MASTER of NUCLEAR ENGINEERING

CURRICULUM

1ST SEMESTER

Theoretical Courses	**Subjects**		***Periods/Week***		***Marks***		***Credit Points***
Departmental Basket	Subject Code	Subject Name	*Lecture*	*Sessional*	*Exam*	*Sessional*	
Paper I	PG/NuE/T/111A	Analytical and Computational Tools in Nuclear Engineering	3		100		3
Paper II	PG/NuE/T/112A	Reactor Physics & Engineering I	3		100		3
Paper III	PG/NuE/T/113A	Concepts in Nuclear Science	3		100		3
Note: Students have to select 3 subjects from the departmental basket (Paper I, Paper II & paper III)							
Inter-disciplinary Basket	Subject Code	Subject Name	*Lecture*	*Sessional*	*Exam*	*Sessional*	
Paper IV	PG/NuE/T/114A	Reactor Control Engineering	3		100		3
		Any other subject from the inter-disciplinary basket of ME, EE, PE, CE, ETCE, IEE, MetE Deptts.					
Paper V	PG/NuE/T/115A	Nuclear Chemical Engineering	3		100		3
	PG/ME/T/115B	Basics of Finite Element Method					
	PG/ME/T/115C	Experimental Methods in Mechanical Systems					
	PG/EE/T/115A	Active Circuits and Systems					
		Any other subject from the inter-disciplinary basket of ME, EE, PE, CE, ETCE, IEE, MetE Deptts.					
Paper VI	PG/ETCE/T/116A	Digital Signal Processing	3		100		3
	PG/ME/T/116C	Fracture Mechanics					
	PG/ME/T/116H	Heat and Mass Transfer					
		Any other subject from the inter-disciplinary basket of ME, EE, PE, CE, ETCE, IEE, MetE Deptts.					
Note: Students have to select 3 subjects (one each) from the interdisciplinary basket (Paper IV, Paper V & Paper VI)							
Sessional Courses	**Subject Code**	**Subject Name**	***Lecture***	***Sessional***	***Exam***	***Sessional***	
Sessional 1	PG/NuE/S/111	Laboratory		3		100	3
Sessional 2	PG/NuE/S/112	Seminar		3		Marks to be added at the end of 2nd semester	
			18	**6**	**600**	**100**	**21**

Total Periods/Week = 24 Total Marks = 700

2nd SEMESTER

Theoretical Courses	Subjects		Periods/Week		Marks		Credit Points
Departmental Basket	Subject Code	Subject Name	*Lecture*	*Sessional*	*Exam*	*Sessional*	
Paper VII	PG/NuE/T/127A	Reactor Physics & Engineering II	3		100		3
Paper VIII	PG/NuE/T/128A	Non-linear and Adaptive Control	3		100		3
	PG/NuE/T/128B	Nuclear Environmental Engineering					
	PG/NuE/T/128C	Corrosion and Material degradation under Reactor Environment					
	PG/ME/T/128E	Design of Industrial Pressure Vessels					
	PG/ME/T/128F	Two-phase Flow, boiling and Condensation					
Paper IX	PG/NuE/T/129A	Integrity Analysis of Nuclear Reactor Components	3		100		3
	PG/NuE/T/129B	Separation Science and Engineering					
	PG/NuE/T/129E	Nuclear and Reactor Instrumentation					
	PG/NuE/T/129F	Reactor Thermal Hydraulics					
Note: Students have to select 3 subjects (one each) from the departmental basket (Paper VII, Paper VIII & paper IX)							
Inter-disciplinary Basket	Subject Code	Subject Name	*Lecture*	*Sessional*	*Exam*	*Sessional*	
Paper X	PG/ME/T/1210E	Microscale Heat Transfer	3		100		3
	PG/PE/T/1210A	Real Time Embedded Systems					
	PG/NuE/T/1210A	Nuclear Materials					
		Any other subject from the inter-disciplinary basket of ME, EE, PE, CE, ETCE, IEE, MetE Deptts.					
Note: Students have to select 1 subject from the interdisciplinary basket (Paper X)							
essional Courses	**Subject Code**	**Subject Name**	***Lecture***	***Sessional***	***Exam***	***Sessional***	
Sessional 1	PG/NuE/S/121	Term Paper leading to Thesis		3		100	3
Sessional 2	PG/NuE/S/122	Seminar		3		200	6
			12	**6**	**400**	**300**	**21**

