvonko Vranesic, "Fundamentals of Digital Logic with VHDL Design", McGraw-Hill publication
11. A VHDL Primer by Jairam Bhaskar
12. Bryan Mealy and Fabrizio Tappero, "Free Range VHDL"
13. Andrew S. Tanenbaum and David J. Wetherall, "Computer Networks", Pearson Education India
14. Douglas E. Comer & David L. Stevens, "Internetworking with TCP/IP Vol. I", Prentice Hall India Learning Private Limited
15. Douglas E. Comer & David L. Stevens, "Internetworking with TCP/IP Vol. II", Prentice Hall India Learning Private Limited
16. Forouzan, "Data Communications and Networking", McGraw Hill Education

EN620: Extractive Metallurgy (40 Lecture Hrs)

Coordinators: Dr. A. Awasthi
(aawasthi@barc.gov.in)

Course Details:

- **Introduction:** Reactive and refractory metals - classification, occurrence in India, method of attaining high temperatures, measurement of temperature, vacuum metallurgy principles including preliminary vacuum chamber design.
- **Metallurgical Thermodynamics:** Concept of equilibrium, activity as effective concentration, experimental determination and theoretical assessment of thermodynamic properties, equilibrium in ternary systems, Pourbaix Ellingham diagrams, activity and vapour pressure measurement, EMF techniques, thermal analysis, kinetics at high temperatures.
- **Metal Extraction:** Reduction of oxides using carbon, hydrogen (including size reduction by hydride-dehydride) and metallothermy (Al, Mg, Ca, Si, La etc), container material issues, effect of vacuum, direct preparation of alloys and intermetallics, carbonitrothermy, extraction of metal (Ca, rare earths) through vapour phase.

Reduction of halides – need to use halides, preparation of chlorides and fluorides, metallothermic reduction of halides, preparation of group IV metals by chloride reduction, preparation of tantalum and rare earth metals by fluoride reduction.

- **Refining:** Significance of the removal of interstitial impurities. Metal refining using electroslog, carbonyl, iodide, float zone, electrotransport processes. Removal of nitrogen and hydrogen. Purification by sacrificial, carbon, aluminium and silicon deoxidation.
- **Electro-pyrometallurgy:** Principles of fused salt electrolysis and electrorefining. Container, carrier electrolyte, oxychloride, pre-electrolysis issues. Reduction as alloy (Nd-Fe), Newer processes of direct electrolysis of metal oxides.
- **Commercial Processes:** Commercial processes of major rare metals (including non-metals like B).
- **Principles of Hydrometallurgy:** Steps in hydrometallurgy, size reduction, leaching types, mathematical formulation: shrinking core model, Uranium technology: acid leaching flow sheet, alkali leaching flow sheet, uranium refining, separation of beach minerals and preliminary flow sheet for thorium recovery, separation of mixed rare earth chloride into LRE, HRE and MRE, ways to leach refractory Nb-Ta ores, concepts of solvent extraction and ion exchange. Spent fuel reprocessing.

Course Outcomes:

This course provides fundamental knowledge of metal extraction, refining, and purification techniques using pyro-, hydro-, and electrometallurgical processes. It enables students to understand thermodynamic principles and industrial flowsheets for the production of reactive and rare metals.

References:

1. Chemical Metallurgy: Principles and Practice - CK Gupta, WILEY-VCH Verlag GmbH
2. Extractive Metallurgy (3 volumes) - Alain Vignes, John Wiley & Sons
3. Materials Thermochemistry - O. Kubaschewski, Pergamon Press

EN 621: Finite Element Method (30 Lecture Hrs)

Coordinators: Dr. A. K. Dureja
(akdureja@barc.gov.in)

Course Details:

- **Part-1: Introduction and 1D elements:** Element shape functions: Generalized co-ordinates, General requirements for shape functions, Lagrangean, Hermitian interpolation functions, C0 and C1 continuity, Natural coordinate system; derivation of shape functions for 1-D elements, Bar element: Derivation of elemental stiffness matrix and load vector; transformation from element to global coordinate system; assembly of global stiffness matrix and load vector; solution of typical 2D-plane truss problems to evaluate displacements and member forces/stress; thermal stress evaluation in Bars/Truss, Euler-Bernoulli beam element: Derivation of elemental stiffness matrix and load vector; solution of simple beam problems to evaluate deflections/rotations; BM/SF distribution and determination of stresses shear deformation in beams, Timoshenko beam element, Concept of shear locking, selective and reduced integration techniques, Straight pipe and pipe bend elements, Ovalization of pipe bend or elbow element, concept of stress stiffening and its implementation in pipe element, modeling of hangers and supports in pipings, Introduction to commercial piping analysis softwares.
- **Part-2: 2D plane elements and isoparametric formulation:** 2D plane elements, 3 noded triangular element, Derivation of elemental stiffness matrix and load vector, Plane stress/ Plane strain & Axisymmetric elements; Evaluation of strain/stress, 2D isoparametric formulation – 4 and 8 noded quadrilateral elements, mapping of parent element to global space, Jacobian matrix; necessary and sufficient conditions for existence of inverse of Jacobian; Derivation of elemental stiffness matrix and load vector for plane and axisymmetric elements; evaluation of strain/stress at Gauss points, numerical integration, Newton-Cotes and Gauss quadrature, Incompatible displacement model: Bending deficiency in the linear strain quadrilateral element; Incompatible quadrilateral elements, Spurious zero-energy modes and its suppression, shear and volumetric locking in continuum elements.
- **Part-2: 3D elements and harmonic analysis:** Introduction and Application to 3D elements: Strain-displacement and stress-strain relationship; Tetrahedron elements; Triangular and prism elements and hexahedron elements, Harmonic analysis using FEM, Eigenvalue extraction for structural using different method such as subspace iteration, Lanczos and Block Lanczos Schemes, Newmark beta method for solution of dynamic problems.
- **Part-3: Plate and shell elements:** Plate bending elements: thin and thick plate theory; elements based on Kirchoff's theory, Elements based on Mindlin theory; Shear locking and reduced integration, Shell element: Strain-displacement relation; Flat shell element; 4 and 8 noded degenerated thick shell elements, basic assumptions, degree of freedom, shape functions and shear locking, membrane locking in shell elements.
- **Part-4: Introduction to Nonlinear problems:** Introduction to Nonlinear problems: Types of nonlinearities, Example problem.

Course Outcomes:

The course provides a comprehensive understanding of finite element analysis (FEM) for structural, thermal, and dynamic problems. It covers the derivation and application of shape functions, stiffness matrices, and load vectors for 1D, 2D, and 3D elements, including bar, beam, truss, plate, shell, and pipe elements. Students will also explore concepts like shear locking, incompatible displacement models, and nonlinearities in FEM. The course emphasizes practical applications through commercial software and hands-on analysis

of various structural problems.

References:

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

EN622: Fracture Mechanics (20 Lecture Hrs)

Coordinators: Dr. Chattopadhyaya
(jchatt@barc.gov.in)

Course Details:**(1) Linear Elastic Fracture Mechanics**

- History and need of fracture mechanics
- Griffith's energy balance theory
- Stress analysis of cracks & concept of 'Stress Intensity Factor' (K)
- Relationship between K and global energy release rate (G)
- Various modes of fracture and Superposition of K
- Calculation of plane stress and plane strain plastic zone size and correction in K - Irwin's approach
- Basic design principles in LEFM
- Plane stress vs. plane strain - Variation of toughness (K_{Ic} and K_{IIc})

(2) Elastic-plastic Fracture Mechanics

- J-integral as energy release rate
- Laboratory measurement of J-integral - η factor
- Fracture resistance of materials – J-R curve and J_{Ic}
- Fracture Stability assessment -Tearing Modulus approach
- J-estimation schemes

(3) Laboratory measurements of material fracture properties

- Common specimens – CT, SE(B) or TPB specimens
- Fatigue pre-cracking
- Chevron notch, Side-grooving
- Instrumentations
- K_{Ic} testing as per ASTM standard
- J-R curve determination as per ASTM standard
- Determination of J_{Ic} from J-R curve – blunting line eq.& SZW

(4) Fatigue and FCGR

- Physical nature of fatigue damage/degradation in metals.
- Stages of fatigue damage, Cyclic stress–strain behavior of metals
- Fatigue crack initiation modeling, Stress based / strain based approaches
- Notched effects on fatigue: notch sensitivity, Neuber's Law
- Effect of surface finish, size, environment and multiaxial stresses on fatigue life
- Experimental determination of fatigue life curve as per ASTM procedures
- Fatigue crack growth under constant and variable amplitude loading
- Fracture Mechanics approach to fatigue – Paris Power law
- Crack closure effect and modification of Paris law
- Environmental effects on fatigue crack growth
- Experimental determination of Paris law constants as per ASTM procedure

(5) Limit load Theory

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

(6) Leak-Before-Break Principles

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

(7) PTS and ASME reference/Master curve

- Overview of ASME Sec XI – Appendix A (Pressure Ves), C & H (Piping)
- Relevance of PTS event in nuclear reactors (PWR)
- Safety assessment procedure during PTS
- Master curve concept
- Determination of Master Curve as per ASTM 1921

Course Outcomes:

The course on Fracture Mechanics provides students with a deep understanding of both linear elastic and elastic-plastic fracture mechanics. It covers key concepts like stress intensity factors, fracture toughness, and J-integral, alongside experimental techniques for material fracture property measurement. Students will gain insights into fatigue crack growth, fatigue life prediction, and the application of fracture mechanics in structural stability assessments, including limit load theory and leak-before-break principles. The course also explores real-world applications in nuclear reactors and safety assessments, with a focus on experimental procedures and ASTM standards.

References

1. T.L.Anderson , ‘Fracture Mechanics: Fundamentals and Applications’, 3rd Ed. CRC Press
2. David Broek, ‘Elementary Fracture Mechanics’, MartinusNijhoff Publishers
3. J.Chattopadhyay, Lecture Notes

EN623: Mechanical Metallurgy (30 Lecture Hrs)**Coordinators: R. N. Singh**
(rnsingh@barc.gov.in)**Course Details:**

- **Elasticity and Plasticity**
 - Concept of stress at a point, stress tensor, state of stress and strain in an elastic continuum.
 - Equations of equilibrium.
 - Principal stress, hydrostatic & deviatoric stress. Elastic stress-strain relations, compatibility equations. Yield criteria
- **Dislocations**
 - Elastic stress field of edge and screw dislocation.
 - Self energy of dislocations.
 - Forces on dislocations (Peach-Koehler equation), dislocation Interactions/reactions, Slip systems in FCC, BCC and HCP
- **Deformation Behaviour**
 - Single crystal deformation, critical resolved shear stress, Schmidt's factor, thermally activated deformation, Strengthening mechanisms.
- **Creep of Metals and alloys**
 - Various stages of creep and creep laws
 - Types of creep tests, evaluation of parameters of a creep test and its use
 - Factors influencing creep resistance
 - Deformation mechanism map and identification of creep mechanisms, Irradiation creep
- **Fracture Mechanics**
 - Concepts of ductile and brittle failure: Griffith's criterion of brittle failure
 - Concepts of compliance, triaxiality of stress, Linear Elastic fracture mechanics, Elastic-plastic fracture mechanics
 - Concepts of R-curves, Evaluation of various fracture parameters, fracture control
- **Fatigue of Metals:**
 - High cycle and low cycle fatigue
 - Factors contributing to fatigue failure and its mitigation
 - Various stages of fatigue damage and Fatigue life improvement
 - Fracture mechanics approach to characterize crack growth behavior
- **Mechanical working of Metals**
 - Microstructural Evolution during cold and hotworking of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, Method of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

Course Outcomes:

The course on Mechanical Metallurgy equips students with a deep understanding of material behavior, focusing on elasticity, plasticity, dislocations, deformation mechanisms, and fracture mechanics. Students will explore fatigue, creep, and mechanical working of metals, with applications in nuclear materials, fabrication processes, and performance evaluation.

References:

1. Engineering Fracture Mechanics-S.A.Meguid.
2. Mechanical Metallurgy-G. E.Dieter
3. Mechanical Behaviour ofMaterials-T. H.Courtney
4. Elementary Dislocation Theory-J.Weertman & J.R.Weertman
5. Introduction toDislocations-D. Hull
6. Mechanical Metallurgy:Principles and Applications-M.A.Meyers&K.K.Chawla
7. Deformation and Fracture Mechanics of Engineering Materials-R.W.Hertzberg
8. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
9. Reactor handbook - Vol. I Materials - C. R. Tipton
10. Nuclear Fuel Elements - Brian R. T. Frost
11. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
12. The Metallurgy of Zirconium - D. L. Douglass

EN624: Mechanics of Solids (40 Lecture Hrs)

Coordinators: Dr. Suneel K. Gupta
(suneelkg@barc.gov.in)

Course Details:

- **Part-1: Governing equations of elasticity, theorems and numericals**

- (1) **Introduction to Theory of Elasticity Mathematical Frame Work**

- Introduction to deformation mechanics, elasticity, plasticity, visco-plasticity, stress-strain curve, Isotropy, Homogeneity, continuum
- Illustration of 1-D elasticity: Navier's Equilibrium equation, Cauchy equation and stress-strain equation
- Solution of 1-D elasticity equation: Natural frequencies; subjected to external harmonic force

- (2) **Analysis of Stresses and Equilibrium**

- Tensors: Notations, Symbols, Coordinate Transformation
- Description / Notations of Forces, Stress
- Navier's Equations of equilibrium,
- Stress Traction Vector, Stress component on arbitrary plane
- Stress tensor transformation using direction cosines
- Characteristic equation, Stress Invariants, Principal stresses
- Lamé's ellipsoid of state of stress
- Mohr's Diagram for 3D state of stress
- Analysis of Stresses: Hydrostatic/Deviator stresses, J_2 -Invariant, Octahedral plane stresses, von-Mises Stress
- Stress based failure theories: Failure surfaces for 3D stress state, Rankine, Tresca, von-Mises, Octahedral shear, Mohr-Coulomb, etc., hydrostatic axis, Stress tri-axiality

- (3) **Displacement, Strain and Compatibility**

- Displacement-gradient, strain and rotation tensor, tensor transformation using direction cosines
- Strain- displacement relations (Cauchy's equations)
- Compatibility equations (Saint-Venant's Equations)
- Principal Strains, Strain Invariants, Cubical Dilation, Strain Deviator Tensor, Maximum and Octahedral Shear Strains

- (4) **Material Behavior: constitutive equations**

- Material behavior: Elastic/Inelastic, Linear/Non-linear, rate-dependent/rate-independent
- Generalized Hook's Law
- Anisotropy and Isotropy of elastic behaviour
- Lamé's stress and strain relationship

- (5) **Elasticity: Governing Equations and theorems**

- Governing Equations of elasticity: stress-displacement, strain-displacement and stress-strain equations
- Boundary Conditions, Classifications of elasticity problem, Stress Formulation, Displacement formulation
- Saint-Venant's principal ; Superposition principal
- Strain Energy and related principals, bounds on elastic constants

- Uniqueness theorem; Betti/Rayleigh Reciprocal theorem
 - Virtual work principle and Potential energy minimization theorem
- **Part-2: Solution Method for elasticity; thermo-elasticity and introduction to plasticity**
 - (6) **Elasticity solution Method for 2D and 3D problems**
 - Stress and Displacement Formulations for 2D Plane strain and Plane stress problems
 - General solution procedures: Analytical, semi-analytical and numerical
 - Stress formulation: Biharmonic equations of 2D elastic problems and Airy's Stress Functions
 - Solution for beam bending problems using polynomials
 - Polar co-ordinates solutions: Elasticity equations
 - - Tube subjected to internal and external pressure (Lame's problem) and special cases
 - - Stress field around a stress free circular hole in stressed plate (Kirsch's problem)
 - (7) **Thermo-elasticity: Thermal Stresses**
 - Deformation under Load/Displacement controlled, Equilibrium/Compatibility governed
 - Thermal stress and their significance, Thermoelastic stress-strain equations (Duhamel-Neumann's equation)
 - Thermal stress due self / external constraints, Stress under thermal transients
 - Thermo-elastic solution for annular circular plate / cylinder
 - (8) **Introduction to Plasticity**
 - Mechanism of plastic deformation, factors affecting plastic deformation
 - Stress-strain curve, strain hardening, cyclic-stress strain curve
 - von-Mises Yielding Criteria, Yield Surface and their significance, Theories of plastic flow and Plastic potential
 - Isotropic and Kinematic Hardening (subsequent yield surfaces, loading, unloading)
 - Prandtl-Reuss Equations of incremental plasticity
 - **Part-3: Theory of Plates and Shells**
 - (9) **Theory of Plates (6)**
 - Introduction, Small deflections of laterally loaded thin plates, governing differential equations for rectangular and circular plates
 - Boundary conditions, Navier type and Levy type solutions, applications to rectangular plates, axisymmetric circular plates. Shear deformation theories.
 - Introduction to analysis of Thick Plates
 - (10) **Theory of Shells (6)**
 - Introduction to shell theory.
 - Classification of shells, Membrane theory of shells of revolution and translation.
 - Application to spherical, conical and cylindrical shells.
 - Bending analysis of cylindrical shells and symmetrically loaded shells of revolution.
 - Application to cylindrical shells, spherical and conical shells.

Course Outcomes:

The course on Mechanics of Solids provides students with a strong foundation in elasticity, plasticity, and the behavior of materials under stress and deformation. It covers key topics such as governing equations, stress-strain relationships, thermo-elasticity, and plasticity theory, along with the analysis of plates and shells.

Students will gain skills in solving complex 2D and 3D elasticity problems and understanding the behavior of materials under thermal and mechanical loads.