Total Periods/Week = 18 Total Marks = 700

3rd & 4th SEMESTER

Subject Code	Subject Name	*Lecture*	*Sessional*	*Exam*	*Sessional*	
PG/NuE/TH/21	Thesis Work		16		300	12
PG/NuE/VV/22	Viva-Voce on Thesis				100	
			16		**400**	**12**

Total Periods/Week = 16 Total Marks = 400

*ME: Mechanical Engineering; EE: Electrical Engineering; PE: Power Engineering; CE: Chemical Engineering; ETCE: Electronics & Telecommunication Engineering; IEE: Instrumentation & Electronics Engineering; MetE: Metallurgical and Material Engineering

SYLLABUS

1st SEMESTER

Analytical & Computational Tools in Nuclear Engineering (PG/NuE/T/111A)

Matrices & Determinants:	Review basics of Matrices and Determinants, Properties of Matrices, Linear dependence of vectors, Gaussian elimination, Eigen values and Eigen vectors – Solve problems using numerical tools (MATLAB etc.)
Functions of 2 variables:	Discuss Maximization and Minimization of Functions of Two Variables: Lagrange Multipliers
PDEs:	General discussion of Partial Differential Equations, Solve PDEs by separation of variables method; Assignments with MATLAB PDE toolbox
Special Functions:	Discussion on Legendre Polynomial, Bessel Function, Gamma Function
Transforms:	Explanation of Laplace transforms, Review the basics of Fourier series and discuss Fourier transforms, Solve ODEs using transforms.
Vector Calculus:	Discussion on directional derivatives: Divergence and Curl, Laplacian Line Integrals and Surface Integrals: Stokes and Divergence Theorems. Curvilinear co-ordinates.
Numerical Solution of ODEs	Analyzing Euler and Runge-Kutta Methods (Explicit & Implicit), Solution of higher-order differential equations, Concepts of Convergence & Stability Stiff Systems
Matrix methods:	Application of numerical methods for handling matrices, ill-conditioned and sparse matrices.
Interval Mathematics:	Introduction to Interval Mathematics; Assignments with INTLAB

Reactor Physics and Engineering I (PG/NuE/T/112A)

Basics:	Concepts of neutron flux, neutron production, moderation and absorption. Neutron multiplication in a homogeneous medium, Derivation of four factor formula. Slowing down power and

moderating ratio, Comparison of over and under-moderated reactors, Slowing down with spatial migration, Explanation of Fermi age, Migration length, Multizone reactors.

Neutron transport: Explanation of Fick's law and its validity, Derivation of steady state neutron diffusion equation, concepts of life-time, reproduction time, slowing down length, Scattering (elastic and inelastic scattering). Assignments involving numerical solution of neutron transport.

Neutron Diffusion: Neutron diffusion (Comparison of treatment of one group neutrons in non-multplying and multiplying media, infinite and effective multiplication factors, buckling (material and geometric), six-factor formula, Determination of neutron flux in a homogeneous medium with various geometries, with and without source, non-leakage probability in bare homogenous cores, neutron cycle and lifetime in finite reactor reactors with and without reflector, reflector saving, form factor. Idea of blanket.

Criticality: Definition of criticality, subcriticality and super criticality, critical mass, Identification of criticality conditions for different reactor geometry, Approach to criticality and numerical criticality search.

Heterogeneous reactors:
Multigroup neutron diffusion with special reference to 2 group approach, heterogeneous reactors, Comparison with homogenous reactors, unit cell concepts,

Neutronics & Reactivity:
Time-dependent neutron diffusion equation, one group kinetic equation, Reactivity and its units. Role of Prompt and delayed neutrons, groups of delayed neutron precursors, point kinetic equations to illustrate the importance of delayed neutrons, reactor period, In-hour equation. Temperature coefficient of reactivity and void coefficient of reactivity, their relevance to reactor safety.

Core burnup and poisons: Burnup equations including fission products, neutron poisons, burnup dependent lattice parameters and their variation. Comparison between Xenon and samarium poisoning. Xenon loads (operating and post shut-down), variation of xenon load with power and enrichment, xenon oscillations and their control.

Reactor Engineering: Relationship between neutron flux and reactor power. Outline of basic reactor types and classification of reactor types and reactor generations. Comparison between BWR, PWR, PHWR, AGCR, FBR, HTGCR, AHWR and other types of research and power reactors, Explanation of the concept of Breeding: breeding ratio and breeding gain, fast and thermal breeders, Fast breeder reactors, Thorium breeders. Typical nuclear plant systems and components. Reactor fuel, cladding, moderator, coolant, control rods. Typical reactor systems - heat removal, steam generation, control, fuel handling, power regulation and shutdown. Case studies using special reference to CANDU, FBR, AHWR.

Reactor heat transfer: Basic principles of heat generation, heat sources and distribution; Explanation of the steps involved in heat removal from reactor systems. Comparison of Heat flow & temperature distribution in plate & solid cylindrical, fuel elements; Analysis of 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. Explanation of the significance of KdT with example. Evaluation of Axial clad surface & coolant temperature distribution in fuel channel and identification of maximum clad surface temperature and its location with a solved example.

Economic comparison of differ coolants based on pumping & heat removal capability. Assessment of boiling in reactor system - critical heat flux & burnout phenomena, heat and mass balance, boiling height, evaluation of heat transfer coefficient in reactor systems. Identification of suitable reactor materials from a review of fuel, coolant, moderator, clad etc. thermal properties in various reactor systems.

Reactor Control: Outline of various techniques to control reactors, typical reactivity balance, long-term burnup, fuel management, Reactor control system, requirements from physics aspects. Reactor shutdown mechanisms and neutron monitoring during operation and shutdown.

Concepts in Nuclear Science (PG/NuE/T/113A)

Quantum Mechanics: Introduction to quantum mechanics, Potential well, quantum states, Derivation of Schrödinger Equation and its solution by separation of variables.

Properties of Nuclei: Calculation of nuclear charge, radius and mass. Definitions of binding energy, packing fraction and mass defect. Nuclear forces, mass formula, nuclear stability.

Fission: The fission process. Explanation of the liquid drop model, association between fission rate and reactor power, fission neutrons, delayed neutrons, fission gammas, fission product energy balance, photo neutrons. Fissile, fertile and fissionable materials. Computation of fission product activity after shutdown, decay heat.

Physics of interaction: Neutron interaction and concept of cross sections (macroscopic and microscopic). Calculation of variation of cross-section with energy, fast, resonance and thermal ranges. 1/v law, resonance absorption, Breit-Wigner formula, Doppler effect, Maxwell-Boltzman distribution and its departure, interaction with thermal and fast neutrons, transmutations. H vs. E curve, conversion, breeding, thorium utilization.

Neutron transport: Formulation of Fick's law and its validity, formulation of steady state neutron diffusion equation, concepts of life-time, reproduction time, slowing down length, Scattering (elastic and inelastic scattering.

Radiations and radiation safety (health physics): Radiation sources, its interaction with matter and units: Difference between Natural and Induced radioactive sources, Definitions of the units of radioactivity, half-life and decay constant, specific activity.

Principles of radiation detection and monitoring: Explanation of the basic operating principles of a) Gas b) Scintillation (including thermo luminescence detectors) and c) Semiconductors detectors. Comparison between different type of Radiation monitors/Radioactivity measurement methods adopted for radiation protection.

Explanation of the 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 (SI units & new units). Exposure measurement: Free air and Air wall chambers (concept of wall thickness should be given), Exposure-dose relationship, Bragg-Gray principle. RBE

Biological effects, Radiation Protection and Regulation: Comparison between radiation effects: stochastic and deterministic. Acute and delayed effects. Exposure-types and units. Dose limits. Principles of radiation protection. Control of external exposures (with problems in each case). Buildup concept, shielding from alpha, beta, gamma and neutron sources. Shielding from mixed sources. Radiation zoning. Precautions with radiation sources.

Reactor Control Engineering (PG/NuE/T/114A)

Review of classical control theory: Derivation of state variable modelling of linear continuous systems, definition of controllability and observability. Explanation of the role of eigenvalues in stability analysis. Concepts of linear sampled data systems: Discrete equivalents of continuous data systems, derivation of state variable modelling of linear discrete data systems, controllability and observability**.** Analysis of stability in discrete domain. MATLAB-based assignments using SIMULINK and CONTROL SYSTEM TOOLBOX.

Reactor Kinetics: Derivation of point kinetic equation, delayed neutrons and delayed neutron precursors, definition of reactivity and its units, discussion of the role of delayed neutrons in reactor control, definition of stable reactor period, in-hour equation, reactivity defect reactivity coefficients in over and under-moderated reactors, Explanation of Doppler effect in FBRs. Case study of Chernobyl disaster.