References

1. Advanced Mechanics of Solids, L. S. Shrinath, Tata McGraw-Hill Publishing Company Limited
2. Elasticity – Theory, Application and Numerics, Martin H. Sadd, Academic Press, Elsevier Publisher
3. Theory of Elasticity, S.P. Timoshenko and J. N. Goodier, McGraw-Hill Publisher
4. Advanced Strength of Material, Enrico Volterra & J. H. Gaines, Prentice Hall Publisher
5. Theory of Thermal Stresses by Bruno A. Boley & Jerome H. Weiner, Dover Publications, Inc.
6. Plasticity Theory and Application, Alexander Mendelson, The Macmillan Company
7. Theory of plates and shells- S.P Timoshenko and S W Krieger McGraw-Hill Publishing Company Limited.
8. Theory of Plates- K. Chandrasekhara, University Press
9. Stresses in shell- W. Flugge
10. Structural analysis of Shells- E. H. Baker
11. Thin Elastic shells- H. Krauss, Wiley International

EN625: Modern Control Systems Design and Simulation (35 Lecture Hrs)

Coordinators: Dr. S. R. Sh imjith
(srshim@barc.gov.in)

Course Details:

- Introduction, Examples of Dynamic Systems, Elementary definitions, Analytical method of modeling.
- State Space Characterization State-Space representation, solution of state equation, state Transition matrix, properties of STM, computation method, Companion form, Diagonal and Jordan form representation of linear models
- Controllability and Observability State transfer and Kalman Controllability criterion, Algebraic controllability and Observability criteria, Gilbert's criterion, Eigenvalue controllability, Duality, Introduction to Digital Control theory, Controllability and observability of Discrete data systems.
- Stability Liapunov's stability criterion, Application to linear models, Extension to non-linear models.
- Control System Design, Pole placement by state feedback. Ackermann's formula, Bass and Gura formula, optimal control formulation, LQR theory, Matrix Riccati equation.
- Linear Observers Luenberger observers, Kalman filter as Optimum observer.
- Other Modeling Approaches Energy approach of modeling, Empirical modeling - impulse and frequency response method, Recursive Least square Identification technique.
- Introduction to Adaptive and Robust control.

Course Outcomes:

The course equips students with the foundational knowledge and techniques for designing and simulating modern control systems, emphasizing state-space methods, stability, and control strategies. It covers key topics such as controllability, observability, pole placement, LQR theory, and the use of observers like Kalman filters, along with an introduction to adaptive and robust control systems.

References:

1. Bernard Friedland, Control System Design: An Introduction to State Space method; Dover Publications.
2. Chi-Tsong Chen, Linear System Theory and Design, Oxford University Press.
3. Thomas Kailath, Linear System; Prentice Hall Inc.
4. M. Gopal, Modern Control System Theory; New Age International (P) Limited.
5. M. Gopal, Digital Control and State Variable Method; Tata Mcgraw Hill, 2/e, 2003.
6. M.S. Grewal, A.P. Andrew, Kalman Filtering: Theory and Practice Using MATLAB; John Wiley & Sons Inc.

EN626 Design Basis Hazards and Geotechnical Engineering (40 Lecture Hrs)

Coordinators: **Shri. A. D. Roshan** (adroshan@aerb.gov.in)

Dr. V. S. Phanikant (phani@barc.gov.in)

Course Details:

- **Design Basis Hazards (Natural)**
 - **Role of civil engineering in achieving overall nuclear safety:** Considerations made in siting of nuclear facilities, plant and building layout, safety functions, and functional roles of buildings/ structures vis-à-vis safety requirements.
 - **Introduction to hazard evaluation:** Hazard due to internal and external events, case studies.
 - **Seismic Hazard:** Source models, recurrence relations, frequency dependent attenuation relations for inter plate and intraplate regions, Deterministic Seismic hazard, data continuity checks, uniform hazard spectrum
 - **Flood hazard**
 - Inland site: Collection of meteorological data and extreme Value Analysis for Precipitation and floods, Design basis floods including dam break, flood routing and protection
 - Cyclone induced flooding for coastal sites: Storm Surge (pressure and wind induced), wave set-up and wave run-up
 - Tsunami: Causes of Tsunami, Tsunami hazards, Tsunami characteristics (velocity, wave period, wave run up and inundation), and tsunami induced flooding
 - **Wind hazard:** Wind rose diagram, Basic wind speed, Hourly mean wind, evaluation of design wind speed (wind speed map of India, Risk factor, height and structural size factor, Topography factor, cyclonic factor etc.)
 - **Solar radiation:** Temperature map (Summer and Winter) of India, direct solar radiation, diffused radiation, radiation from ground surface, Total solar radiation, estimation of surface temperature, minimization of solar radiation effect. Assessment of surface temperature using ASHARE handbook, design of insulation for building roofs/walls (exposed surfaces)
 - **Snow hazard:** Design snow load, shape coefficients for various types of roof, ice load on wires, effects and Mitigation Ground subsidence, Landslide and mudslides
 - **Design Basis Hazards (Human-Induced):** Aircraft/missile impact (determination of load-time function, evaluation against impact, fire and vibratory loads), Explosions/Blast (Identification of sources, characterization and impact assessment), Toxic gas release (Identification of sources, characterization and impact assessment)
- **Geotechnical Engineering**
 - **Soil Mechanics**
 - Soils and their classification based on USCS, IS 1498, AASHTO systems, Grain size distribution, Plastic limits etc.
 - Compaction of soils – Laboratory and Field compaction, Selection of compaction equipment on soil characterization, Dynamic compaction, Ground improvement techniques -Vibroflotation, Stone columns etc.
 - Tests on soil and rock – Laboratory tests – UCS, Tensile test, Petrography, E value, Permeability;

Field tests – Permeability (Packer tests), Vane shear test, Static penetration test, Cone Penetration tests, Pressure meter tests, pile load tests etc.

- Bearing capacity – Determination of bearing capacity for soils and Rock.

- **Geotechnical and Geophysical investigations:**

- Geotechnical investigations: Different Stages of investigations, Scheme of investigations, Soil sampling (Disturbed and Undisturbed), Rock sampling, Core Recovery (CR), Rock Quality Designation (RQD), Rock mass Rating (RMR). Direct and In-direct explorations, Trial pits, Borings etc.
- Geophysical investigations : Seismic waves – Compression, Shear, Rayleigh and Love waves, Seismic refraction survey, Cross-hole, Up-hole and Down-hole seismic surveys, Electrical resistivity, Acoustic logging, Advantages and Disadvantages

- **Soil Dynamics and Liquefaction:** Deformation & strength characteristics of soil under dynamic loading; soil Damping – material & Radiation damping; liquefaction studies, evaluation of liquefaction potential of site.

Course Outcomes:

Students will be able to evaluate natural and human-induced design basis hazards relevant to nuclear and critical infrastructure and apply appropriate mitigation and safety design measures. They will also gain proficiency in geotechnical investigation, soil and rock characterization, foundation design, and dynamic soil behavior including liquefaction assessment for safe and reliable structural performance.

References:

1. Kramer. S (2007) "Geotechnical and earthquake engineering".
2. USNRC-RG-1.132 – Site investigation of Nuclear Power Plants
3. IS 875(Part 3) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures: Wind load
4. IS 875(Part 4) (1987) “ Code of practice for design loads (other than earthquake) for buildings and structures.: Snow load
5. Hydrology and Water Resources Engineering (2005) by S. K. Garg, Khanna Publishers.
6. Engineering Hydrology (1994) by K. Subramanya, Tata McGraw-Hill Publication.
7. ASHARE Handbook (2005) – Fundamentals. Solar Heat Gain and Visible Transmittance”
8. Bowles J.(2007) " Foundation analysis and Design"
9. GopalRanjan, ASR Rao – “Basic and applied soil mechanics”.
10. Milutin Srbulov (2014) "Geotechnical Earthquake Engineering: Simplified Analyses with Case Studies and examples (Geotechnical, Geological and Earthquake Engineering)".
11. All relevant IS codes.
12. Design Basis flood for NPPs on Inland and Coastal sites (AERB/SG/ 6A and 6B)
13. Manual on Rock mechanics, Central Board of irrigation and Power
14. AERB/SC/S rev.1, Site evaluation of Nuclear Facilities’
15. AERB/SG/S-7, Human induced events and establishment of design basis
16. AERB/NPP/SG/CSE-2, (2008), Geotechnical Aspects and Safety of Foundation for Buildings and Structures Important to Safety of Nuclear Power Plants
17. AERB/NF/SG/S-3, (2008), Extreme Values of Meteorological Parameters

EN627: Network and Information Security (45 Lecture Hrs)**Coordinators: Shri. Gigi Joseph
(gigi@barc.gov.in)***Course Details:*• **Network & Information Security****Part 1**

- **Refresh course on various communication technologies** such as LAN technologies, VSAT network technologies, Optical Communication network, Advanced TCP/IP, Routing protocols, Multicast Routing protocol, IPv6
- **Anatomy of an Attack:** Network Mapping using ICMP queries, TCP Pings, traceroutes, TCP and UDP port scanning, FTP bounce scanning, stack fingerprinting techniques, Vulnerability scanning, System and Network Penetration, Denial of Service.
- **Network Layer Protocols attacks and defense mechanisms:** Hacking Exploits in ARP, IP4, IPv6, ICMP based DOS, ICMP covert Tunneling, Network Controls against flooding, Network Monitoring.
- **Transport Layer Protocols Attacks and Defense mechanisms :** Covert TCP, TCP Syn flooding DOS, TCP Sequence Number Prediction attacks, TCP session hijacking, UDP Hacking Exploits, Network security controls for defense mechanism, OS hardening, kernel parameter tuning, DDOS & DDOS Mitigation, Stateful firewall, application firewalls, HIDS, NIDS and IPS.
- **Application Layer Protocol Attacks and Defense mechanisms:** DNS spoofing attacks, DNS cache poisoning attacks, organization activity finger printing using DNS, SMTP vulnerability and Hacking Exploits, Mails relays, SMTP Security and Controls, Buffer Overflow Attacks, SQL Injection, Cross Site Scripting HTTP security and controls. Web attacks types (Cross Site Scripting, Cross Site Request Forgery, SQL Injections, Cookie Poisoning, Buffer overflow, Zero day attack)
- **Forensics**
 - Network Forensics (Analyzing Network Data, Different network analyzer tools, Investigating Network Traffic, looking for evidence)
 - Email forensic: Email Phishing attacks, Email forensics

Part 2

- Introduction to VPN
- SSL VPN
- IPsec VPN
- MPLS and MPLS VPN
- Wireless LAN - 802.11
- Bluetooth
- Overview and Introduction to Cryptography
- Stream Ciphers: Basic Definitions and Framework, Stream ciphers: using a pseudorandom bit generator to generate a keystream, The RC4 stream cipher: key scheduling algorithm and keystream generator, Salsa Stream Ciphers
- Block Ciphers: Confusion and Diffusion, Feistel and SPN Ciphers, Definition of Block Ciphers, Modes of operation for Block Ciphers, Definition, examples of Feistel Ciphers
- The birthday paradox, Double-encryption, Meet-in-the-middle attacks, Triple-encryption
- DES/AES high-level description of DES
- Hash Functions: Description, construction and properties, keyed vs. unkeyed, attacks
- Data Integrity, Authentication, MAC: Definition of a secure MAC algorithm, Applications of MAC algorithms (data integrity, data origin authentication), Generic attacks on MAC algorithms
- Asymmetric Cryptosystems: definitions, overview and introduction exponential ciphers, Algorithmic Number Theory, Number Theory Background, Generator of Z_n^* , where n is prime.
- The Euler phi function. Number of elements of order t in Z_p^* .
- Probabilistic Primality Testing: Fermat Test, Miller-Rabin Test, Carmichael Numbers
- True Primality Testing: Mersenne numbers, prime test using factorization of $n-1$, Prime number generation (random search, strong primes)
- Factoring Integers I : trial division quadratic sieve, running time multiple polynomial variant, parallelization Pollard's rho algorithm, Pollard's $p-1$ algorithm
- Introduction to RSA: key-pair generation, encryption scheme,
- signature scheme, Security of RSA Encryption, The RSA problem (RSAP) and its relation to factoring
- Chosen-ciphertext attack on Basic RSA, Forward search attack on Basic RSA, Security of RSA Key Generation, security of the key generation process
- Discrete Logarithm Cryptographic Schemes: The discrete logarithm problem, The digital signature algorithm (DSA), Diffie-Hellman, ElGamal
- Certification authorities, Public-key infrastructure, The certification process, Trust models (cross certification).

Course Outcomes:

This course enables students to understand network architectures, security threats, and attack mechanisms across different protocol layers. It develops skills to design secure networks using firewalls, intrusion detection systems, VPNs, cryptographic techniques, and public key infrastructures for protecting information systems.

References:

1. Mastering network Security (Author: Chris Brenton)
2. TCP/IP Guide (Author: Charles M Kozierok)
3. Computer Network (Author: Andrew S Tanenbaum)
4. Cryptography and Network Security: Principles and Practice By William Stallings
5. Planning for PKI By Russ Housley, Tim Polk

EN628: Nuclear Chemical Engineering (35 Lecture Hrs)

Coordinators: Shri. M. S. Deshpande
(msd@barc.gov.in)

Course Details:

- **Introduction**
 - Role of chemical engineering in the nuclear industry
- **Recovery & processing of nuclear materials from ores/intermediates**
 - Uranium ore processing: Ores and their classification, options available and production of Uranium concentrate from Indian ores. Recovery of Uranium from non-conventional sources, New developments, uranium refining.
 - Thorium: Occurrence, importance and production of Thorium from Monazite by solvent extraction process involving separation of Thorium, Uranium and Rare Earths.
 - Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation, production of nuclear grade zirconium.
 - Recovery of pure hafnium
 - Separation of niobium and tantalum
 - Rare Earths: Occurrence, importance and separation.
- **Uranium conversion / reconversion**
 - Conversion of nuclear grade uranium to UO_3 / U_3O_8 by dry thermal and wet routes. Pros and cons of different routes.
 - Reduction to UO_2 and stabilization.
 - Production of UF_4
 - Production of reactor grade U metal by metallothermic reduction, process and equipment choices
 - Electrochemical technology for production of fluorine, its purification
 - Fluorination of UF_4 , trapping and purification of UF_6
 - Reconversion of UF_6 to UO_2 by dry and wet method
 - Reconversion of UF_6 to UF_4 by cold and hot wall process
- **Isotope Separation**
 - Isotope Separation : SWU and value concepts; Cascade theory; Process for separation of Uranium; Gas centrifuge, Diffusion; Optimization of separation cascades
 - Processes for heavy water production and their comparative evaluation; Pre-enrichment process; Chemical exchange: H_2S-H_2O , NH_3-H_2 , monothermal and bithermal process, salient features of equipment like contacting towers, tower internals, Heavy water plants in India, final enrichment and upgradation plants, Distillation and electrolysis, tritium removal
 - Laser based isotopic separation processes
- **Fuel Reprocessing**
 - Introduction to spent fuel reprocessing; Typical compositions and burn-up of irradiated nuclear fuels;
 - Thermal reactor fuel reprocessing: Spent fuel storage planning at reactor sites, cooling before reprocessing; decontamination, product specification and recovery requirements, Evolution of solvent extraction process for reprocessing, PUREX and THOREX processes in detail; head-end process, flow sheet, co-decontamination and partitioning cycles.
 - Fast Reactor fuel reprocessing: Aqueous separation processes; Pyro-chemical processes
 - Reprocessing of thorium based fuels: Challenges in reprocessing of thorium based fuels; FBR & AHWR fuel reprocessing
- **Nuclear Waste Management**

- Sources, characteristics and classification of radioactive wastes; objective and general philosophies of management. Impact of closed fuel cycle on nuclear waste management.
- method of treatment for low, intermediate and high level- solid, liquid and gaseous wastes with examples.
- Conditioning of radioactive waste- cementation and vitrification method, matrices for waste immobilization and product characterization
- Storage for primary and secondary solid wastes, ultimate disposal; options in the Indian context.
- Chemical engineering in treatment, conditioning and management of radioactive waste: Application of unit operations including heat and mass transfer for waste volume minimization during treatment and conditioning of waste (evaporation, solvent extraction, ion exchange, reverse osmosis, scrubbing, filtration, adsorption, incineration); Stoichiometric application to understand the concept of DF and VRF and their usefulness in nuclear waste management.
- Special process equipments used for nuclear waste management such as melter technology for vitrification, mixer-settler for solvent extraction, evaporation, solvent extraction, ion exchange, reverse osmosis, scrubbing, filtration, adsorption, incineration etc.
- Advancement in field of nuclear waste management; concept of radio-toxicity and advance processes such as actinide partitioning to minimize it; value recovery from nuclear waste for societal benefits; partitioning and transmutation.
- Challenges with futuristic waste (likely to arise from Fast reactor and Thorium fuel cycles)

Course Outcomes:

This course provides knowledge of chemical engineering processes involved in nuclear material extraction, fuel conversion, isotope separation, reprocessing, and radioactive waste management. It emphasizes safe handling, process optimization, and application of unit operations in the nuclear fuel cycle.

References:

1. Benedict and Pigford 'Nuclear Chemical Engineering' McGraw Hill. 2nd ed.
2. Uranium Extraction Technology, Tech. Rep. Series, IAEA, Vienna 1993
3. Laser Isotope Separation, Ed. J.A Paisner, SPIE vol.1895 (1993)
4. J. T. Long, Engineering for Nuclear Fuel Reprocessing, Gordon & Breach Science Publishers Ltd (1967)
5. M. F. Simpson, J. D. Law, Nuclear Fuel Reprocessing, In: Encyclopedia of Sustainability Science & Technology Series, Springer, New York (2018)
6. R. Taylor, Reprocessing and Recycling of Spent Nuclear Fuel, Woodhead Publishing Series in Energy: Number 79, Elsevier, New York (2015)
7. M. I. Ojovan, W. E. Lee, New developments in glassy nuclear wastefoms, Nova Science Publishers, Inc, New York, 2007
8. M. I. Ojovan, W. E. Lee, An introduction to nuclear waste immobilization, Elsevier, OXFORD, UK, 2005.

EN629: Nuclear Materials (50 Lecture Hrs)

Coordinators: Dr. T. Mahata
(tsmahata@barc.gov.in)

Course Details:

- **Melting & Casting (10)**

- Introduction to vacuum measurement units and types of vacuum pumps including diffusion pump & turbo-molecular pump. Vacuum melting & casting processes, including general descriptions of vac. ind. melting, vac arc melting, electron beam melting, plasma arc melting & inductoslag refining with process parameters and comparative studies.
- Relevant curves for variation of vacuum, temperature, fluidity etc. during vacuum melting with their effects on purification, homogeneity, grain-size control. Magnetic stirring in vacuum arc melting, effect of vibration during solidification on grain sizes. Sacrificial deoxidation under EB melting. Control of defects in castings. Discussion of vacuum melting process of uranium, zirconium alloys and Ti-alloys with relevant flowsheets.
- Solidification process, calculation of rate of solidification, parameters affecting solidification process with special reference to formation of defects during solidification under vacuum, and method to overcome such problems. Introduction to continuous casting processes and other special casting processes and their relative merits.

- **Mechanical working of Metals (10)**

- Microstructural Evolution during cold and hot working of Metals, Equilibrium equations, Levy-Von Mises plasticity equations, method of solving problems in mechanical working. Evaluation of workability Deformation mechanism maps. Dynamic recovery and recrystallisation, miscellaneous fabrication processes with special reference to fabrication of metallic fuel elements and production of thin walled fuel clads with texture and microstructure control.