Dynamics of Poison build up: Calculation of Iodine and Xenon build up. Computation of negative reactivity build up due to Xe, Comparison between reactor states and restart requirements following a trip.

Control Mechanisms: Description of different reactivity control mechanisms and general characteristics of control rods. Definition of control rod worth. Case study I: Control mechanisms in a CANDU reactor. Case study II: LZCS in a 500 MWe PHWRs with the overview of disturbances like setback and trip. Computation of total reactivity worth of control mechanisms in each case.

Reactor in State Space: State space representation of reactor kinetics. Extension of the same for zonal models of reactors. Perturbation analysis about steady state, stability, controllability and observability. Numerical simulation of reactor state model using MATLAB or equivalent software.

Nuclear Chemical Engineering (PG/NuE/T/115A)

- Recovery & processing of nuclear materials from ores / intermediates.

- Uranium ore processing: Ores and their classification, options available and production of Uranium concentrates from Indian ores. Recovery of Uranium from non-conventional sources, New developments, uranium refining.
- Thorium: Occurrence, importance and production of Thorium from Monazite
- Zirconium: Occurrence, importance and production of Zirconium from Zircon. Zirconium and Hafnium separation and production of nuclear grade zirconium.
- Rare Earths: Occurrence, importance and separation.
- Uranium Conversion / reconversion: Conversion of nuclear grade uranium to UO2, production of UF4 and reactor grade U metal / UC from concentrates, process and equipment choices; flow sheets of refining plants. Metallothermic reduction, process choices, applications.
- Electrochemical technology for production of Fluorine, UF_6: choice and problems, Fluorination of UF_4, Purification and collection process for UF_6, Conversion to UO_2.
- Isotope Separation: SWU and value concepts; Cascade theory; Process for separation of Uranium; Optimisation of separation cascades.
- Processes for heavy water production and their comparative evaluation, Pre-enrichment process; Chemical-exchange: H_2S-H_20, NH_3-H_2, monothermal and bithermal process, Heavy water plants in India. Final enrichment and upgradation plants, Tritium removal.
- Laser based separation and new processes; laser based isotopic separation processes.
- Introduction of spent fuel – Nature, history, composition with burn up, storage and off reactor cooling.
- Reprocessing - Needs, history of reprocessing, current and future trends: relative merits and demerits, extractants and diluents in reprocessing.
- <u>Purex process :</u>
    a. Head end process: mechanical declading (chop-leach Process) Chemical dissolution Solvent extraction: Core decontamination cum partiontioning cycle, purification cycles for uranium and plutonium.
    b. Conversion to oxides, products specifications, criticality, product storage.
    c. Radioactive waste streams and off gas handling
    d. Equipment selection- mass transfer devices viz. pulsed columns, centrifugal extractors, mixer settlers, annular pulsed columns, electro pulsed columns, transfer devices etc.
    e. Cell layout, ventilation, shielding and remote handling.

- Thorium based fuel reprocessing and its challenges.
- Fast reactor fuel reprocessing
- Pyrochemical reprocessing.

<u>Nuclear waste management:</u>

- Introduction to radioactive waste, definition, nature, classification, categorization
- General philosophy of radioactive waste management.
- Reactor waste and reprocessing waste

- Treatment methods for low and intermediate level waste: Chemical treatment, ion exchange, evaporation & membranes.
- Conditioning of radioactive wastes: Cementation, Bituminization, Polymerization.
- Solid and solidified waste: characterization, volume reduction techniques.
- High level waste and its management: Vitrification process: History of vitrification, Pre-treatment, Calcination, Vitrification
- Vitrification equipment: Thermosyphon evaporators, calciner, melters (metallic melter, ceramic melter and cold crucible melters) Canisters and overpacks: Size, thermal load, materials of construction.
- Parititioning of high level wastes – need, recovery and recycle & transmutation.
- Interim storage of high level waste – Types of storage, thermal and mechanical design.
- Organic waste and treatment methods – chemical and oxidative destruction, incineration
- Disposal of radioactive waste and its monitoring :

  Near surface disposal- concept and modules
  Deep geological disposal- concepts, URL, Host media (clay, salt and rock)
  Waste form interaction with host media
  Migration behaviour and modeling
- Decontamination of equipment: Chemical decontamination, electro chemical, decontaminants, foams and gels, supercritical techniques.
- Decommissioning of nuclear facilities.

Basics of Finite Element Method (PG/ME/T/115B)
Offered by the Department of Mechanical Engineering

Basic concepts, approximate solution, Weighted residual methods, Galerkin method, Piecewise defined trail functions, shape functions, vibrational methods - RayleighRitz method. One dimensional problems in finite element procedure - modeling, element formulation with different approaches, assembly, properties of element matrix and system equations and treatment of boundary conditions, solution of equations. Standard discrete system- like truss, beam etc. Two dimensional problems of continuum, simple elements-application to plane and axisymmetric problems of elasticity, Scalar field problems - torsion, steady state heat transfer, potential flow, seepage, electric and magnetic fields, fluid flow in ducts(FEA of heat transfer, field problem and fluid flow). Isoparametric elements, higher order shape functions, mapping and numerical integration.

Experimental Methods in Mechanical Systems (PG/ME/T/115C)
Offered by the Department of Mechanical Engineering

Introduction – Theoretical, Computational and Experimental Research Methodologies. Objectives of Experiments: Monitoring, Control and Research. System and Variable Identifications for Mechanical Systems, Planning of Instrumentation, Design of Experiments.

Basic Concepts in Measurements – Generalized Description of Measurement System. Operational Description of a General Measurement System and Elimination Methods of Interfering Inputs to the Desired Inputs. Null and Deflection Methods of Measurements, Analog and Digital Measurements, Static and Dynamic Measurements. Accuracy, Precision, Sources of Errors in Measurements, and Uncertainty Analysis. Performance Characteristics, Order of Instruments and Calibration.

Sensors and Transducers; Data Sampling, Signal Conditioning and Acquisition. Examples of Transducer for Mechanical Measurements, Working Demonstration.

Active Circuits and Systems (PG / EE / T/ 115A)
Offered by the Department of Electrical Engineering

Special operational amplifiers: high voltage/high current, chopper and chopper stabilized amplifiers, instrumentation amplifier, isolation amplifier. Nonlinear function circuits: limiter, log/anti-log, multiplier/divider, peak detector, comparator, true RMS/DC converter, square wave oscillators. Timing and counting circuits: digital counters, shift register, analog and digital timers, frequency counters. 3Sinusoidal and relaxation oscillators: phase shift, ring, Wien-bridge, tuned, quadrature oscillator, crystal oscillator and clock circuits, voltage controlled oscillators – sine, square and triangle, frequency synthesizers. Frequency-to-voltage converters: Diode pump integrator, frequency and RPM transducers. Phase and phase /frequency comparators – analog and digital. Programmable logic devices: PLA, PLD , CPLD, FPGA and its application Microelectronic fabrication: Optical lithography, Etching, Physical deposition and sputtering, Chemical vapor deposition epitaxial growth, Device isolation, contacts and metallization, CMOS technologies Optoelectronic devices: photo diode/transistor, LDR, LED and LCD and PLASMA displays, opto-coupler, opto-interrupter, high speed detectors – PIN and avalanche photo diodes Active filters: types, filter approximations – Butterworth and chebyshev, filter realisations, frequency and impedance scaling, filter transformations, sensitivity, switched capacitor circuit.

Digital Signal Processing (PG/ETCE/T/116A)
Offered by the Department of Electronics and Telecommunication Engineering

Structures for the implementation of LTI systems: Direct form I and II structures, linear constant co-efficient difference equation, recursive and non-recursive systems, canonical form, Moving Average System, cascade realizations, parallel form realizations, design examples, FIR and IIR systems.

Composite-Radix FFT: Radix-3 and Radix-4 FFTs, DIT and DIF FFT algorithms, Flow diagram, decomposition of DFTs.

Design of FIR filters: Linear-phase FIR filters, symmetric and antisymmetric impulse responses, magnitude and phase characteristics of the frequency response, design examples, linear-phase zeros and their implementations, Window techniques, concept of main and side lobes, Rectangular, Hamming, Haning, Blackman and Bartlett Window functions, comparison of different types of windows.

Digital Signal Processor: Architecture, Instructions, Assembly level Programming, introduction to Code Composer Studio.

Fracture Mechanics (PG/ME/T/116C)
Offered by the Department of Mechanical Engineering

Introduction Historical perspective, Fracture mechanics approach to design, Overview and Classification.