- **Powder Metallurgy & Advanced Ceramics**

- Introduction: Particulate materials – Metallic and ceramic powders, Difference between advanced ceramics and traditional ceramics. Different types of advanced ceramics and applications
- Phase equilibria and phase diagram: Reaction Kinetics and example of important ceramic systems.
- Structure: Crystal structure, defects in ceramics, Defect chemistry
- Principles of main powder production method, Techniques of fabrication of metal powders, ball-milling and high energy milling
- Solid state and wet chemical route of powder preparation of nuclear fuel materials – oxides, mixed oxides, carbides, intermetallics
- Powder processing, Blending, granulation and process aids, Agglomeration and deflocculation, role of surfactants and binders in processing of powders
- Characterization of powders: Particle size and size distribution, particle shape, surface area, porosity, pore size distribution, pycnometry, zeta potential measurement
- Sintering: Solid state, liquid phase and sintering in presence of viscous liquid. Sintering of both oxides and non- oxide materials including nuclear fuel and control rod materials etc. Sintering under pressure. Spark plasma sintering, Microwave sintering
- Shape fabrication: Pressing (cold and hot pressing), iso-pressing (cold and hot); slip and tape casting, powder extrusion, gel casting, powder injection molding, colloidal processing and spray techniques and different new techniques.

- Properties: Mechanical – Effect of defects, Toughening, Super plasticity etc. Electrical – Dielectric, Superionic conductivity and HTSC. Magnetic – Ferrimagnetism. Optical; Thermal. Role of powder metallurgy techniques in imparting specific properties
- Case studies and applications of powder metallurgy with emphasis on applications relevant to DAE
- Advance energy materials, functional ceramics, thermoelectric materials

Course Outcomes:

This course introduces material processing techniques such as vacuum melting, mechanical working, powder metallurgy, and advanced ceramic fabrication. It focuses on microstructure control, material characterization, and property optimization for nuclear and advanced energy applications.

References:

1. Nuclear Reactor Fuel Elements Metallurgy and Fabrication - A. R. Raufmann
2. Reactor handbook - Vol. I Materials - C. R. Tipton
3. Nuclear Fuel Elements - Brian R. T. Frost
4. Zirconium in Nuclear Industry - ASTM Special Technical Publications 939
5. The Metallurgy of Zirconium - D. L. Douglass
6. Laser & Electron Beam Processing of Materials Edited by C. W. White & P. S. Peercy
7. Corrosion and Wear Handbook for Watercooled Reactors - Edited by D. J. Depaul
8. Metals Handbook - Vol 7 Powder Metallurgy, American Society for Metals
9. Powder Metallurgy Principles and Application MPTF - F. V. Lenel
10. "Introduction to Ceramics" by Kingery et al.
11. "Ceramics Through Chemistry" by Brinker et al.
12. "Electroceramics" by Buchanan
13. "Ceramics Fabrication Processes" by Wang.
14. Powder Metallurgy: Science, Technology and Materilas, A. Upadhyaya and G.S. Upadhyay, Universities Press
15. Ceramic Processing and Sintering, M.N. Rahman
16. Sintering Theory and Practice, R.M. German
17. Tape casting: Theory and Practice, Richard E. Mistler, Eric R. Twiname.
18. 'Ceramics Fabrication Processes" by Wang.

EN630: Nuclear Metallurgy (30 Lecture Hrs)**Coordinators: Dr. Sudhir Mishra**
(sudhir@barc.gov.in)**Course Details:**

- Nuclear Fuels Fabrication and Characterisation Introduction: Research reactor and power reactor fuel types- plates, pins, kernels etc. Indian scenario, fissile and fertile isotopes, fuel cycles and reactivity, fuels of different types- metallic, alloy and dispersion fuels for research reactors, ceramic (oxide, carbide and nitride) fuels for thermal power reactor and fast reactors.
- Fabrication of fuel: Fabrication of oxide, mixed-oxide and mixed-carbide fuel for power reactors. Fabrication, characterization and property evaluation of advanced fuel type such as AHWR fuel and particle fuel. Processes encountered in fabrication, fuel property evaluation- thermal and physical properties.
- Handling of Pu: Health physics, radioactivity and safety aspects. Equipment and laboratory facility for Pu fuel fabrication.
- Irradiation Behaviour and Post-Irradiation Examination of Fuels and Structural Materials Introduction: Design aspects of fuel elements/ bundles and in-core components in power reactor operating environment and criteria for material selection for reactor components.
- Irradiation effects in nuclear fuels: Irradiation behaviour of metallic uranium - irradiation growth, thermal cycling, swelling, adjusted uranium, blistering in uranium rods. Irradiation effects in ceramic oxide and mixed oxide fuels, definition and units of fuel burnup, main causes of fuel element failure in power reactors and remedies to avoid failures. Modelling of fuel element behaviour. Behaviour of fuel under off normal and accident condition, criteria for fuel failure during LOCA: oxidation, deformation, stored energy.
- Irradiation effects in structural materials: Irradiation hardening and embrittlement, corrosion and hydriding of Zr alloys under irradiation, enhancement factor, blister formation in cladding and pressure tube, Delayed hydride cracking, irradiation- creep and growth in Zr alloy components, life assessment of pressure tubes in PHWR, Irradiation effect in stainless steel cladding: Sodium corrosion, helium embrittlement, void swelling etc.
- PIE Techniques for fuel and component Hot cell facility for irradiated material examination, purpose of PIE, NDT and DT techniques for fuel examination, informations obtained on irradiated fuel, pool side inspection of fuel, PIE of pressure tubes and other fuel channel components, Failure analysis of reactor components.

Course Outcomes:

This course covers nuclear fuel fabrication, irradiation effects, and post-irradiation examination of fuels and structural materials. It emphasizes material behavior under reactor conditions, safety considerations, and performance evaluation of nuclear components.

References:

1. "Materials in Nuclear Applications" – C.K. Gupta
2. "Nuclear Reactor Materials and Applications" – Benjamin M. Ma
3. "Nuclear Reactor Fuel Elements, Metallurgy and Fabrication" – A.R. Kaufman
4. "Nuclear Fuel Elements" – Brian R.T. Frost
5. "Fundamental Aspects of Nuclear Reactor Fuel Elements" – D.R. Olander

EN631: Physical Metallurgy (40 Lecture Hrs)

Coordinators: Dr. S. Neogy
(neosuman@barc.gov.in)

Course Details:

- Diffusion and Related phenomena: Mechanisms of Diffusion, Interstitial diffusion, Substitutional diffusion, Diffusion equations and solutions. Steady and non-steady diffusion. Recovery, Recrystallization and Grain Growth.
- Thermodynamics and Phase Equilibria, Fundamentals of Thermodynamics, One component system: Polymorphism and Effect of Pressure, Two component System:- Free energy of dilute, ideal and real solutions -Quasi-chemical calculation of miscibility gap,-Spinodal decomposition and Order disorder reactions -Free energy-composition plot, phase equilibria and phase diagrams, Reaction kinetics, Effect of Crystal Defects, Point defects and Point defect clusters, Generation and annihilation during irradiation.
- Phase Transformations: Classification of phase Transformations, Kinetics and Crystallography, Nucleation, growth and coarsening, Solidification, Diffusionless phase transformations: Precipitation, Spindal, Ordering and Massive transformations, Diffusion less transformations: Martensitic transformation and Omega transformation, Hybrid Transformation: Bainitic transformation.
- X-ray, and Neutron diffraction, various types of electron diffractions, Basics of transmission and scanning electron microscopy and concepts of image formation, characterization and identification of defects in TEM, Dislocations, Stacking faults in Ordered and Disordered structures and Antiphase boundaries, Interfaces and Grain Boundaries. Lattice correspondence, orientational relationship, applications to twinning and martensitic transformations.

Course Outcomes:

This course explains the fundamental principles of diffusion, phase equilibria, and phase transformations in metals and alloys. It also introduces microstructural characterization techniques using diffraction and electron microscopy to correlate structure with material properties.

References:

1. Introduction to Metallurgical Thermodynamics - D. R.Gaskell
2. Physical Chemistry of Metals – L.W. Darken and R.W.Gurry
3. Metallurgical Thermochemistry - O.Kubuschewski
4. The Principles of Chemical Equilibrium with Applications in Chemistry and Chemical Engineering- K. Denbigh
5. Modern Chemical Kinetics- H. Eyring
6. Kinetics of Phase Transformations in Metals -J. Burke
7. Phase Transformations in Metals and Alloys – D.A. Porter and K.E. Easterling
8. Diffusion in Solids-P. G. Shewmon
9. Modern Metallography -R.E. Smallman and K.H.G. Ashbee
10. Electron Microscopy and Analysis, Third Edition -P.J. Goodhew, F.J. Humphreys and Richard Beanland
11. Transmission Electron Microscopy: A Textbook for Materials Science, D. B. Williams and C. B. Carter, Springer,2016

EN632: Process Control and Instrumentation (MT) (25 Lecture Hrs)

Coordinators: Smt. Rajalakshmi R
(rajlaxmi@barc.gov.in)

Course Details:

- **Principles of Measurement (2)**

- Basic definitions like Accuracy, Precision, Hysteresis, Resolution, Sensitivity, Time constant etc; Force balance and Motion balance, Instrument Selection criteria, Primary Instrument Standards and their Traceability.
- Sensors, Transducers and Transmission Method for parameters (10)
- Temperature: Filled systems, Bi-metallic sensors, Thermocouples, Resistance Temperature Detectors, Thermistors, Optical & Radiation Pyrometers (including transmissivity and emissivity corrections).
- Pressure and Vacuum: Manometers, Diaphragms, Capsules, Bellows, Bourdon tubes (C-Type, Spiral and helical), McLeod gauge, Pirani gauge and Thermocouple gauges, Differential Pressure Transmitters.
- Flow: Bernoulli's Theorem, Constant area and Variable area type flow meters, Ultrasonic flow meters, Electromagnetic Flow meters, Turbine type flow meters and Target type flow meters.
- Level: Direct type (Gauge glass, Float, Piston tube, Torque tube) level indicators and Indirect Type (Pressure gauge, diaphragm type, purge method, Differential Pressure type, Ultrasonic type, electrical conductivity type, Capacitance type and Nuclear radiation type) level indicators.
- Analytical Measurements: Density, Conductivity, pH, Humidity.

- **Principles of Automatic Control Systems (8)**

- Feedback and Feed forward control as applied to Process Instrumentation, Modes of control, Generation of control modes, Selection criteria.
- Final Control Elements, Control Valves and their characteristics, Valve positioners, Actuators and Dampers.
- Fail Safe Principles, Simple logic circuits, Ladder Circuits for control action.

Course Outcomes:

This course introduces the fundamental principles of measurement and automatic control systems, covering key concepts like accuracy, precision, and sensor technologies for parameters such as temperature, pressure, flow, and level. It also explores the design and operation of feedback and feedforward control systems, including control valves, actuators, and fail-safe principles essential for process instrumentation.

References:

1. Instrument Technology, Volumes I to V, by E.B.Jones
2. Measurement Systems, Application and Design by Earnest Doebelin
3. Automatic Process Control by Donald P. Eckman
4. Principles and Practice of Flow meter Engineering by S.L.Spink
5. Process Instruments and Control Handbook Edited by Douglas M. Considine
6. Handbook on applied Instrumentation, Edited by D.M.Considine and S.D.Ross
7. Instrument Engineers Handbook, Part I & II by Bela. G. Liptak
8. Mechanical and Industrial Measurements, by R.K.Jain
9. Fundamentals of Temperature, Pressure and Flow measurements by Benedict

EN633: Process Instrumentation & Control (EE) (30 Lecture Hrs)**Coordinators: Shri Partha Das
(parthad@barc.gov.in)****Course Details:**

- General Concepts Definition of Accuracy, Linearity, Repeatability, Hysteresis, Deadband, Resolution, Sensitivity. Calibration of instrument, Error analysis of a system, Standards and their traceability.
- Measurement, Transmission and indication of process variables
- Pressure and Differential Pressure measurement: manometers, mechanical pressure gauges - Bourdon, Diaphragm, Bellows, Dead weight testers. Pressure and differential pressure Transducers and transmitters, strain gauge, capacitance type, piezoresistance type and piezoelectric type pressure transducers, Smart pressure / DP transmitters, Vacuum measurement-Mcleod gauge, Pirani gauges, cold cathode and hot cathode ionization gauges
- Flow: Differential pressure flow elements: Orifices, venturies, flow nozzles, pitot tube, annubar, Different types of standard pressure taps for orifices. Variable Area Flowmeters-rotameters, Magnetic, Turbine, vortex flowmeter, Ultrasonic flowmeters- Transit time, Doppler type, clamp on type ultrasonic flowmeters, Coriolis and thermal mass flowmeters.
- Temperature: Thermocouples- Types of thermocouples, ranges, sensitivity and their limits of error and applications, mineral insulated thermocouples- construction and applications, types of hot junctions- grounded, ungrounded and exposed junction, thermocouple extension and compensating cables, cold junction compensation techniques. RTDs-TDs, 2 wire/ 3 wire / 4 wire RTD, self heating error. Thermistors -Construction, performance and applications, Filled system thermometers. Thermowell, Temperature transmitters., Optical pyrometer, total radiation pyrometer.
- Level: Hydrostatic pressure and differential pressure method, wet legs- cold reference leg and hot reference leg, condensing pots, density compensation in boiler level measurement, zero elevation and zero suppression. Gauge glass, Purge system, capacitance probes, displacer type, ultrasonic type, radar type and conductivity type level gauge.
- Conductivity, pH, Relative humidity and viscosity measurement
- Automatic Control and Control Valves Feed back control as applied to process control, Modes of Control, PID controllers and tuning, Cascade control, Feed-forward control, Control Valves, Valve actuators, Valve Coefficient, Valve sizing, Valve characteristics, Cavitations and flashing in control valves, Valve positioner.
- P & I Diagrams: P &ID symbols, Typical P &ID.

Course Outcomes:

This course introduces the fundamentals of industrial instrumentation and control, covering measurement techniques for key process variables such as pressure, flow, temperature, level, and analytical parameters. It also develops understanding of automatic control systems, PID controllers, control valves, and P&ID interpretation for effective process monitoring and control.

References:

1. "Process/ Industrial Instruments and Control Handbook" - Gregory K. Mcmillan, Douglas Considine; McGraw Hill Publication
2. "Instrument Engineer's Handbook", Vol I & II, Bela G. Liptak; CRC Press
3. "Jones' Instrument Technology", Vol 1-5, Nolting B E; Elsevier Publication
4. "Measurement Systems", Ernest O Doebelin; McGrawHill Publication
5. "Principles and Practice of Flow meter Engineering" - L.K. Spink; Foxboro Company
6. "Fluid Meters - Their theory and Application", H.S. Bean. ASME Publications
7. "Instrumentation for Process Measurement and Control", Norman A. Anderson, CRC Press
8. "Process Control Systems: Application Design and Tuning". F.G. Shinsky, McGrawHill.
9. "Automatic Process Control", Donald P Eckman; Wiley India Pvt Ltd
10. "Process Control Instrumentation Technology", C. D. Johnson; Prentice Hall

EN634: Advanced Process Instrumentation & Control (45 Lecture Hrs)**Coordinators: Dr. Shimjith**
(srshim@barc.gov.in)**Course Details:****• Instrumentation, Controls & Computers**

- General requirements of Instrumentation, sensors/transducers for various process parameters, viz. pressure, flow, level, temperature, conductivity, pH, vacuum, etc., pneumatic & electronic signals, functioning of electronic transmitters, specifications & installation practices, RTDs & Thermocouples, use of thermowells, insertion lengths, etc.
- Introduction to process control & control loop dynamics, controller actions, viz. P, PD, PI & PID, tuning of controllers, cascade, feed-forward, split-range & ratio controls, selection & sizing of control valves.
- Use of PC for data acquisition & control, add-on cards 7 types, concept of a scheduler and use of PC for real-time control applications.

• Advanced Process Control Background theory

- Introduction to state-space controls, state & measurement equations, general solution of the state equation, state-transition matrix, casting differential equations & transfer functions into state space form, controllability & observability, introduction to the pole-placement problem, introduction to Luenberger observer & parameter estimation, knowledge of Z-transforms, conversion from continuous domain to discrete domain and understanding of the state-space framework in discrete domain.
- Introduction to Advanced Process Controls
- Introduction to multi-variable controls, de-coupling, relative gain array (RGA), etc. System identification, model-predictive control (MPC), data processing & introduction to design of experiments.)

Course Outcomes:

This course provides advanced knowledge of process control strategies, including multivariable control, state-space methods, and model-based control techniques. It also emphasizes real-time data acquisition, computer-based control systems, and advanced controller design for complex industrial processes.

EN635: Process Modelling, Simulation & Optimization (45 Lecture Hrs)

Coordinators: Dr. K. K. SinghS
(kksingh@barc.gov.in)

Course Details:

- **Simulation**

- Introduction: Introduction to process modelling, simulation and optimisation. Deterministic versus stochastic models. Dynamic and steady state models.
- Flowsheet Analysis: Degrees of freedom (DOF), DOF of individual units including reactors, heat exchangers etc. DOF analysis of cascades/flowsheets with examples.
- Approaches To Plant Simulation: Sequential modular; Equation oriented; simultaneous modular
- Steady State Sequential Modular Simulators: Concepts of partitioning, tearing and nesting as applied to flow sheets; Method of representation of plant topology-, recycle detection and calculation ordering algorithm; recycle convergent Method.
- Steady State Equation Oriented Simulators: Strategies for formulation of plant models, sparse systems and Solution procedures; Solution method for simultaneous modular approach.
- General Approaches for Non-Linear Systems: Conversion promotion criterion, Wegstein's method, Broyden method. Dominant eigen-value method. Examples of solving non-linear systems.
- Commercial Simulators: Use of commercial simulator as a design aid. Introduction to Aspen Plus, Hysim, Process etc. Illustrative example from process plants and nuclear power plant to demonstrate problems solving using commercial simulators.

- **Optimization**

- Classification of optimization problems. Necessary and sufficiency conditions for optimum, Search procedures for unconstrained optimization problems, Non - linear programme: Complex box; Reduced gradient; Penalty function; Sequential quadratic programming, Optimization using a simulator,
- CASESTUDY: Simulation and modelling of heavy water cascade, use of lumping and de-lumping strategies. Decomposition of complex, topology, rate base model versus equilibrium base model for tower internals, evaluation of transport coefficients using mass transfer with reaction models, use of analogies for evaluation of interface coefficients.
- Recent Developments: Multi-objective optimisation, Plant optimisation by Genetic Algorithms and Neural Nets.

Course Outcomes:

This course focuses on mathematical modeling and simulation of chemical and nuclear process systems using sequential and equation-oriented approaches. It also introduces optimization techniques and modern tools such as commercial simulators and intelligent algorithms for improving plant design and operational performance.

References:

1. Bisio, A and R.L. Kabel, 'Scale-up of Chemical processes', Wiley-Interscience, NY (1985).
2. Crowe, C.M., A.E. Hamielec, T.W. Hoffman, A.I. Johnson, D.R. Woods and P.T. Shannon, Chemical Plant Simulation, Prentice Hall Inc., Englewood Cliffs, N.J (1971).
3. Davis, M.F., Numerical Method and Modelling for Chemical Engineers, Wiley, NY. (1984).
4. Denn M.M, 'Process Modelling, Wiley, N.Y. (1986)
5. Husain, A., Chemical Process Simulation, Wiley Eastern limited, New Delhi (1986)

6. Luyben, W., Process Modelling, Simulation and Control for Chemical Engineers. McGraw - Hill (1990)
7. Szucs, E, Similitude and modelling, Elsevier, Budapest (1980).
8. Westerberg, A.W., H.P.Hutchinson, R.L.Motard, and Wirter, Process Flowsheeting, Cambridge University Press, Cambridge (1979).
9. Edgar J.F & D.M.Himmelblau : Optimization of Chemical Process McGraw Hill 1989
10. Reklitis G.V., A. Ravindran, K.M.Ragsdell, Engineering Optimization Method & applications, John Wiley,N.Y (1983)

EN636: Reactor Control & Instrumentation and Human Machine Interface (35 Lecture Hrs)

Coordinators: Shri. D. A. Roy
(daroy@barc.gov.in)

Course Details:

• Module I

- Control and Instrumentation Power Supplies: Class I, II, III, IV power supplies, Centralized 24V/48V DC power supply, distributed power supplies, quality of power supply, Isolation transformer, grounding/earthing aspects in C & I systems.
- Control Room, Control Panels and Cabinets: Conventional control rooms, Modern control rooms, Control room layout, Environmental specifications for control room, Control room lighting, Control room cabling, Communication systems for control room. Control Panels- Panel types, Panel layout, Panel construction materials, Human Engineering principles in control room and panel design- relevant standards (EPRI; NUREG), Components of control panel, Panel wiring, Power distribution in panels, Wiring and terminal identification. Control Cabinets- Sizes, Materials, Degrees of environmental protection, EMC protection, Standard accessories for mounting and cable routing. Seismic qualification of control panels and cabinets. Alarm Annunciation System-Functions of alarm annunciation; Types of annunciations (audio/visual); Alarm Sequences; applicable standard (ISA S18.1); Modern alarm displays; Grouping and Coding of alarms.
- Instrumentation for design of Reactor Regulating System and Reactor Protection System: Introduction to Reactor Protection System and Reactor Regulating System: Elements in RPS/RRS, from sensor to Reactor Protection/Control Devices, Design Principles, Typical list of Reactor Trip parameters, Seismic qualification, Class-1E qualification, EMI/EMC qualification.

• Module II

- Relay & Control Interlock Logic Circuits: Relay Terminology and general application: Criteria for relay selection, Pickup, hold and dropout voltage, Contact type and arrangement, Contact protection, latched relay, Electromechanical versus Solid-State Relay characteristics and comparison. Typical control logic circuits for control of process equipments, Interfaces with electrical Control gear
- C & I Cables: Types of cables, Conductor materials, insulating materials, Sheath materials, Shielding, armouring, FRLS and Fire Survival cable, mineral insulated cables, cable sizing, noise reduction, cable layout, cable trays, panel wires, conductor identification, Cable Testing, wiring practices.

• Module III

- Overview of plant automation.
- Design of HMI, Soft Console versus Conventional control panels
- Guidelines for design of HMI displays
- Case study of a commercially available Professional HMI package.
- Building HMI systems, Creating and using process databases, managing databases, Implementing an alarm strategy, Configuring and displaying alarms and messages, Security features, Creating process mimics, Trending historical data, method of passing data to HMI package.
- Practical

Course Outcomes:

This course will introduce the students to the fundamentals of Reactor Control & Instrumentation (C&I) systems, including power supply requirements for instrumentation, control room design concepts, and exposure to relevant codes and guides. The course will expose the students to relay and control logic design, selection criteria for relay, PLC, and DCS technologies, and essential C&I cable requirements through practical insights and system-level understanding

EN637: Reactor Control Engineering & Instrumentation-I (25 Lecture Hrs)**Coordinators: Smt. Ratna Bharma
(rbharmra@barc.gov.in)****Course Details:**

- Physics of Reactor Control -Revisit
- Reactor Kinetics - Point kinetic model, Reactor Response to step and ramp reactivity inputs, Stable reactor period.
- Reactor as a Control Element: Basic zero energy state space model and transfer function, Feedback loop transfer functions, Effect of temperature and voidage, Poisoning due to xenon and samarium, Fuel burn-up, Reactor system stability analysis from transfer function and state space model.
- Large Reactor Control: Modeling techniques for large reactors - modal, nodal and quasistatic method (introduction only) Flux Tilt, Spatial instability.
- Typical Reactor Control System: BWR, PWR, PHWR and Fast reactor control RRS of a research reactor, 235 MWe PHWR and 500 MWe PHWR
- Reactor Operation: Approach to criticality, Re-start up, Operation in power range, Shutdown.
- Power Plant Control: Power plant programming - constant T_{av} program, constant pressure program, Boiler level and pressure control, PHT pressure control, Bleed condenser pressure and level control, Pressurizer pressure and level control.
- Interfaces of Reactor instrumentation to other relevant plant systems like Reactor Regulating System, Flux Mapping System, Failed Fuel Detection System, Radiation Monitoring System, including networking and RADAS.
- Distributed Control System (DCS) and Computer Based Systems: Distributed Process Control, DCS configurations, Components of DCS, Data Highways, Human machine interface, Operator Stations, Presentation of information on operator station. Programmable Controllers (PLC) – Basic PLC architecture, PLC Programming Languages, Typical PLC Specifications, Redundant PLC architectures, relevant communication protocol and standards.
- PC based process control system, Supervisory Control and DATA Acquisition System (SCADA), Features of SCADA software.

Course Outcomes:

This course will introduce the students to the fundamental principles of nuclear instrumentation, including in-core and ex-core detectors, modes of signal processing such as pulse and Campbell techniques, and reactor core instrumentation with system familiarisation. The course will also expose the students to health physics instrumentation and its application in nuclear facilities

References:

1. M A Schulz, "Control of Nuclear Reactors and Power Plants"
2. J M Harrer, "Reactor Control Engineering"
3. D L Hetrick, "Dynamics of Nuclear Reactors"
4. L E Weaver, "Dynamics of Nuclear Reactor Systems"
5. L E Weaver, "Reactor Kinetics and Control"
6. W.M. Stacey Jr., "Space Time Nuclear Reactor Kinetics", Academic Press, New York 1969.

EN638: Reactor Control Engineering & Instrumentation-II (20 Lecture Hrs)

Coordinators: Shri. P. V. Bhatnagar(pvbhat@barc.gov.in)

Smt. Ratna Bharna(rbhamra@barc.gov.in)

Course Details:

- **Fundamental Considerations / Philosophies, requirements, and scope of reactor and health physics instrumentation.**
- **Reactor Instrumentation**
 - Measurement ranges of reactor neutron flux and considerations
 - Principles of detection and types of neutron detectors: in-core and out – of –core
 - Modes of signal processing: Pulse, Campbell, DC
 - Introduction of nuclear systems in reactors for safety, safety related and monitoring.
- **Health Physics Instrumentation**
 - Type of radiation detectors in health physics instruments and basic principles- Gas-filled, Scintillation, semiconductor and misc.
 - Signal Processing - Pre-amplifier, Count rate meters, Scalar timers, Nuclear ADCs, SCA, MCA.
 - Introduction to various radiation monitors - Personal monitors, Area Monitors, Neutron Monitors, Stack Monitors, Contamination Monitors, Criticality Alarm Monitors.

Course Outcomes:

This course will introduce the students to the fundamental principles of nuclear instrumentation, covering in-core and ex-core detectors, modes of signal processing including pulse and Campbell techniques, reactor core instrumentation and system familiarisation, and health physics instrumentation used in nuclear facilities

References:

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

EN639: Reliability Engineering (EE) (25 Lecture Hrs)

Coordinators: Dr. (Smt) Gopika Vinod
(vgopika@barc.gov.in)

Course Details:

- **Introduction: Reliability Engg Applied to C&I Systems**

- Explain the course coverage and the general issues related to the reliability and safety of the current C&I Systems. The reliability of computer-based C&I system as a function of circuit hardware, software and human errors experienced in the NPPs and research reactors.
- Terms and definitions with adequate explanation and giving examples from electrical, electronic and computer-based systems.
- Quality, Reliability, Availability, Maintainability and supportability, MTBF, Failure and hazard rates, CCF, CMF, Failure Modes, FMEA, FMECA, Fault tolerance, Confidence and Risk Factors etc.

- **Reliability Maths/Statistics**

- Mathematical and statistical expressions required for reliability study.
- Types of failures in electrical, electronic and computer components
- Failure probability concept, statistical distribution models_
- Binomial, Poisson, Exponential, Normal, Lognormal, Weibull distributions
- Chi-square distribution and its use in confidence and risk factors
- Baye's theorem
- Reliability or life characteristics of hardware electronic circuit components, and comparison with the characteristics of mechanical/electro-mechanical components and computer software.
- Bath-tub curve and explanation of different parts of the life characteristic curve, and corresponding failure distributions.
- -Derivation of exponential reliability expression_
- $R(t)=[\exp(-\lambda t)]$ for electronic components and systems.
- Examples to solve

- **Fault Tolerance and Systems Reliability**

- Fault tolerance concept for electronic and Computer based C&I systems.
- Circuit hardware redundancy concept to enhance system reliability, types of redundancy_
- Series, parallel, active, passive, and voting redundancy
- Redundancy and other fault tolerance method for software
- FMEA, FMECA concepts for C&I and Examples to solve
- Concepts for the analysis of System Reliability, availability, and maintainability.
- System reliability and availability analysis method:
- Boolean logic
- Digraph, cutset-tie set method
- Fault tree model, and consideration of CCF, CMF, software errors
- Markov Model
- Example from C&I system in the NPPs

- **QA/QC Concepts in Brief**

- QA/QC Concepts in the components, systems procurement, manufacture and

- site installation for C&I systems in the NPPs.
- **Environmental Qualification and Reliability Testing**
 - Environmental qualification, testing of the C&I systems. Qualification standards (IEC, IEEE, IS, MIL, JSS55555). Qualification case study: for Systems and Equipment.
 - Effects of various environments on the electrical/ electronic components
 - Climatic Qualification tests: Temperature, Humidity
 - Special environments: EMI/EMC tests on C&I Systems, Gamma radiation/LOCA Qualification tests
 - Reliability Testing of the electronic components, equipment and C&I systems.
 - Reliability screening tests for electronic components
 - Accelerated environmental tests
 - Failure terminated and time terminated tests
 - Estimation of MTBF (q)/Failure Rate(l) of electronic components and systems using c2 distribution for confidence level.
 - Few examples to solve
 - **PSA/PRA Concepts in NPPs**
 - Probabilistic Safety (Risk) Assessment: PSA/PRA method or safety/ risk assessment in the NPPs.
 - Explain Event Tree
 - Fault-Tree-Fault Tree method for risk assessment in terms of core damage frequency.
 - Level-1, Level-2, Level-3 PSA studies (Brief introduction only).
 - **Additional safety concepts**
 - Defense-in-depth, fail-safe concepts in the design of C&I, and other safety critical systems in the NPPs.
 - Single failure criteria, engineered safety systems in the NPPs
 - Safety Classification and Seismic categorization of C&I Systems of NPPs (Class IA, IB, IC, IE)
 - Target reliability goals, reliability allocation to safety systems as per their safety importance in the NPPs
 - Reliability and safety aspects for the integrated C&I systems
 - (Hardware, software, human errors considerations)
 - IEC, IAEA, AERB, IEEE standards & guidelines relevant to C&I in the NPPs
 - Human Factors (man-machine interface) reliability, and human reliability issues in the NPPs
 - Current research topics in reliability and safety analysis such as Fuzzy Logic, Neural Network Method, etc.

Course Outcomes:

This course will introduce the students to the principles of reliability engineering for computer-based C&I systems, covering hardware, software, and human factors. The course will expose the students to reliability mathematics, fault tolerance and redundancy concepts, and practical methods such as FMEA/FMECA, fault tree analysis, and Markov models for analyzing reliability, availability, and maintainability of C&I systems.

References (latest editions to be referred):

1. Reliability Engineering for Nuclear and other High Tech Systems By Lakner and Anderson, Elsevier Applied Sci. Publ. (1985)
2. Reliability Engineering for Electronic Systems By R.H. Mayers et al, John Wiley, NY (1964)
3. Practical Electronics Reliability Engg By Jerome Klion, Van Nostrand, NY (1992)
4. Reliability and Risk Analysis By Norman J McCormick, Academic Press (1981)
5. Fault Tolerant and Fault Testable Design By Parag K. Lala, Prentice Hall, (1985)

6. Dependability of Critical Computer Systems, Vol.1&2 By F.J. Redmill, Elsevier Applied Sci. Publ. (1988)
7. An Introduction to Reliability and Maintainability Engg By Charles E. Ebeling, Tata-McGraw Hill Publ. (1997)
8. Reliability Technology By A.E. Green and Bourne, UKAEA, John-Wiley (1972)
9. IEC Standards: 880, 987, 1225, 1226 on C&I Systems
10. AEA Safety Standard/Guide G:1.3, Instrumentation & Control for the safety of Nuclear Power Plants (2002)
11. IAEA-TECDOCS: 780, 790 on Computer based C&I Systems.
12. MIL-Std-217F: US Military Handbook: Reliability Prediction of Electronic Equipment (1993)
13. Reliability of Computer and Control Systems by Viswanadham et al, North-Holland/ Elsevier Publ.(1987)
14. Software Reliability Method, by Doron A.Peled (Bell/Lucent Labs), Springer Publisher (2001), ('Formal Method' has been explained).
15. Handbook of Reliability Engg Ed. Igora Ushakov & R. Harrison John Wiley & Sons (1994)
16. Burn-in by Fenn Jenson Failure Models by I.B. Gertsbakh
17. System Reliability_ Concepts & Applications by K.B. Klassen (1989).

EN640: Software Design Practices and Formal Method (40 Lecture Hrs)**Coordinators: Dr. Ajith K. John
(ajith@barc.gov.in)****Course Details:****• Software Design Practices**

- Introduction to Object oriented programming
- Unified Modeling Language
- Software Life Cycle Models
- Software Architecture
- Software Design Principles
- Software Design Patterns
- Software Packaging
- Software Testing
- Software Configuration Management

• Formal Method

- Introduction to Formal Method, Role of Formal Method in Software Life Cycle–development and Verification (1)
- Formal Specification and Modeling: Specifications & Proofs, Specification Techniques
- Behavioural Modeling: Concurrent & Reactive Systems. Asynchronous and Synchronous models, Synchronous languages, Example Specifications in CSP, State charts, Lustre and Esterel (8)
- Formal Verification: Propositional and Predicate Logic and proof system, Program testing – Assertions and their verification (dynamic and static), Need of Formal Verification, Sequential Program Correctness, Safe-subset of Programming Languages (7)
- Verification by Model Checking: Concurrent and Reactive systems, System properties and their specification in logic, Case study from hardware and software, model checking tools (SPIN, NuSMV etc.) (4)

Course Outcomes:

This course will introduce the students to techniques for software modelling, including the application of model checking and theorem proving. The course will also expose the students to agile programming practices and fundamental software testing concepts

References:

1. Software Engineering: Roger S. Pressman, McGraw Hill
2. Software Engineering: Ian Sommerville, 5th edition, Addison-Wesley
3. Unified Modeling Language User Guide: G.Booch, J.Rumbaugh, I. Jacobson, Addison-Wesley
4. UML Distilled: Martin Fowler
5. Design Patterns: Erich Gamma
6. Specification and Verification of Reactive Systems Vol I&II, Zohar Manna & Amir Pnueli, McGraw Hill, 1995
7. Science of Computer Programming: David Gries, Springer, 1981
8. Symbolic Model Checking, K.McMillan, Kluwer, 1993

EN641: Machine Learning and Big Data Analytics (25 Lecture Hrs)**Coordinators: Shri. Gigi JosephS
(gigi@barc.gov.in)****Course Details:****• Module-I: Machine Learning Algorithms: (4 Lectures)**

- Introduction to Machine Learning and Deep Learning: Definitions, Applications.
- Fundamentals of Machine Learning: Types of Machine Learning, Training and Test Data, Model evaluation and validation.
- Understanding Data Sets: Dimensionality, Dimensionality Reduction; Principal Component analysis (PCA), Linear Discriminant Analysis (LDA), t-Distributed Stochastic Neighbor Embedding (t-SNE).
- ML Algorithms: Naive Bayes, Linear Regression, Decision Trees, K-Nearest Neighbor (KNN), Support Vector Machine (SVM), One-Class Support Vector Machine (SVM) and K-Means.
- Ensemble Learning: Bagging, Boosting, Stacking; Random Forest, AdaBoost, Gradient Boost.

• Module-II: Deep Learning Algorithms: (10 Lectures)

- Introduction to Neural Networks.
- Convolutional Neural Networks, Recurrent Neural Networks, Long Short-Term Memory Networks (LSTM), Graph Neural Networks, Autoencoder, Generative Adversarial Networks (GANs), Attention models, Transformers and BERT (Bidirectional Encoder Representations from Transformers).
- Hyperparameter tuning, Regularization, Model optimization and Transfer learning.
- Model Interpretability/Causality and Explainability, Model debugging, Model and data versioning, Distributed training, Model deployment and inferencing, Model monitoring, Hyperparameter search.
- Reinforcement Learning: Key concepts, Applications, Algorithms: Q-Learning, Deep Q-Network (DQN) and Policy Gradient.

• Module-III: Time Series analysis: (5 Lectures)

- Fundamentals of Time Series Analysis: Components, Types of data, Stationarity, Auto-Correlation Function and Partial Auto-Correlation Function.
- Models: Moving average (MA), Autoregressive (AR), Autoregressive Moving Average (ARMA), Autoregressive Integrated Moving Average (ARIMA) and Seasonal Autoregressive Integrated Moving Average (SARIMA).
- Anomaly Detection: Anomalies in Cross-Sectional and Time Series Data, Introduction to Security Information and Event Management (SIEM), Anomaly Detection in SIEM.