Linear Elastic Fracture Mechanics Griffith Energy balance, R- curve instability, Stress field around rack, Stress Intensity Factor K, Crack tip plasticity, K- controlled fracture, Relationship between K & G.

Elastic-plastic Fracture Mechanics: Elastic - Plastic fracture parameters, CTOD, J-Contour Integral, Different methods of measurement of J-CTOD relationship, J-R curve, J - controlled fracture. EPRI method, Failure assessment diagram, Fatigue crack propagation

Dynamic fracture: Dynamic crack propagation and crack growth arrest, Dynamic fracture toughness (KID), Determination of KID. Fracture Mechanisms in metal Ductile fracture, Cleavage fracture, Ductile to brittle fracture, Intergranular Fracture.

Heat and Mass Transfer (PG/ME/T/116H)
Offered by the Department of Mechanical Engineering

Conduction: Fourier law of heat conduction; Governing equation and boundary conditions for different coordinate systems; One dimensional steady state conduction with and without heat sources; Fins of constant and variable cross-sectional area; Transient heat conduction; Multidimensional steady state heat conduction problems with and without heat sources; Heat conduction in anisotropic media.

Convection: Reynolds transport theorem and transport equations; One dimensional problems – Couette flow, Poisuille flow, Stefan flow etc.; Forced convection in thermally developed and developing flows; Derivation of boundary layer equations by order of magnitude analysis; Solution of boundary layer equations by similarity variable and integral methods; Introduction to natural convection; Natural convection in boundary layers; Integral method, scaling analysis.

Radiation: Basic definitions, surface properties, view factors; Radiation exchange in black and grey enclosure; Radiosity matrix; Interaction of surface radiation with other mode of heat transfer. Mass Transfer: Basic definitions; Fick's law of diffusion; Species conservation equation; Solution of one dimensional mass transfer problem.

Laboratory (PG/NuE/S/111)

Demonstration of activity measurements using BF3 counters, Scintillation detectors, Solid state detectors, Proportional Counters, GM counters. Construction of energy distribution spectrum using multi-channel analyzers. Particle accelerators. Self-Powered Neutron detectors.

Specialization specific modules.

Seminar (PG/NuE/S/112)

Each Student is required to present a seminar along with a report on any advanced topic related to Nuclear Engineering.

2nd SEMESTER

Reactor Physics and Engineering II (PG/NuE/T/127A)

Radiation Safety: Identification and Evaluation of the various neutron & gamma radiation sources within the reactor system; Calculation of attenuation of neutrons & gamma rays. Evaluation of dose rates for gamma rays for various source geometries, buildup factors for homogeneous & multiple layer shields. Formulation of Removal diffusion theory for neutron attenuation; coolant activation, heat generation. Evaluate streaming of radiation through gaps & void in the shield; Description of various shielding arrangements of Indian reactors.

Reactor Safety: Introduction to the concepts of redundancy, defense in depth, multiple-barriers. Definitions of incidents and accidents. Exposure and its allowable limits. LOCA, LORA. Analysis of the working principles of various engineered safety features: ECCS, ALPAS, Containment Systems and criteria for design, hydrogen generation, core-catcher etc.

Nuclear Accidents: Definition and analysis of Nuclear Accidents, Emergency Preparedness and Management: Reasons for accidents, classifications of accidents, Determination of accident severity using International Nuclear Events Scale (INES). Types of emergency, emergency preparedness. Critical evaluation of major accidents through case studies.

Nuclear fuel cycle: Introduction to the concept of Nuclear Fuel Cycle: Differentiating between Open and Closed fuel cycles and evaluating the relevant pros and cons. Fuel processing, reprocessing. Enrichment. Radioactive wastes: classifications and management.

Fusion: Introduction to nuclear fusion: Explanation of fusion as Energy Source, comparison between DD and DT Reactions, Lawson Criteria, Ignition, Breakeven condition, Fusion-based fissile-fuel Breeder. Analysis of charged particle motion: Introduction to Larmor gyration, particle drifts in combined electric and magnetic fields and in inhomogeneous and temporally varying electric and magnetic fields. Basic processes in plasmas: Collisions in plasmas, ionization, recombination, concepts of diffusion, mobility, and ambipolar diffusion. Thermal ionization and the Saha equation, LTE and equilibrium models. Confinement Schemes: Inertial confinement fusion: Basic concepts, requirement, Energy Gain, Problems related to ICF. Magnetic confinement fusion: Open and close magnetic confinement, Pinches, Mirrors, Stellarator, Tokamak.

Tokamak: Components and Sub systems of Tokamak and their functions, concept of tokamak Reactor, Safety factor, Rotational Transform, Magnetic Shear, Beta parameter, q-Limit, density–Limit, Tokamak Equilibrium and Pressure Balance. Electromagnetcs for tokamaks: Toroidal and poloidal field coils. Ohmic transformer. Superconducting magnets and cryogenic systems. Ultra high vacuum systems for tokamaks: Plasma Heating: Ohmic Heating, Electromagnetic Wave Heating, ICRH, LHRH, ECRH, NBI. Fueling of Tokamak Plasma: Need for fueling, Gas fueling, Neutral Beam Fueling, Pellet Injection. Particle and heat exhaust from tokamaks: Scrape-off layer, Role of Limiter and Diverter, Single-Null and Double-Null diverters, Materials of Limiter and Diverter. Heat and particle exhaust from divertor. Steady State Operation: Need for Steady State Operation, Quasi - steady State Operation using Non-Inductive Current drive. Fusion Reactor Blankets: Tritium breeding and extraction. Fusion Reactor Materials: Low-activation materials. Damage due to 14 MeV neutrons. Important Tokamak Experiments: Brief Introduction to Important Experiments in the World including

JET, TFTR, ASDEX, Toresupra, JT–60, TRIAM–1M, ITER, DEMO etc.

Nuclear Environmental Engineering (PG/NuE/T/128B)

- Fundamental processes and governing equations of radiations and radionuclide transport. Design principles and evaluation methods for waste disposal systems. Shielding and dose calculations, Review of nuclear waste management regulations.
- Air pollutants transportation, Introductory treatment of atmospheric dispersion of pollutants, Diffusion of stack effluents.
- Choice of Techniques, Selection of Equipment for the treatment of gaseous, particulate and liquid effluents.
- Design of pollution control devices, Design of chimneys, Stacks for pollution control.
- Counter current wet scrubber, Venturi scrubber, Absorption system design, Adsorption and combusion devices, Bag filters, Electrostatic precipitation, Recycle systems and sustainable development.
- Sampling procedures, Analytical methods, Odours and their control, Noise pollution and abatement

Corrosion and Material Degradation under Reactor Environment (PG/NuE/T/128C)

- Corrosion fundamentals; Forms of Corrosion; Type of Corrosion in Nuclear Reactors; Effect of Water Chemistry in light water nuclear reactors.
- Overview of materials degradation by stress corrosion in PWRs
- Stress corrosion cracking: susceptibility, initiation, propagation
- Corrosion fatigue crack growth behavior of low-alloy RPV steels at different temperatures and loading frequencies under BWR/NWC environment
- Specific Case Studies
- Monitoring and Mitigation of Corrosion in Nuclear Reactors

Non-linear and Adaptive Control (PG/NuE/T/128E)

- Nonlinear Control: Illustration of the state-space representation of non-linear systems. Classifications of common non-linearities and explanations of their origin. Examples of phase plane analysis for relay-based control. Popov's stability criterion. Formulation of local linearization with Jacobian and Lyapunov's first theorem. Stability analysis by Lyapunov's theory. Explanation of describing function method and Limit cycle. Explanation of control schemes using the concept of feedback linearization. Explanation of the sliding mode control scheme. Illustration of the concept of observability for non-linear systems.

- Adaptive Control: Linear parametric model. Adaptive laws. Derivation of model reference adaptive control scheme and its application. Robustness in adaptive control. Adaptive control of nonlinear systems. Explanation of gain scheduling control with its applicability.

Design of Industrial Pressure Vessels (PG/ME/T/128E)
Offered by the Department of Mechanical Engineering

Introduction , Review of Theory, Design philosophy, Criteria in vessel design, Design of pressure vessel to code specification, Organization of the ASME Boiler and Pressure Vessel Code , Materials, Specifications and their Selection, Materials and Metallurgy, Vessel Supports, Skirts, Base Rings, Saddles, Lugs and Legs Rules of Design including Earthquake, Wind Loadings, External Loadings and Nozzle Forces, Design-Construction features, Fabrication , Innovation and Economics, Post Weld Heat Treatment, Inspection and Non Destructive Testing, including Radiography, Hydrostatic Testing Design through pressure vessel package like PV Elite e. g. Tall vertical vessel, horizontal vessel, Heat Exchanger, with different codes.