• Module- IV: Big-Data Analytics: (6 Lectures)

- Fundamentals of Big-Data: Definitions, Characteristics, Challenges.
- Data Ingestion & Processing: ETL (Extract, Transform, Load) pipelines, Technologies: Flume, Nifi, Kafka.
- Big Data Technologies: Hadoop, Spark, Hive.
- Data Retrieval: Inverted Indexes, Lucene, Elasticsearch.
- Streaming Analytics & Big Data Visualization.

Course Outcomes:

This course will introduce the students to machine learning and deep learning techniques for data analysis and prediction, including time series modeling and anomaly detection. The course will also expose the students to advanced learning models and big data analytics frameworks for large-scale data processing and visualization

References:

1. "Introduction to Data Mining"- Pearson, Michael Steinbach, Pang-Ning Tan, and Vipin Kumar.
2. "Deep Learning"- MIT Press, by Ian Goodfellow and Yoshua Bengio and Aaron Courville.
3. "Time Series Analysis and Its Applications" - Springer, Robert H. Shumway and David S. Stoffer.
4. "Big Data Analytics"- Wiley, Seema Acharya, Subhasini Chellappan.
5. "Hadoop: The Definitive Guide: Storage and Analysis at Internet Scale" - O'Reilly, Tom White.

ELECTIVE COURSES

EN701: Advanced Computational Techniques (30 Lecture Hrs)

Coordinators: Shri. K. Rajesh
(rajesh@barc.gov.in)

Course Details:

- **Programming Language: Python**

- Python: Basic data-types, Containers: Lists, Dictionaries, Sets, Tuples, Functions, Classes
- Numpy: Arrays, Array indexing, Datatypes, Array Math, Broadcasting
- Matplotlib: Plotting, Subplots, Images

- **Advanced Computational Techniques**

- Discretization technique using Finite Difference, Finite Volume, Finite Element, Orthogonal Collocation, Meshless, Spectral Method.
- Grid Generation - Transfinite Interpolation, PDE based techniques, grid adaptation
- Artificial Neural Network- Its taxonomy, application for mapping, quantization, prediction & optimisation using Backpropagation ANN.
- Optimization - Using traditional Gradient based techniques, population based GA & ACO
- Applications using above all method to DAE related problems.
- New generation CFD solvers like mesoscopic solvers, etc. for fluid flow simulation

- **Parallel Programming**

- Introduction to parallel computers, classification, technologies, ratings
- Parallel programming concepts, examples, terms and definitions, parallelism, parallel programming models
- Different examples of parallel programs and parallelization strategies
- Message Passing Interface (MPI), concepts of MPI, MPI Library calls
- MPI Point to Point communication calls
- MPI Collective communication calls

- **Scientific Visualization**

- Geometry Classification - 2D & 3D grids.
- Structured & Unstructured grid development.
- Data storage techniques for 1D, 2D & 3D grids.
- Data visualization techniques for scalar & vector data.

- **Pitfalls and Precautions in programming**

- Floating Point Representation
- Errors, Cancellation, Propagation, Kahan Summation Algorithm
- Overflow/Underflow, Stability of an algorithm

- IEEE 754 standard

Course Outcomes:

This course will introduce the students to programming fundamentals and numerical discretization methods including finite difference, finite volume, and finite element techniques, along with grid generation and artificial neural networks. The course will also expose the students to parallel programming using MPI and scientific visualization methods

EN702: Advanced Electrical Engineering Design-II (25 Lecture Hrs)

Coordinators: Shri. S. Malhotra
(sanjaym@barc.gov.in)

Course Details:

- **Special Electrical Machines**

- Special Electrical Machines and their applications: Vector Control of PM Synchronous Servo Motor
- Variable reluctance stepper motor (VRSM), Switch reluctance motor (SRM) and Hysteresis Motor
- Materials: Soft and Permanent Magnetic Materials, their properties and applications: Pulse Transformer design, Ferrite Pulse sharpening.

- **Pulse Power Technology**

- Breakdown in gases, Vacuum, liquid and solids
- Concepts of Pulse Power storage, Compression and switching
- High Voltage Generation and measurement
- Transmission line theory and pulse forming networks
- Non-linear pulse circuits Capacitive and inductive pulse generation
- Non-linear pulse circuits
- Special transients (NEMP, HPM, & UWB) Compact generators

Course Outcomes:

This course will introduce the students to vector control of PM synchronous motors, design and applications of variable reluctance stepper and switched reluctance motors. The course will also expose the students to pulse power techniques and high voltage systems

EN703: Artificial Intelligence, Machine Learning & Applications (30 Lecture Hrs)**Coordinators: Shri. Dinesh Sarode
(dinesh@barc.gov.in)****Course Details:**

- **AI Basics:** Introduction, Problem solving through search, search strategies, A* search, Heuristic functions, Robot path planning – visibility algorithm, wavefront algorithm, sub-division algorithm, probabilistic roadmap planner.
- **Automated reasoning** – propositional logic, predicate logic, resolution-refutation, Knowledge Base and Expert Systems.
- **Genetic Algorithm (GA):** Introduction, terminology, operators and working principle, encoding and decoding of decision variables, selection mechanisms, selection pressure vs. population diversity, premature convergence, fitness scaling, Elitism, Real-coded Gas, Multimodal function optimization, Multiobjective optimization, Dominance and Pareto-optimality, Multiobjective Gas.
- **Artificial Neural Network (ANN)** Biological neurons and artificial neurons, types of neurons, activation functions, single layer perceptrons and linear separability, training, perceptron convergence theorem, Multi layer perceptrons, back propagation and related issues, speeding up backpropagation, Unsupervised clustering and classification method, ANN applications.
- Data Mining Knowledge Discovery in Databases and Data Mining, Data Mining tasks – Association, Classification, Clustering.
- Reinforcement learning Dynamic programming, Value iteration and Policy iteration, Temporal difference method, Q-learning, ANN implementation of reinforcement learning algorithms, Applications in Robot control.
- Machine Learning Method and Algorithms – To be provided by Course Coordinator

Course Outcomes:

This course will introduce the students to search problems and AI algorithms, soft computing techniques such as ANN and SVM, and data mining technologies. The course will also expose the students to reinforcement learning and dynamic programming concepts

References:

1. Artificial Intelligence: a modern approach, by Russell & Norvig

EN704 Advanced Fracture Mechanics (30 Lecture Hrs)

Coordinators: Dr. Suneel Gupta
(suneelkg@barc.gov.in)

Course Details:

- **Advanced Linear Elastic Fracture Mechanics (5)**

- Introduction to LEFM, Griffith theory and concept of strain energy release rate
- William's series solution for crack-tip stress field for plane problems, Westergaard's complex stress function approach for crack-tip stress and displacement fields for mod-I,II and II problems,
- Estimation of energy release rate and SIF for elastic crack problems
- Crack tip plasticity and effective SIF, Dugdale's strip yield model and Burdekin-Stone's solution for effective SIF

- **Elastic-plastic Fracture Mechanics (5)**

- Concept of nonlinear energy release rate and J-integral, Path-independence of J-integral,
- HRR singularity, Derivation of crack-tip stress and displacement fields for small scale yielding condition using deformation theory of plasticity,
- Crack-tip opening displacement and crack-tip opening angle as loading parameter, Relationship between J and CTOD,
- J-controlled crack growth and validity criteria for J-dominance,
- Asymptotic analysis and elastic-plastic solutions in small scale yielding
- Crack-tip constraint parameters and generalized two-parameter fracture mechanics,
- J-estimation scheme. Ainsworth's engineering approximation for J,
- Laboratory measurement of J, η and χ factors, Fracture resistance curve and crack-initiation toughness, ASTM standards for evaluation of JIC and J-R curves, Standards for CTOD testing, Stability of crack growth and concept of Tearing modulus.

- **Dynamic and time-dependent fracture (5)**

- Dynamic crack propagation and arrest, Elasto-dynamic crack-tip stress fields and their dependence upon speed of crack propagation,
- Generalized energy release rate for dynamic problems, Variation of kinetic and deformation energy with time, concept of transition time and its importance for evaluation of dynamic SIF,
- Dynamic fracture toughness KID and its variation with crack speed, crack arrest toughness KIA,
- Dynamic contour integral for estimation of energy release rate in dynamic problems,
- Non-linear aspects in dynamic fracture mechanics,
- Creep crack initiation and growth, Crack-tip stress fields for creeping solids,
- Concept of C^* and $C(t)$ integral, Fracture parameters for transient and steady state creep, Transition time, Viscoelastic fracture mechanics, Viscoelastic J integral for polymeric materials.

- **Environmental-assisted crack growth (2)**

- Hydrogen embrittlement in metals and hydrogen-assisted crack growth,
- cohesive zone models and numerical aspects,
- Stress corrosion cracking,
- Fracture models for environmental assisted crack growth in metals.

- **Computational Fracture Mechanics (4)**

- Crack-tip stress and strain singularity in LEFM and EPFM, Barsoum's crack tip element and derivation of stress and strain singularity,
- Generalized crack-tip singularity element,
- Evaluation of SIF using results of FE analysis for mode-I and mixed mode problems,
- Virtual crack extension technique,
- Stiffness derivative method to evaluate SIF,
- Evaluation of J as a domain integral and computational aspects,
- J-integral evaluation for dynamic problems.

- **Micromechanism and mathematical models for fracture process (5)**

- Micromechanisms of ductile and cleavage fracture, Concept of void nucleation, growth and coalescence
- Statistical aspects of cleavage fracture process, RKR model, CK model, Beremin's model, Weibull statistics and applications in cleavage fracture model,
- Rice and tracey's model, GTN and Rousselier's model for ductile fracture,
- computational aspects of micromechanical models for ductile and cleavage fracture.

- **Mixed mode fracture, Fracture mechanics for welds, non-metals and composites (4)**

- Crack growth for arbitrarily oriented cracks and concept of mixed mode fracture, Critical SIF and orientation for crack initiation in mixed mode fracture,
- Overview of fracture process in non-metals and composites, Toughening mechanism in ceramics and ceramic composites, Interlaminar toughness of composites,
- Standard testing method for evaluation of fracture toughness of non-metals,
- Suitability of K and J for polymers, Experimental procedure for evaluation of time-dependent fracture parameters of viscoelastic polymers,
- Specimen design for fracture assessment of welds, Effect of crack location and orientation on fracture toughness of welds, Fracture toughness testing in the DBTT regime.

Course Outcomes:

This course will introduce the students to the fundamentals of fracture mechanics, covering linear elastic and elastic-plastic behavior and crack growth criteria. The course will also expose the students to dynamic and environmental fracture phenomena, computational analysis methods, and material-specific fracture behavior and testing practices.

EN705: Data Base Management System and Web Technology (30 Lecture Hrs)

Coordinators: Shri. J. J. Kulkarni
(jjk@barc.gov.in)

Course Details:

- **Advanced RDBMS**

- Architecture of Oracle RDBMS (3)
- Recap of SQL language(5)
- Introduction to PostgreSQL and MySQL(3)
- Data warehousing concepts (2)
- Concepts of clusters, distributed databases, grid enabled databases, database replication(2)

- **Web Technologies**

- Introduction to Web Technology(2)
- DHTML (3)
- CGI /PHP (4)
- Web services and XML (2)
- Ajax(1)
- Content Management Systems(1)
- Web 2.0 / Semantic Web(2)

Course Outcomes:

This course will introduce the students to SQL and complex queries, data modeling, and real database design. The course will also expose the students to clusters, distributed databases, and working with web technologies.

EN706: Digital Signal Processing, Image Processing & Applications (30 Lecture Hrs)**Coordinators: Shri. M. Padmanabhan**
(mpadmana@barc.gov.in)*Course Details:*

- **Digital Signal Processing**
 - **Introduction:** Basic elements of a digital signal processing system, Fourier series and Fourier transform, z-transform, Convolution, Correlation, Sampling theory, Aliasing, Antialiasing filter, Quantization noise, Signal reconstruction.
- **Discrete Fourier Transform**
 - Interpretation of DFT, Properties of DFT, DFT of real signals, Periodic & linear convolution and correlation using DFT.
 - **Fast Fourier Transform:** Efficient computation of DFT using decimation-in-time and decimation-in-frequency algorithms, Computation of Inverse DFT using FFT algorithm, Spectrum analysis using the FFT, Use of FFT algorithm in linear filtering and correlation.
 - **Digital filters:** FIR and IIR filters, Design techniques for FIR and IIR filters, Realization of FIR and IIR systems.
 - Overview of DSP processors and DSP Applications
- **Image Processing & Applications**
 - **Introduction:** Digital image model, Image sensor, Digitizer, Computer, Color image basics, Standard file format.
 - **Image Enhancement:** Spatial & Frequency Domain Method; 2-D Fourier Transform, Filtering, Image smoothing.
 - **Segmentation and Hough Transform:** Edge Detection, Thresholding, Representation; Line/circle/corner Detection.
 - Morphological operations.
 - Texture Analysis.
 - Image Compression Method.
- **Applications**
 - DNN based Object Detection, Segmentation and Recognition.
 - Recognition & Interpretation of Patterns.
 - Inspection & Measurement Applications.
 - Robot Vision-Camera Calibration, Stereo Vision, Hand Eye Calibration, Depth from defocused image.
 - Biometrics, Medical Image Processing & Video Analytics.
 - Image Degradation & Restoration.

Course Outcomes:

This course will introduce the students to digital signal processing techniques, including Fourier transforms, FFT, and digital filters. The course will also expose the students to image processing and image compression techniques and their applications

EN707: Embedded Electronics Software and Embedded System Security (25 Lecture Hrs)

Coordinators: **Dr Amol Wakankar**
(amolk@barc.gov.in)

Course Details:

- **Programmable Digital System Design, Representation & Synthesis**
 - Embedded Hardware Design Methodologies. Programming languages & their Semantics for digital systems, Basic constructs in VHDL. Introduction to Design Flows and EDA Design Tools.
- **Real-time Software**
 - Hard & Soft Real-Time Systems, Task Model of Real-Time Systems, Periodic, Aperiodic, Execution Times, Release Times, Deadlines, Precedence Graphs, Context Switch and Interrupt latency, Schedulers and Schedule: Scheduling paradigms, static schedules, dynamic scheduling, Round robin, Priority, Rate Monotonic Scheduling, EDF, Optimality of EDF. Sufficient Static Schedulability Conditions, Liu & Layland Theorem, Issues with Priority Scheduling: Inversion, Priority Inheritance
 - Real Time Operating System Services, Examples of RTOS for embedded systems, Overview of Device Driver Development
- **Embedded System Security**
 - Security of Embedded Systems, Attack Models in Networked Systems, Threats and Vulnerability (2)
 - Basic Cryptographic Primitives, Confidentiality, Integrity, Authentication mechanisms, Principles of 2 Factor Authentication (3)
 - Principles of hardening of Operating Systems (2)
 - Security Standards (1)

Course Outcomes:

This course will introduce the students to digital system design flows and EDA/SE tools, real-time system task models, and scheduling paradigms for hard real-time systems. The course will also expose the students to practical RTOS concepts.

References

1. The Guide to ARM: by Trevor Martin
2. Advanced Microprocessors & Microcontrollers: by B.P. Singh & Renu Singh
3. Fieldbus Technology: by N.P. Mahalik
4. Designing with FPGAs & CPLDs: by Bob Zeidman
5. VHDL: Analysis and modeling of digital systems by Navabi
6. Real-Time Systems by Jane W. S. Liu, Pearson Education
7. MicroC/OS-II: The Real-Time Kernel by Jean J. Labrosse, CMP Book

EN708: Construction Materials, Management and Quality Assurance (30 Lecture Hrs)

Coordinators: Dr. M. K. Pradhan
(mpradhan@barc.gov.in)

Course Details:

- **Construction Materials**
 - Concrete: Ingredients, properties of concrete, mix design of normal, heavy density and serpentine concrete, High Performance Concrete with mineral admixtures (micro-silica, fly ash etc.)
 - Reinforcement: Passive and active (Prestressing)
 - Structural Steel, High Strength Friction Grip Bolt, Mechanical Couplers
 - Paints
 - Water-proofing materials & membranes
- **Shuttering/Formwork:** Design philosophy, different design requirements, climbing shutter design, slip form work.
- **Prestressing system:** Cable ducts, anchorage and grouting, qualification of Prestressing system
- **Quality Assurance (QA)**
 - QA in Civil Engineering design
 - QA in materials
 - QA in construction
 - QA in operation & maintenance
 - Inspection during construction, Regulatory inspection
- **Construction Procedure & Construction Safety**
 - Dewatering, rock excavation, consolidation grouting
 - Construction safety, Job Hazard Analysis.
- **Contract Management:** Introduction, Basics, preparation of tender, mode of tendering, contract and its clauses, discharge of contract, dispute adjudication.

Course Outcomes:

This course will introduce the students to construction materials and systems, formwork and prestressing methods, and construction procedures with safety considerations. The course will also expose the students to quality assurance practices and construction management and contract administration principles.

References:

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

EN709: Fluid Power Technology (25 Lecture Hrs)

Coordinators: Shri. P. K. Limaye
(pklimaye@barc.gov.in)

Course Details:

- **Basic principles of Hydraulics and pneumatics**
 - **Hydraulic Fluids**
 - Properties of hydraulic fluids and pneumatic air,
 - Types of fluid, composition of fluids, effects of additives,
 - Advantages of oil vs. air as working fluid.
 - **Fluid power pumps and compressors**
 - Purposes, classification of pumps and compressors
 - Classification of pumps: roto-dynamic pumps - Centrifugal pumps; positive displacement pumps - (i) Rotary pumps - external gear pump, internal gear pump, gerotor pump, sliding vane rotary pump, lobe pump, screw type rotary pump.
(ii) Reciprocating piston pumps - radial piston reciprocating pump, rotating barrel type axial – piston pump, bent axis type axial - piston pump, wobble pump, simplex, duplex and triplex reciprocating pumps
(iii) Pressure head and energy in pump system, pump characteristics, Types of compressors, selection of compressors and efficiency of compressors.
 - Fixed displacement pumps, variable displacement pumps, pressure compensated pumps, load sensing pumps; advantages of pressure compensated and load sensing pumps.
 - Advantages of various pumps, advantages of positive displacement pumps Vs. centrifugal pumps, Pump flow and pressure, Pump drive, torque, power and efficiencies – mechanical, hydraulic, volumetric, overall efficiency.
- **Hydraulic and Pneumatic control valves**
 - **Pressure control valves:** Construction and working principles of relief valves, counter balance valves, sequence valves, unloading valves, pressure reducing valves, Pneumatic Pressure regulating valves.
 - **Flow control valves:** Non-compensated flow control valves, throttle valves, pressure compensated flow control valve, pressure, temperature-compensated, flow control valve, method of speed regulation.
 - **Directional control valves:** Introduction, constructions, operation and application of directional control valve (DCVs) for pneumatics & hydraulics, check valves, different types of valves, 4/3 valves, type of actuation of DCVs, mounting interfaces, designation
 - **Actuators:** Different types of linear actuators, construction, cylinder seals, Pneumatic reciprocating actuators, rod-less actuators. Rotary actuators – motors (garmotors, gerotormotors, vanemotors, Radial piston motors, axial piston motors) and limited rotation rotary actuators, their types, construction, advantages of hydraulic & pneumatic motors and their characteristics & efficiencies.
 - **Seals:** Application and type of hydraulic and pneumatic seals, dynamic and static seals, O-rings, their advantages, O- ring face seals, O-ring radial seal, application of o-rings, installation of O-rings, O-ring failures, labyrinth seals.

- **Pipes, Tubes and Hoses, fittings:** Definitions, designations, construction of hoses, hose end connections – permanent and reusable type, threads in hydraulic applications, BSP, NPT, UNF etc., types of connectors, definitions, adjustable, non adjustable fittings, tube fittings, type of fittings – flared and ferrule type pneumatic tubing and connections.
- **Accessories:** Applications, principles, selection of different types of accessories like Filters, heatexchanger, hydraulic accumulators, Reservoirs, pressure gauges, fillers, breathers, pressure switches, temperature indicators, sight glass, level indicators and switches, regulators, lubricators, mufflers, dryers, etc.
- **Hydraulic Circuit Design**
 - Introduction to fluid Power Symbols, Overview of IS 7513,
 - Flow control, pressure control and direction control in hydraulic circuits. Accumulator circuits, regeneration circuits, press circuits etc. Analyzing resistive loads, overrunning loads and inertial loads. Open loop hydraulic circuits design criteria.
 - Sizing & selection of Hydraulic circuit components: Reservoir, Filters, Fluid conductors, Pumps, Cylinders, Motors, Accumulator, Direction, pressure & flow control valves.
 - Trouble shooting in hydraulic circuits.
- **Electrohydraulic proportional and servo controls:** Control of proportional and servo hydraulic linear actuators, system design using servo actuators, shake table.
- **Water Hydraulics and Component Design:** Merits and demerits of water as working fluid, Cavitation in hydraulic components, Seals, different types of water hydraulic valves, their conceptual designs (DPRS,ADPCV,PCFCV, POPCV) & sizing.
- **Fluid film Bearings:** Hydrostatic and Squeez film lubrication, Fixed, active and self-compensation, Hydrodynamic and Elasto-Hydrodynamic lubrication, Gas lubrication, Finite bearings etc.
- **Lubrication:** Lubrication Fundamentals, Understanding Additives, Base Oils and Grease Thickeners, Lubricant Performance Properties, Food-grade and Environmentally-friendly Lubricants, Hydraulic Fluids, Contamination Control, Oil Drains, Flushing and Reservoir Management Storing, Handling and Managing Lubricants, Used Oil Sampling and Analysis Fundamentals, Essential Field Inspections, Radiation resistant lubricants
- **Advance Tribology:** Wear map, water lubrication, selection of materials and coatings for wear resistance, systematic investigation of worn surfaces, bearing life theories

Course Outcomes:

This course will introduce the students to the basic principles of hydraulics and pneumatics, including pressure, directional, and flow control. The course will also expose the students to fluid power pumps and compressors, fluid logic and advanced hydraulic control circuits, along with electronics and instrumentation used in hydraulic systems

EN710: Service Life Estimation and Retrofitting of Concrete Structures (25 Lecture Hrs)**Coordinators: Dr. Yogita Parulekar (yogitap@barc.gov.in)****Dr. Praveen Kumar (praveen@barc.gov.in)****Course Details:**

- **Introduction to Structural Health Monitoring**

Basics of ageing phenomenon, Concept of structural health monitoring, Estimation of concrete strength using rebound hammer test, USPV test and Core test, Introduction to advance NDT techniques, solution to inconsistencies in test results, examination of variability of test results, detection of cracks in concrete using Vibro Acoustic modulation technique, Damage identification in concrete using smart materials like Piezo-electric sensors, Corrosion estimation using NDTs, Equipotential contour mapping using Half-cell potential techniques and evaluation of probability of corrosion. Corrosion current density, icorr estimation using Linear Polarisation resistance technique, Tafel plots for estimating Ecorr and icorr, Condition survey of inaccessible, underground and underwater concrete structure.

- **Quantification of corrosion effect**

Effects of corrosion on cover cracking, Models for time to cover cracking in RC structures. Bond deterioration and rebar area reduction, Different empirical bond models due to corrosion deterioration, Methodology of Evaluation of bond slip relation with corrosion from basic CEB FIP (2010) bond model of uncorroded rebar, Deducing moment curvature relationship of RC element due to reduction in area, bond slip and reduction in material properties of corroded rebar. Estimation of capacity curve of the structure considering deterioration due to corrosion.

- **Service life estimation of structures**

Factors affecting service life (Environment, design, and construction considerations), Various method for predicting the service life of concrete (based on ACI 365.1) , Diagnosis of concrete quality based on cement content, permeability/porosity and concrete mix, Diffusion coefficient of concrete, Fick's law of diffusion, estimation of time required to reach critical chloride concentration, evaluation of time for corrosion propagation period , Evaluation of total service life of the structures.

- **Structural Qualification**

Intent of structural qualification, Data Collection: original design basis, geotechnical investigation, drawings, accounting for lack of data, material properties. Hazard Classification, Loads and Load combinations for requalification. Re-evaluation of safety against normal operating and wind loads/seismic loads, Analysis methodology: linear static analysis, linear dynamic analysis, Seismic Margin assessment using IAEA safety series 28 procedure: Computation of HCLPF seismic Margin Earthquake (SME).

- **Repairs and Retrofitting**

- Approach to repair/retrofit/replacement based on structural assessment, Objectives of repair/ retrofit, types of structural modifications, major factor for selection of repair or retrofit method, Repairs: types of repair materials, non-structural repairs, structural repairs, special repairs.
- Retrofit: major goals of retrofit, retrofit strategies using strengthening approach and response control approach, Increase of strength estimation of structures using jacketing and FRP wrapping, Retrofit using various passive energy absorbers Evaluation of hysteretic damping and reduction in response of structures

with damper devices Assessment of effectiveness of repairs by non-destructive testing method, Safety aspects during repair/retrofit, Enhancement of service life considering repairs and retrofit.

- **Maintenance and Monitoring Programme**

Preventive and corrective/remedial maintenance, In-Service Inspection (ISI): objective, procedure and frequency of inspection, Instrumentation and periodic data monitoring: types of instrument and their application; data collection, storage and analysis; time limited ageing analysis, Quality control/assurance at all stage.

- **Case Studies**

- Service life estimation of concrete structure
- Structural health assessment and Repairs/retrofit of concrete structure.

Course Outcomes:

This course will introduce the students to the principles of structural health monitoring and non-destructive testing for condition and corrosion assessment of concrete structures. The course will also expose the students to service life estimation methods and strategies for assessment, repair, retrofitting, and maintenance through practical case studies.

References

1. CPWD (2002), Handbook on Repair and Rehabilitation of RCC Buildings, Central Public Works Department, New Delhi, India.
2. CPWD (2007), Handbook on Seismic Retrofit of Buildings, Central Public Works Department, New Delhi, India.
3. A&SED/SG/AM/ECS (2021), Ageing Management and Structural Assessment of Existing Concrete Structures, A&SED, BARC, Mumbai, India.
4. BIS (2013), Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings - Guidelines, February, 2013: Bureau of Indian Standards, IS 15988: 2013, New Delhi, India.
5. AERB (1998, Amended in 2017), Safety Standard on Design of Concrete structures important to Safety of Nuclear facilities, AERB Safety Standard no. AERB/SS/CSE-1, Atomic Energy Regulatory Board, Mumbai, India.
6. AERB/SS/CSE (Rev.1), “Civil Engineering Structures Important To Safety Of Nuclear Facilities”
7. AERB/SS/CSE (Rev.1), “Civil Engineering Structures Important To Safety Of Nuclear Facilities”
8. AERB/SS/CSE (Rev.1), “Civil Engineering Structures Important To Safety Of Nuclear Facilities”
9. IAEA (2016), Ageing Management of Concrete Structures in Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-3.5, International Atomic Energy Agency, Vienna.
10. ASCE (2017), Seismic Evaluation and Retrofit of Existing Buildings, ASCE 41-17, American Society of Civil Engineers, Virginia, USA.
11. ASCE (2017), Seismic Analysis of Safety-Related Nuclear Structures, ASCE/SEI 4-16, American Society of Civil Engineers, Virginia, USA.
12. IAEA, (2002), Guidebook on non-destructive testing of concrete structures.
13. ACI 228.2(2004), Non-destructive Test Method for Evaluation of Concrete in Structures
14. AERB/SS/CSE (Rev.1), “Civil Engineering Structures Important To Safety Of Nuclear Facilities”

EN711: Beyond Design Basis Events: Concepts and Assessment of Civil Structures (25 Lecture Hrs)

Coordinators: Dr. Ajai S Pisharady (aspisharady@aerb.gov.in)
Dr. Rajiv Ranjan (rranjan@npcil.co.in)

Course Details:

- **Introduction (5)**
 - Safety in Design, General Design Objective, Safety Assessment, Plant states, Defence in depth, postulated initiating events
 - Approach for analysis of PIEs for NO, DBA, and DEC conditions: Events Identification and Categorization, Events to be Analysed, Acceptance Criteria for Plant States, Normal Operation, Design Basis Accidents, Design Extension Conditions, Deterministic Safety Analysis, Analysis Approaches
 - Approaches for mitigation of BDB scenarios: reinforcing and enhancing safety further, Safety Approach in case of Unexpected Events, Requirements for Additional Facilities, Specific Provisions and Means
 - Identification of SSCs for BDB assessment
- **Specification/ characterisation of loading/Hazards (8)**
 - Deterministic and Probabilistic Method of Hazard assessment, Examples of BDB events
 - BDB Natural events
 - BDB specification for EQs : scenarios of earthquakes considered, BDB following deterministic approach, BDB following probabilistic approach
 - BDB specification for Flood events : climate change, scenarios for rainfall, methodology of evaluation of BDB rainfall, scenarios for cyclone, methodology of evaluation of BDB rainfall, tsunamis, and methodology of evaluation
 - BDB specification for Wind : scenarios
 - BDB Human induced events
 - Internal pressure : possible PIEs, progression of pressure and temperature under DB and BDB scenarios
 - Aircraft impact : scenarios, correlated hazards,
 - Blast loading
- **Method of assessment and case studies (12)**
 - Assessment for Natural Events : Development of Numerical models, assessment approach, acceptance criteria with regard to assessment
 - Earthquake: Need for displacement based analysis, Introduction to Pushover analysis, nonlinear time history analysis; specific modelling aspects for these analyses, acceptance criteria, Typical case study pertaining to assessment/design for of a structure for beyond design basis events: Earthquake
 - Wind : Case study pertaining to BDBE assessment of stack
 - Flood:
 - a) Inland Flood
 - b) Cyclone
 - c) Tsunami
 - Typical case study pertaining to assessment of site for flood
 - Assessment for Human induced events and acceptance criteria : selection and generation of Numerical models, material modelling , strain rate concept, specific modelling aspects and methodologies
 - i. Internal pressure and acceptance criteria : Case study on ULBC of containment structure
 - ii. Aircraft impact and acceptance criteria: Typical case study on assessment for air craft impact.

iii. Blast loading

Course Outcomes:

This course will introduce the students to the domain of safety of NPPs under different states, philosophy of defense-in-depth, approaches to safety analysis (deterministic and probabilistic techniques) and PIEs in safety analysis. The course will expose the students to safety analysis through case studies.

References

1. AERB/SC/D-LWR, (2015), Design of Light Water Reactor Based Nuclear Power Plants
2. AERB/NPP-PHWR/SG/D-19, (2018), Deterministic Safety Analysis for Pressurized Heavy Water Reactors
3. Report of AERB Committee to Review Safety of Indian Nuclear Power Plants Against External Events of Natural Origin, (2011), <https://www.aerb.gov.in/storage/images/PDF/09-November-2011.pdf>
4. AERB/SS/CSE Rev.1, Civil Engineering Structures Important to Safety of Nuclear Facilities
5. AERG/SG/S-7, Human-Induced Events and Establishment of Design Basis Events
6. FEMA 356: Pre-standard and Commentary for the Seismic rehabilitation of buildings, Federal Emergency Management Agency, Washington, USA.
7. (FEMA-356), Federal Emergency Management Agency, Washington, USA
8. ATC-40: Seismic Evaluation and Retrofit of Concrete Buildings, Volume 1, Applied Technology Council, Redwood City, USA.
9. IAEA Safety Reports Series No.28 : Seismic Evaluation of Existing Nuclear Power Plants, International Atomic Energy Agency, Vienna.

EN712: Material Science in Nuclear Engineering-ME (25 Lecture Hrs)**Coordinators: Dr. Supratik Roychowdhury**
(supratik@barc.gov.in)**Course Details:**

- **Classification, structure and mechanical properties of materials**
 - Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (Low and High cycle) and Impact toughness measurement.
- **Corrosion**
 - Basic principles
 - Types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test method, NACE/ASTM/IS standards.
- **Metallurgy of steels & advanced alloys**
 - Classification of carbon steels, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel.
 - Selection and application of advanced alloys for nuclear industry
- **Nuclear Materials**
 - Fabrication, properties and application of Zircalloys, Zr-Nb alloys.
 - Metallic fuels and ceramic fuels (oxide, mixed oxide, mixed carbide) and their properties and applications.
- **Advanced Polymeric materials and Composites**
 - Physical and Chemical Properties, corrosion, mechanical properties
 - Equipment design with polymeric materials
 - Fabrication principles; standards for design, fabrication and testing.

Course Outcomes:

This course will introduce the students to the domain of corrosion, causes and remedies. The course will expose the students to the metallurgical aspects of commonly used materials in nuclear industry, their characteristics and advancements in structural materials.

References

1. "Introduction to Materials Science for Engineers" – James Shackelford
2. "Physical Metallurgy Principles & Practice" - V. Raghavan
3. "Introduction to Solids" - L.V. Azaroff
4. "Structure and Properties of Materials" – Wulff Series, Wiley Eastern, New Delhi
5. "Materials in Nuclear Application" - C.K. Gupta
6. "Nuclear Chemical Engineering" – Benedict and Pigford

EN713: Materials Characterization (20 Lecture Hrs)**Coordinators: Dr. B. Vishwanadh
(bvisu@barc.gov.in)****Course Details:****• Microscopy Techniques**

- Scope of metallographic studies in materials science, Understanding image formation, resolution of a microscope, numerical aperture, magnification, depth of field and depth of focus, Important lens defects and their correction, principles of phase contrast. Bright field and dark field contrast, sample preparation, Optical microscopy, interference and polarized light microscopy, quantitative analysis using optical microscopy (inclusion analysis, size distribution etc.).
- Optical Microscopy, Scanning electron microscopy, transmission electron microscopy, X-ray diffraction and analysis, thermal characterization, Chemical analysis by X-rays.
- Construction and working principles of transmission electron microscopes, Image formation, resolving power, magnification, depth of focus, elementary treatment of image contrast. Bright field and dark field images, sample preparation techniques. Selected area diffraction, reciprocal lattice and Ewald sphere construction, indexing of selected area diffraction patterns, High resolution electron microscopy
- Scanning electron microscopy: interaction of electrons with matter, construction and working principle of scanning electron microscopes. Secondary and back scattered electron microscopy, resolution depth of field and depth of focus, other modes of operation, Applications in failure analysis, fracture surfaces etc.
- Other microscopy techniques: Atom force microscope, scanning tunneling microscope, EBSD, Field ion microscopes.

• X-Ray Diffraction and Applications

- Properties of x-rays: continuous and characteristic x-rays, absorption, filter, production and detection of x-rays.
- Diffraction of x-rays. Intensity of Diffracted beams - Scattering by an electron by an atom, by a unit cell, structure-factor calculations: factors to be considered in calculating the intensities.
- Experimental method in x-ray analysis; Laue method, powder photographs diffractometer and spectrometer measurements.
- Applications: orientation of single crystal, crystal structures of polycrystalline materials, precise lattice parameter measurements, phase diagram, order-disorder transformation, chemical analysis, residual stress, texture, structure of polycrystalline Aggregates, crystal size crystal perfection, crystal orientations.

• Chemical Analysis (with applications in materials science)

- Basics of spatial-analytical techniques, classification of analytical techniques based on sources, requirements of samples for various technique, precautions required for thin film chemical analysis,
- Principles of energy dispersive and wave dispersive spectrometry

• Basics of Analytical Transmission Electron Microscopy

- Concept of interaction volume and its relation with atomic number and accelerating voltages, Fundamentals of different correction parameters like ZAF correction, LIII corrections
- Cliff Lorimer factor, thin film correction

• Basics of SIMS, RBS and their Derivatives

- Advantages and shortcomings, concept of analytical images, different modes of analytical information, resolutions and limitations, concept of electron energy loss spectra, Zero loss, plasmon, near edge spectrum
 - Fundamentals of energy filtering and its uses in life sciences
 - Near edge and far edge fine spectrum and their applications in determining energy states of material at atomic level.
 - Case studies for metallic bulk samples, life science samples, nano-materials
- **Physical and Thermal Characterization Techniques**
 - Thermal expansion: Method and their principle, Type of Dilatometers and their application for sintering studies, Estimation of Phase diagram
 - Thermal Conductivity: Method and their principle, advantages and limitations of each method, data of nuclear Fuels
 - TGA/DTA/DSC: Method and their principle and application for estimation of properties like Melting point, Transition Temperatures, Heat Capacity, Heat of Reaction, Oxidation behavior, Measurement of (O/M) ratio ,
 - Elastic Properties: Method and their principle and application for estimation of different properties like Elastic Modulus, Shear Modulus, Poisons Ratio, Bulk Modulus_ application of these properties for estimation of other parameters
 - Hardness: Different method and their principle and application for estimation of different properties like Softening Coefficient, Intrinsic hardness, Activation Energy of creep, Indentation Creep. Estimation of Fracture toughness of ceramics by indentation method

Course Outcomes:

This course will introduce the students to the domain of material characterization. The course will expose the students to the key areas of microscopic techniques like Optical Microscopy, Scanning electron microscope, Atom force microscope, scanning tunneling microscope and X-ray diffraction. The students will learn different physical and thermal characterization techniques.

EN714: Membrane Technology (25 Lecture Hrs)

Coordinators: Dr. A. K. Ghosh
(akghosh@barc.gov.in)

Course Details:

- **Fundamentals and Overview of Membrane Processes: (4)**

- Introduction, Membrane definition & characteristics of membrane Processes
- Merits and Demerits over conventional unit operations
- Classification and description of membrane processes; features and application areas
- Pressure driven membrane processes (MF, UF, NF, RO and Gas separation)
- Concentration gradient driven membrane processes (Dialysis, Forward Osmosis)
- Electro-membrane processes (Electro-dialysis, Bipolar Electrolysis, Membrane based Fuel cell)
- Membrane processes with phase changes (Pervaporation, Membrane distillation).

- **Novel Membranes**

- Advanced Polymeric membranes, Inorganic Membranes, Nano-composite membranes, Fuel cell membranes, Ion-exchange membranes, Gas Separation membranes
- Carbon nano-tubes based membranes for water desalination and purification.

- **Membrane Materials, Preparation and Characterization: (7)**

- Materials Selection: Physico-chemical properties, Mechanical and Chemical stability, Polarity and non-polarity, Molecular weight and molecular architecture
- Membrane preparation techniques - Phase-Inversion, In-situ polymerization, Track-etching etc.
- Membrane Casting Aspects for continuous casting; thin film coating for thin-film composite (TFC) membrane preparation using continuous coating machine.
- Casting parameters – its monitoring and adjustment, Types of defects and identification, Preparation chemistry of membranes.
- Membrane Characterization & Diagnostic Tools and Techniques
 - (a) Surface characterization: Pore size, pore size distribution, surface morphology (SEM) – surface charge (contact angle and zeta potential) – surface roughness (AFM)
 - (b) Bulk characterization: Porosity, mechanical strength, performance evaluation using standard test condition (permeability and selectivity).

- **Engineering and Design Aspects of Membrane Technology (8)**

- Transport through membranes - Preferential sorption - capillary model, Solution Diffusion model, Irreversible thermodynamics model.
- Derivation of basic transport equation for RO membranes
- Application of basic transport equations and solute transport parameters for predicting RO membrane performance
- Modeling and molecular dynamics simulations on membrane transport.
- Module designs and analysis – tubular, plate and frame, spiral wound and hollow-fiber, Concentration polarization and its effects on performance.
- Design Aspects of Membrane based plants.
- Pretreatment considerations, Water chemistry - turbidity, alkalinity, pH, hardness, dissolved silica and residual chlorine
- Fouling and Scaling – types and control, Scaling assessment parameters (SDI, MFI)

- Process design and system design for water desalination – Cascade arrangements of modules, High pressure pumps
- Energy considerations and Energy Recovery devices– pelton wheel, turbo-charger and pressure exchanger
- Membrane cleaning and protocols

- **Membrane Technology Applications (6)**

- Techno-economics of membrane desalination plant - seawater/brackish water
- Application potential and design considerations of membrane processes with regard to aqueous streams of nuclear fuel cycle.
- Hybrid membrane systems, Combo systems – membrane + conventional – for separation application
- Membrane Technology: Sustainable Solutions in Water, Health, Energy and Environmental Sectors
- Membrane technology for radioactive waste treatment.
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Course Outcomes:

This course will introduce the students to the fundamentals of membrane technology, types of membranes, preparation and characterization of membranes. The course will also expose the students to the engineering design aspects of membrane technology and its application to industrial systems.

References

1. Introduction to Membrane Science and Technology by H. Strathmann (2006)
2. Membrane Technology & Applications by Richard W Baker (2008)
3. Membrane Characterization by Nidal Hilaletal. (2017)
4. Membrane Separations Technology: Principles and Applications by R D Noble & S A Stern (2003)

EN715: Multi-Scale Material Modeling (30 Lecture Hrs)

Coordinators: Dr. M. K. Samal
(mksamal@barc.gov.in)

Course Details:

- **Part-1: Introduction and simulation at atomistic length scale (7 lectures)**

Concept of multi-scale materials modeling, Introduction to different length and time scales, Density function theory (DFT) and its linkage with MD simulations, Fundamentals of atomistic simulations, Interatomic potentials and different models, Locality of interatomic interactions, Equilibrium distribution of atoms, Energy minimization, Steepest-descent method, Conjugate gradient relaxation and global minimization method in MD simulations, Averaging over the configurational space using Monte Carlo simulation, Stochastic Monte Carlo process, Metropolis algorithm, Verlet and velocity Verlet algorithm, Stress definition in terms of virial stress, periodic boundary conditions, Stress Control, Temperature Control, Ensembles and extended systems, Nose-Hoover Thermostat, Dislocation core energy and Peierls stress calculation, Free energies of configurational States, Free energy of a vacancy in dislocation core, Transition pathways for rare events problem, Transition state theory.

- **Part-2: Dislocation dynamics simulations (8 lectures)**

Introduction to crystal dislocations, Perfect crystal structures, Lattices and bases, Miller indices, Burgers vector, Atomistic mechanisms of dislocation motion, Driving forces for dislocation motion, Conservative vs. non-conservative motion, Volterra model and Peierls–Nabarro (PN) model of dislocations, Elastic energy of the PN dislocation and misfit energy, Lattice resistance to dislocation motion, Non-locality of dislocation energy, Complex dislocation geometries, Line Dislocation Dynamics (DD) simulations, Nodal representation of dislocation networks and forces, Elastic energy, Core energy, work done due to forces on dislocations, Periodic boundary conditions in DD simulations, Nodal mobility functions, Time integration techniques, Example of simulation of a Frank-Read source, Tracking topological changes, Parallel simulations, Spatial Domain decomposition and dynamic load balance, Dislocations as Phase-Field Objects, Calculation of elastic and lattice energy, Elastic energy of eigenstrain fields, Ginzburg–Landau and Cahn–Hilliard equations, Example of solution of dislocation-solute interaction.

- **Part-3: Simulations considering mechanism of crystal plasticity (8 lectures)**

Introduction to crystal plasticity finite element (CPFE) simulations, constitutive models and hardening laws, Dislocation density-based constitutive laws, Geometrically necessary dislocations, Martensite formation and transformation-induced plasticity models CPFE, Decompositions of deformation gradient and entropy density, Constitutive relations of stress-elastic strain and temperature-reversible entropy, CPFE framework for simulation of deformation twinning, Simulation of displacive transformations in CPFE, Texture and dislocation density evolution, Concept of material damage in CPFE and length-scale bridging with micromechanical damage models.

- **Part-4: Micromechanics of deformation of ductile and brittle materials (7 lectures)**

Different types of damage in materials, Definitions and method for measurement, Damage description through micro and macro cracks, Cavity nucleation and growth and concept of ductile damage, Constitutive models for brittle and ductile damage, Concept of effective stress and isotropic damage variable, Hypothesis of strain, stress and energy equivalence to derive damage variable, Thermodynamic potential and dissipation inequality, Associated flow rule and damage evolution equations, Constitutive models for elasto-plastic isotropic damaged materials and method of integration, Example of damage in a bar specimen, Generalized anisotropic damage tensor and elastic-plastic constitutive model for anisotropic damaged materials. Introduction to cohesive zone modelling, Traction-separation laws and evaluation of softening parameters.

Course Outcomes:

This course will introduce the students to the domain of multi scale modeling with special emphasis on types of defects, their propagation and its effect on material properties. The course will expose the students to the simulation techniques involved in multi scale material modeling.

References

1. A. Satoh. Introduction to Practice of Molecular Simulation
2. Elsevier, 30 Corporate Drive, Suite 400, Burlington, MA 01803, USA, 2011 Edition, ISBN: 978-0-12-385148-2
3. A.S. Argon. Strengthening Mechanisms in Crystal Plasticity, Oxford University Press, 2008 Edition, ISBN 978-0-19-851600-2.
4. M.J. Field. A practical introduction to the simulation of molecular systems, Cambridge University Press, ISBN-13 978-0-521-85252-4, second Edition, 2007.
5. D, Hull, D.J. Bacon. Introduction to Dislocations. Butterworth-Heinemann, ISBN: 978-0-08-096672-4, Fifth Edition, 2011.

EN716: Emergency Preparedness and Response (29 Lecture Hrs)**Coordinators: Shri Probal Chaudhury
(probal@barc.gov.in)*****Course Details:***

- Natural Radioactivity in Environment;
- Biological Effects of Radiation;
- Transport of Radioactive material;
- Radiation Shielding & Criticality and control;
- Principles of defence-in-depth;
- Engineered Safety features;
- Nuclear Fuel Cycle and its Radiological impact on Environment;
- Physical Protection of Nuclear facilities;
- Safety and Security of Radiation Sources;
- Occupational Radiation Protection;
- Regulatory aspects of Nuclear facilities and Environment;
- Nuclear weapon effects (Blast, heat, Radiation and EMP);
- Nuclear/Radiological Accidents/Terrorism;
- Protection strategy for Nuclear/Radiological Emergency (NRE);
- General requirements for Emergency Preparedness and Response (EPR);
- Hazard Prediction and Analysis of Nuclear/Radiological Emergencies;
- International Nuclear and Radiological Event Scale;
- Decontamination (Personnel, Soil and Equipment);
- Systems and methodology for Radiological impact assessment;
- Mobile Monitoring methodology for Nuclear Emergencies;
- Principles of Emergency Planning and Response;
- Generic Intervention Levels and Operational Interventional Levels;
- Protective Measures for NRE;
- Radiological Emergency Preparedness and Response in Indian Context;
- Role of First Responders during Radiological Emergencies;
- Medical management of radiation injuries;
- Radioactive Waste Management;
- Regulatory aspects of Emergency Preparedness and Response; and
- Regulatory aspects of Occupational Radiation Protection.

Course Outcomes:

This course will introduce the students to the domain of types of radioactivity emergencies, effect of radiation on flora and fauna, radiation shielding and radiation control techniques. The course will expose the students to the techniques of radiation hazard analysis, decontamination techniques and methodologies for radiological impact assessment.

References

1. Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).
2. Preparedness and Response for a Nuclear or Radiological Emergency, General Safety Requirements, No. GSR Part 7, 2015
3. Nuclear Security Fundamentals, IAEA Nuclear Security Series No. 20, IAEA, Vienna (2013).
4. The 2007 Recommendations of the International Commission on Radiological Protection, Publication 103, Elsevier, Oxford and New York (2007).
5. Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSG-2, IAEA, Vienna (2011).
6. Planning and Preparing for Emergency Response to Transport Accidents Involving Radioactive Material, IAEA Safety Standards Series No. TS-G-1.2 (ST-3), IAEA, Vienna (2002).
7. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).
8. Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, IAEA, Vienna (2011).
9. Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control, IAEA Nuclear Security Series No. 15, IAEA, Vienna (2011).
10. Convention on Early Notification of a Nuclear Accident and Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Legal Series No. 14, IAEA, Vienna (1987).
11. INES: The International Nuclear and Radiological Event Scale User's Manual, 2008 Edition, IAEA, Vienna (2013).
12. Dangerous Quantities of Radioactive Material (D-values), Emergency Preparedness and Response Series, EPR-D-VALUES 2006, IAEA, Vienna (2006).

EN717: Project Management (25 Lecture Hrs)**Coordinators: Shri. Arindam Pal
(apal@npcil.co.in)****Course Details:**

- Definition of a Project, type of project, cost & schedule of Nuclear Power Projects.
- Definition of Planning, importance of planning in a Project
 - Resources of project.
 - Project Organization Chart, functions of different units of construction
- Contract packages: Types of, Tendering requirements action steps, delegation of power in a project.
- Scheduling in a project by PERT: resource requirements, resource allocation for an activity, constraints for an activity, earliest start time EST, latest completion time LCT.
 - Scheduling in a project by critical path method, CPM
 - Scheduling in a project by Precedence Diagram Method.
 - Use of Project Management Software for project planning, scheduling & monitoring.
 - Preparation of master control management milestone network, Level-1,2, 3 & 4 network.
- Preparation of Target Plan, updating of progress, monitoring variance & reporting
 - Constraints of project and its effective management
 - Development of Six-Monthly Plan and its review process
 - Resource based planning
 - Physical & Financial Monitoring of project, Use of S-curve
 - Capital Budgeting & expenditure control in a project
 - Daily, weekly & monthly progress reporting
- Verification of project data and their analysis, type of float/slack, critical path and near critical path.
- Agenda for the daily, weekly & monthly meeting, record of the meeting.
- Contingency plan.
- Construction Interface with different Units of Construction.
- Construction Management, Project Management, Project management Software Tools.
- Management Milestones, Incentive Milestones.
- Daily work plan. Target evaluation. Supervision. Target review meet. Mid course correction. ERP, ERM. Analysis method, SWOT analysis.
- Problem Solving techniques, RCA, Activity network preparation.

Course Outcomes:

This course will introduce the students to the domain of project management, different techniques for scheduling the project activities and project monitoring. The course will expose the students to the key aspects of project monitoring, reviewing and rescheduling.

References:

1. NPCIL NU-Power publication on Effective role of Planning in TAPP-3&4
2. IAEA technical report series no 279: Nuclear Power Project Management-A Guidebook
3. Primavera Project Planner/MS project Reference Manual
4. Applicable training manual

EN718: Reliability Engineering (ME) (25 Lecture Hrs)**Coordinators: Dr. (Smt) Gopika Vinod**
(vgopika@barc.gov.in)**Course Details:****• Part-1: Introduction:**

Bayesian method, Functions of Random Variables, Elements of Component Reliability, Definition of reliability, Availability and risk, Basic Component reliability model, Failure rate & hazard rate, Life testing, Component reliability.

• Part-2: Limit state and probability of failure

Reliability in Engineering Design, Limit state, Joint probability density function, Probability of failure, Calculation by numerical integration, simulation and sampling techniques, Monte Carlo simulation method, Directional simulations, Generation of Uniform Random Number, Generation of Normal Random Number, General procedure of generating random numbers from an arbitrary distribution, Importance sampling, Latin Hypercube Sampling and other techniques.

• Part-3: Method to estimate reliability of component

Accuracy of probability estimates, Reliability Index, first order method such as projected gradient method, Penalty function method, Augmented Lagrangian method, First order second moment reliability index, Hasofer-Lind Reliability Index, Rackwitz-Fiessler procedure, Second order algorithms such as Newtons method, Correlated random variables, SORM with Adaptive approximations, Code calibration and evaluation of partial safety factors, Load-resistance model.

• Part-4: Reliability-based structural optimization

Reliability-based structural optimization, Feasible directions algorithm, Penalty function method, Design variable linking and reduction of number of constraints, Stochastic expansion for probabilistic analysis, Polynomial chaos expansion, Stochastic approximation and non-Gaussian random variable generation, Introduction to stochastic FEM.

• Part-5: System reliability and PSA

System Reliability Analysis – Elements and systems, series and parallel systems, Reliability bounds on structural systems, Failure mode and Effect analysis, Reliability block diagram, Redundancy techniques in system design, Fault tree and Event tree analysis, Reliability and availability of repairable systems, Application of Reliability - PSA of nuclear plants, Identification of initiating event, Event sequence modeling, system modeling, input data analysis including common cause failure and human reliability data quantification, determination of core damage frequency and its significance. Internal and external events, Reliability centered maintenance, Risk based in-service inspection strategies, important measures, Risk based ranking matrix.

Course Outcomes:

This course will introduce the students to the domain of theory of probability and its relationship with reliability of SSCs, methods and techniques for reliability assessment and system reliability analysis based on PSA.

References:

1. Mishra, K.B., "Reliability Analysis and Prediction", Elsevier, 1992.
2. Shooman, Martin L., "Probabilistic Reliability: An Engineering Approach", McGraw Hill, 1968.
3. Modarres, M., Reliability & Risk Analysis, Marcel Dekker, 1993.
4. Kapoor, K.C., and Lamberson, L.R., "Reliability in Engineering Design", John Wiley & Sons, 1977.
5. Balaguruswamy, E., "Reliability Engineering" Tata Mcgraw-Hill, 1984.
6. Provan, J.W., "Probabilistic Fracture Mechanics & Reliability", Martinus Nijhoff, 1987.
7. Nowak, A.S. and Collins, K.R., "Reliability of Structures" McGraw Hill, 2000.
8. Ayyub, B.M. and McCuen, R.H., "Probability, Statistics and Reliability for Engineers", CRC Press, 1997.

EN719: Signal Conditioning, Recovery & EMI Aspects (30 Lecture Hrs)

Coordinators: Dr. Sanjay Malhotra
(sanjaym@barc.gov.in)

Course Details:

- **Review of Analog Signal Conditioning & Recovery Techniques**

Conditioning raw signals from transducers, signal extraction from a common mode reference, Error budget in Signal Conditioning circuits, Recovery of Signal buried in Noise, Phase Lock Loops, Lock-in Amplifiers, Noise Equivalent circuits of Pre-amplifiers, Pulse Amplifier designs, Active Filter Design, Types of A/D and D/A converters, nature of errors in the devices, advances in A/D and D/A technology, Sigma-Delta converters.

- **Theory of Quantization**

Theory of analog to digital conversion, analysis of quantization errors, theory of digital to analog conversion, application of decimation and interpolation to A/D and D/A conversion, over-sampling, design of digital anti-aliasing filters, fast algorithms for implementation.

- **Theory of Signal Analysis and Reconstruction**

Function space, orthogonal basis functions, Limitation of Shannon's theorem, Reconciliation by approximation in shift invariant space, generalized basis functions, analysis and reconstruction with B-spline basis, wavelet basis, bi-orthogonal wavelet (dual) basis, consistent estimate (sampling), Interpolating wavelets, perfect reconstruction with wavelets, over-sampling, multi-scale characterization from extremas in wavelet domain.

- **Review of EMI Aspects**

Introduction to Electro-Magnetic Interference, EMI sourcing circuits, Capacitance Coupling, Inductance Coupling, Noise Reduction Technique, Shielding, Shielding materials for electro-static coupling & electro-magnetic coupling, Shielded Cables, Use of Twisted cable pairs, Equipment Shields, Grounding, Various grounding schemes, Schemes for Instrumentation Grounding in Reactors, Design for Electro-magnetic Compatibility, Overview of EMI Test Standards for Systems in Nuclear Installations, Testing Standards for Emissivity & Susceptance, Anechoic chambers.

- Introduction to Modeling Method and Tools

- **EMI Modeling**

Propagation of EM waves, Antenna theory, Synthesis of Radiation Patterns, Waveguide theory, Coupling & Reflection, Reflective Surfaces, Source-term modeling, Susceptance Modeling, EM Topology.

Course Outcomes:

This course will introduce the students to the domain of signal conditioning, noise analysis, recovery of signal, A/D and D/A conversion techniques. The course will expose the students electromagnetic interference, causes and remedies.

EN720: Software Engineering (25 Lecture Hrs)

Coordinators: Dr. Ajith John
(ajith@barc.gov.in)

Course Details:

- Introduction: Importance of software engineering, software characteristics, life cycle and models, phases, processes, work-products of different phases (1)
- Analysis and Design I: Data models, Functional modeling, structured analysis and design, design attributes and metrics. CASE tools. (3)
- Analysis and Design II: Object oriented method, Unified Modeling Language (UML), notion of objects, classes, attributes, Method, interfaces, associations, generalisation, composition, polymorphism. Modeling structure and behavior.
- Use case diagrams, class diagrams, state diagrams, sequence diagrams. architectural and detailed design. Modeling real-time software. Introduction to Object Oriented languages. CASE tools.(10)
- Software Quality Assurance: Quality attributes, metrics, reliability, SQA activities(3)
- Verification and Validation: Reviews, inspection and walk-through, Static analysis, formal method Testing principles, unit testing, integration testing, acceptance testingUnit testing: black box testing, white box testing – coverage criteria, Equivalence class partitioning, boundary value testing(2)
- Software Configuration Management: Configuration items (with examples), baselines, libraries, version control. (2)
- Software engineering standards (2)

Course Outcomes:

This course will introduce the students to the fundamentals of software engineering with special emphasis on data models, analysis and design methods, quality assurance, verification and validation techniques. The course will expose the students to software engineering standards also.

EN721: Vibrations (25 Lecture Hrs)

Coordinators: Shri. M. K. Agarwal
(mkagra@barc.gov.in)

Course Details:

- **Part-1: Vibrations Theory, Analysis Method, Earthquake loads, Flow-Induced-vibrations (13 lectures)**
 - **Single-degree-of-Freedom (SDOF) Systems:**
 - Free vibration equation of motion and its solution for undamped and damped conditions, Concept of natural frequency;
 - Material and structural damping – evaluation of damping in SDOF systems;
 - Response to general dynamic loading – Duhamel's Integral.
 - **Multi-Degree-of-Freedom (MDOF) Systems:**
 - Equations of motion – Lumped mass and distributed parameter systems;
 - Eigen value problem, concepts of Eigen values and eigen vectors;
 - Normal mode vibrations - Free and forced; Orthogonality conditions; Mode superposition method
 - Direct integration method; Vibration of continuous systems;
 - **Earthquake Ground Motion:**
 - Earthquake motion – Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE); Magnitude and Intensity of an earthquake;
 - Design Basis Earthquake – Design Time History and Design Response Spectra;
 - **Response of SSCs to earthquake loading-Analysis Method:**
 - Response Spectrum Method and Time History Method of Analysis – Concept of Mode participation factor, modal Combination and spatial combination rules;
 - Introduction to Seismic design of equipment and piping systems as per ASME Sec.III Appendix-N and IS-1893 code
 - Sloshing load consideration for vessels / tanks
 - **Flow Induced Vibrations (FIV)**
 - Fluid-Flow across smooth circular cylinder and in an array of cylinders; Strouhal number, Added Mass;
 - Models and analysis for vortex-induced Vibration;
 - Sources of Vibration in pipes containing fluid;
 - **Lab visit: video-demonstration of vibration and shake table tests, experimental evaluation of frequencies and damping values**
- **Part-2: Rotor Dynamics and Balancing (6 lectures)**
 - **Rotor Dynamics:**
 - Basic Concept: a) Critical speed, b) Unbalance response; Whirling of rotating shaft – Jeffcott rotor;
 - Phase-amplitude relationship, effect of damping;
 - Amplitude buildup at critical speed;
 - Effect of support flexibility;
 - Performance verification of rotating machinery.
 - Concept of vibration absorption, isolation and dampers, transmissibility and isolation efficiency

- **Dynamic Balancing:**
 - Static and Dynamic unbalance;
 - Single plane and two plane balancing;
 - Sources of unbalance;
 - Method of mass correction and balancing practice;
 - Balancing quality standards and specification for rotors;
 - Classification of rotors and type of balancing required.
- **Part-3: Vibrations Measurement, Signal Analysis and diagnostics (6 lectures)**
 - **Vibrations Measurement:**
 - Types of transducers, their principle and application ranges; Accelerometer, Eddy current transducer and LVDT, Modes of vibration measurement (Displacement, Velocity and acceleration);
 - **Signal Analysis:**
 - Characterization of periodic, a periodic and random signal; Fourier Spectrum, Power spectrum, Cross-power spectrum, Coherence, auto and cross-Correlation and significance of these parameters;
 - **Condition monitoring and diagnostics**
 - **Vibration standards for acceptance**
 - **Lab visit: Demonstrations on vibration measurements and Signal Analysis tools, video demonstration on condition monitoring and diagnosis**

Course Outcomes:

This course will introduce the students to the domain of theory of vibration, method of analysis and its application to seismic analysis of SSCs. The course will also expose the students to the fundamentals of flow induced vibration and rotor dynamic analysis. The students will get hands on experience to vibration measurement, signal processing, signal analysis and acceptance criteria as per vibration standards and codes.

References:

1. Den Hartong J.P., "Mechanical Vibration", Mc-Graw Hill Book Co., 1956.
2. Meirovitch L., "Elements of Vibration Analysis", McGraw Hill Book Co., 1986.
3. Meirovitch L., "Analytical Method in Vibration", MC Millan Co., 1967.
4. Rao J.S., "Rotor Dynamics", John Wiley and Sons, 1991.
5. Blevins R.D., "Flow Induced Vibration", Von Nostrand Co., 1977.
6. Clough R.W., and Penzian J., "Dynamics of Structures", McGraw Hill Book Co., 1989.
7. "ASMEBoiler and Pressure Vessel Code", Sec.III, Appendices 1986.
8. "Vibration Measurement", By Gheorghe Buzdugan.
9. "Machinery Vibration Measurement and Analysis", By Victor Wowk.
10. "Vibration for Engineers", By A.D Dimahogones.
11. "Vibration Analysis and Measurement", By J.D.Smith.
12. "Vibration Analysis", By Steve Goldman.
13. "Vibration Primar", By M.Jackson.
14. "Vibration in Rotating Machinery", By H.R. Martin.
15. "Mechanical Vibrations", By Singiresu S.Rao.

EN722: Safety and Reliability of Civil Engineering Structures (25 Lecture Hrs)

Coordinators: Dr. K. Bhargava
(kapil_66@barc.gov.in)

Course Details:

- **Introduction to Probability Theory**

Set theory, statistics and probability, failure and success, reliability terminology, safety and reliability, maintainability, availability, Probability Distributions: continuous and discrete random variables, Binomial, Geometric, Poisson, Normal, Lognormal, Exponential, Weibull, Gumbel.

- **Structural Reliability**

Loads and strength, concept of probability failure and structural safety, Limit State, Monte Carlo Method, simulation of random variables, Cornell Reliability Index, Mean Value First Order Second Moment method, Hasofer Lind Reliability Index, Rackwitz Fiessler method, Treatment of correlated random variables, Partial Safety Factors and their estimation, system failure probability, case studies.

- **Probabilistic Safety Assessment**

Probabilistic Seismic Hazard Assessment, Source models, Ground motion prediction models, Seismic fragility analysis of components, system analysis for seismic risk, safety assessment with respect to external events such as Tsunami & Flood

- **Industrial Safety**

Consideration of industrial safety aspects in layout and design of buildings, fire hazard analysis, fire protection, fire prevention and firefighting, safety in handling machinery, equipment and tools, organizational aspects of industrial safety, fitness and protection of personnel.

- **Safety assessment of existing structures**

Health assessment of concrete and steel structures, rehabilitation and retrofitting of structures, service life prediction.

- **Introduction to decommissioning of structures**

Course Outcomes:

This course will introduce the students to the domain of theory of probability and its application to structural reliability assessment and PSA of System, Structures and Components (SSC). The course will expose the students to the key aspects of industrial safety in layout and design of buildings.

References:

1. Hahn, G. J. and Shapiro, S. S. (1994), "Statistical Model in Engineering" Wiley-Interscience.
2. Ranganathan, R. (2000), "Reliability analysis and design of structures", Jaico Publishing House.
3. PRA procedure guide NUREG/CR2300/Vol. 1&2 (1983), "A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants", The American Nuclear Society.
4. AERB(1990), Code of Practice on Design for Safety in PHWR based Nuclear Power Plants, AERB/SC/D
5. AERB (1998), Civil Engineering Structures – Important to Safety of Nuclear Facilities, Safety

Standard No. AERB/SS/CSE.

6. AERB (1996), “Atomic Energy (Factories) Rules”.
7. AERB (1991), “Safety Guide for Works contract”, Safety Guide No. AERB/SG/IS-1
8. AERB (1996), “The guidelines for refurbishing work of Civil Engineering Structures of CIRUS Reactor Complex”, Report prepared by Civil Engg. Safety Committee for Operating Plants (CESCOP),AERB
9. ASCE 43-05 (2005) “Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”.
10. Regulatory Guide 1.165 (1997), “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion”, U.S. Nuclear Regulatory Commission.
11. AERB/NPP/SM/CSE-2, (2004), In-Service Inspection Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants
12. AERB/SM/CSE-1, (2002), Maintenance Of Civil Engineering Structures Important To Safety Of Nuclear Power Plants

EN723: Welding Science and Technology (MT) (20 + 5 practical/demonstrations)**Coordinators: Dr. Laik
(laik@barc.gov.in)****Course Details:**

- Overview of welding processes
- Cold Bonding/Solid State Bonding
- Arc Welding Processes
- Beam Welding Processes
- Arc-Beam Hybrid Welding Processes
- Study of welding arc characteristics
- Metal transfer during arc welding
- Heat flow during welding
- Gas-metal and slag-metal reactions
- Weld pool solidification
- Effect of welding process parameters on the macro- and micro-structure of weld metal
- Thermal cycles in the heat affected zone
- Phase transformations in the weld metal and the heat affected zone
- High power density processes such as laser and electron beam welding
- Welding metallurgy under high cooling rates
- Phenomena of hot-cracking and cold cracking
- Residual stresses and distortion during and after welding
- Residual stress measurements
- Application of above principles to welding of carbon and alloy steels, cast irons, stainless steels, aluminium and titanium alloys.

Course Outcomes:

This course will introduce the students to the domain of different welding techniques and process involved therein. The course will expose the students to the effect of welding process parameters on weld quality.

References:

1. K. Easterling, Introduction to Physical Metallurgy of Welding, Butterworths Pub., 1983.
2. Sindo Kou, Welding Metallurgy, John Wiley & Sons, New York, 1987.
3. S.A. David (Ed.), Advances in Welding Science and Technology, American Society for Metals, Ohio, 1986.
4. R. W. Messler, Principles of Welding: Processes, Physics, Chemistry, and Metallurgy, Wiley-VCH Verlag GmbH & Co. KGaA
5. W. M. Steen and J. Mazumder, Laser Material Processing, 4th Edition, Springer

EN724: Radiation Damage of Metals and Alloys (ME & MT) (25 Lecture Hrs)**Coordinators: Dr. S. Neogy**
(neosuman@barc.gov.in)**Course Details:****• Radiation Damage Event (5 lectures)**

Projectile (electron, neutron, light and heavy ions)–Nucleus Interactions, Energy Loss Theory, Energy Transfer Cross Sections, Range Calculations, Displacement of Atoms (Displacement Theory, Displacement probability, Damage Cascade, Displacement Cross Section, DPA calculation models).

• Point Defect Formation and Reaction (5 lectures)

Freely Migrating Point Defect Formation, Defect Configurations (Loops, Network Dislocations, Voids, Bubbles, SFT), Radiation-Enhanced Diffusion, Defect Reactions (Recombination, Loss to Sinks, Sink types), Point Defect Balance Equations, Radiation-Induced Segregation.

• Irradiation Effect on Microstructure and Mechanical Property (5 lectures)

Recoil Dissolution, Radiation-Induced Precipitation, Radiation Disorder, Metastable Phases, Amorphization, Composition Changes, Irradiation Hardening, Embrittlement, Swelling, Irradiation Creep and Growth, Irradiation effect on corrosion.

• Simulation of Neutron Irradiation (5 lectures)

Ion Irradiation as Surrogate for Neutron Irradiation, Use of SRIM, DPA estimation in reactor materials, Irradiation Experiment Parameters, Irradiation facilities, Radiation Damage Assessment (microstructural and mechanical property characterization techniques), Numerical techniques, Case Studies.

• Post-irradiation Characterization of Neutron Irradiated Fuel and Structural Materials (5 lectures)

Neutron irradiation induced changes in microstructure, mechanical properties (strength, ductility, fracture toughness), Fluence Measurement, Chemical Analysis.

Course Outcomes:

This course will introduce the students to the domain of radiation induced damage, mechanisms of radiation damage and its effect on microstructure and mechanical properties of material. The course will expose the students to different simulation techniques and post irradiation characterisation of materials.

EN725: Molecular Engineering (CH & MT) (20 lectures+5 tutorials)

Coordinators: Dr. S. K. Musharaf Ali
(musharaf@barc.gov.in)

Course Details:

- **Basics of Electronic Structure Theory**

Basics of Quantum Mechanics, Wave Function based method including Hartree, Hartree-Fock (HF) and post-HF, Basis sets including Gaussian, Slater and LCAO, Density Functional Theory (DFT), Different approximations to exchange-correlations

- **Basics of Statistical Mechanics**

Basic postulates of Statistical Mechanics, Macroscopic and Microscopic States, Ensembles, Thermodynamics, Time average and Ensemble Average, phase space and trajectories; distribution functions, partition functions, Time Correlation function, velocity integration techniques: Verlet and leapfrog algorithms.

- **Method of Computer Simulations**

Electronic Structure Calculation (ESC), Monte-Carlo (MC), Classical Molecular Dynamics (CMD), Ab-initio Molecular Dynamics (AIMD), Reciprocal space, Bloch Theorem, Band Structure Method

- **Molecular Modeling: Applications and Examples**

Thermodynamic properties, radionuclide separation, Glasses for radionuclide immobilization, Hydrogen storage, Hydrogen production using water splitting, catalysis, crystallization, stacking-fault energies, order-disorder phase transformations, radiation damage to materials (defect formation and migrations), nano-fluidic.

- **Software introduction and Tutorials/Hands-on sessions**

TURBOMOLE, Quantum Espresso, GROMACS, LAMMPS, COSMOTerm & pre- and post-processing toolkits, e.g., MOLDEN, ATK, VMD, VNL

Course Outcomes:

This course will introduce the students to the domain of electronic structure theory and statistical mechanics. The course will expose the students to the key areas of computer simulation methods aimed at molecular modeling,

References:

1. Computational Chemistry (Oxford Chemistry Primer) G. H. Grant and W. G. Richards (Oxford University Press)
2. Molecular Modeling – Principles and Applications, A. R. Leach (Addison Wesley Longman)
3. Introduction to Computational Chemistry, F. Jensen (Wiley)
4. Essentials of Computational Chemistry – Theories and Models, C. J. Cramer (Wiley)
5. Exploring Chemistry with Electronic Structure Method, J. B. Foresman and A. Frisch (Gaussian Inc.)
6. Quantum Chemistry, Ira N Levine, Pearson Education
7. Solid state physics, Ashcroft, Neil W.; Mermin, N. David (1976). New York: Saunders College Publishing.

8. Introduction to solid state physics, C. Kittel, Wiley India Edition, January 2019
9. Electronic Structure: Basic Theory and Practical Method, Richard M. Martin, University of Illinois, Urbana-Champaign
10. Density-Functional Theory of Atoms and Molecules, R. Parr and W. Young, Oxford University Press
11. Computer Simulation of Liquids, D. J. Tildesley and M. P. Allen
12. Understanding Molecular Simulation, Daan Frenkel, Berend Smit, Academic Press

SKILL ENHANCEMENT & ASSESSMENT

EN591: Viva Voce (200 Marks)

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

EN592: Practicals (100 Marks)

EN592.1: Process Control Trainer

This module is aimed at introducing the trainees to the Feedback Control Systems and providing them with hands-on experience on a process control trainer. It comprises a series of experiments as detailed below.

- **Expt 1**
 - Introduction to typical processes under control – a boiler with drum pressure as feedback parameter and fuel flow as controlled parameter.
 - Elements of control loop. Sensor, controller, final control element. Study of process response with P, PI and PID control.

- **Expt 2**
 - Optimisation of process control - using ultimate sensitivity method.
 - Critical gain and critical period for the process is found by increasing controller gain till sustained sinusoidal oscillations are set with constant amplitude.
 - Optimum gain and integral / differential time constants are calculated using empirical formulae.

- **Expt 3**
 - Feed forward control configuration - study of process response in comparison with normal feedback control. Steam flow is used as an additional parameter to implement feedforward – feedback configuration.

- **Expt 4**
 - Smart Differential Pressure transmitter.
 - Study the transfer characteristics – pressure v/s current output. Calibrate transmitter for a given pressure range.
 - Re range transmitter using HART communicator.
 - Re configure transmitter for linear and square root characteristics.

- **Expt 5**
 - Final control element - Linear pneumatic control valve.
 - Study of transfer characteristics - percentage of flow rate v/s opening of valve. Discussion on types of control valve and salient specifications.
 - Virtual instrumentation and wireless data communication between controller and PC.

EN592.2: Nuclear Detectors

- A series of experiments are carried out by the trainees to make them conversant and proficient in the handling of equipment for 'Nuclear Radiation Detection and Measurements'.
- NaI(Tl) γ - Ray Scintillation Detector
- This experiments imparts training on the use of NaI(Tl) detector using known γ - Ray sources (Co^{60} & Cs^{137}), plotting of calibration curves and identification of unknown sources.
- α -Particle spectroscopy using a Solid-State Detector
- This experiment imparts training on the use of the Solid-State Detector using known α -Particle source (Th^{229}), plotting of calibration curves and determination of the thickness of a Mylar Foil using the experimental setup.

- **Gieger-Muller Counter**

This experiment imparts training on the use of the G-M counter using known sources, studying plateau of the G-M counter, testing counting statistics of the counter and studying absorption behaviour of β -rays emitted from Tl^{204} for finding the Half Value Layer thickness of Al.

EN593: Mini-Project Work (300 Marks)

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

The trainee compiles a project report highlighting the scope, Method and deliverables of the project followed by a seminar presentation to an expert committee of the work carried out. The Mini-Project carries a weightage of 300 Marks, 150 being awarded by the expert committee and 150 by the guide.). Project runs on a part time basis for 11 weeks from mid April to Mid July.