Two Phase Flow, Boiling and Condensation (PG/ME/T/128F)
Offered by the Department of Mechanical Engineering

Boiling: Pool boiling, nucleate boiling mechanism; Bubble dynamics, film boiling; Leidengrost phenomenon; Transition between nucleate and film boiling; Hydrodynamic instability models. Condensation: Nucleation, liquid-vapour interface phenomena; Drop-wise and film condensation on surfaces; Bulk condensation; Similarities between boiling and condensation. Two-phase flow: Two-phase flow parameters and equations; Dimensionless groups for two-phase flow, flow patterns in two-phase flow, pressure drop and heat transfer in two-phase flow; Basic types of instabilities and introduction to phenomena like flow excursion and flow oscillation; Instrumentation for two-phase flow.

Integrity Analysis of Nuclear Reactor Components (PG/NuE/T/129A)

- Outline of the layout of primary cooling system in PHWR (Primary Heat Transport Piping System). Stress analysis of PHT pipes under mechanical and thermal loading, Conditions of plastic instability. Conditions of unstable fracture. Anchor design. Rigidity analysis of pipng system in loop. Failure Assessment diagram (FAD). CEGB-R6-analysis (level I & level II). LBB (leak before break) analysis.
- Explanation of the layout of primary cooling system and secondary cooling system in FBR. High temperature failure analysis, creep failure, thermal fatigue. Comparison between the failure modes in PHWR and FBR.
- Environmental failure: Stress corrosion cracking, degradation of irradiated material, hydrogen embrittlement.
- Failure analysis of nuclear structural components under variable load (seismic loading). Flow induced vibration analysis of nuclear fuel rods.

Separation Science and Engineering (PG/NuE/T/129B)

- Selection of separation techniques. Rate based and equilibrium separations.
- Energy requirements of separation processes.
- Gas absorption: Equilibrium data - representation and estimation; Co-current and countercurrent flow.
- Distillation: Equilibrium data - representation and estimation; Multistage Tray, Spray and Packed Towers-Design of the tower and tower internals. Solvent Extraction: Equilibrium data - representation and estimation,
- Adsorption: Equilibrium data - representation and estimation (Langmuir, Freundlich, B.E.T. etc. models); Pressure swing adsorption and temperature swing adsorption. Parametric pumping, chromatographic separation.
- Leaching: Method of calculation for Single-stage, multistage crosscurrent and countercurrent operation.
- Frontiers in separation technology: Desalination; Overview of the membrane separation processes:
- Reverse Osmosis (RO): Process description and terminology. Membranes & module design. Application of Microfiltration (MF): Overview. New membrane separation processes: Ultrafiltration, Pervaporation. Application of membranes in water treatment and in radioactive waste management

Nuclear & Reactor Instrumentation (PG/NuE/T/129E)

- Explanation of fundamental considerations, philosophies and requirements. Justification of redundancy and redundancy models (TMR). Reliability considerations.
- Principles of radiation detection and types of detectors: Explanation of the working principles of ion chambers, proportional counters, GM counters, scintillation detectors and photo-multipliers, semiconductor detectors. Comparison between in-core and out of core detectors, SPND, General detector characteristics and specifications-resolution. Detector calibration.
- Explanation and comparison between different detector signal conditioning modes - pulse, Campbell and DC modes. Generation of Logarithm and Period signals.
- Pre-amplifiers: Comparison between different types of noise in pre-amplifiers. Calculation of optimum time constant. Explanation of count-rate meters, Nuclear ADCs, and Multi-channel Analyzers (MCA). PC based MCAs and their different modes. Particle identification by pulse-shape analysis. Scalar Timers. Low and High Voltage power supplies. Application of FPGA for nuclear pulse processing.
- Introduction to various reactor instrumentation and radiation monitors. Distinctions between startup and intermediate power range instrumentation systems. Reactor regulating system, Flux mapping system, Failed fuel detection system, Stack monitoring system, iodine monitoring system, Area Gamma and

neutron monitors, GM survey meters, Gun monitors, Neutron REM monitors, RADAS.

- Accelerator instrumentation. Comparison between CAMAC and VME bus for Beam-line and Control Instrumentation.
- Noise reduction techniques. Correlations; auto correlation and cross-correlation. Explanation of the concept of spectral density. EMI interference, comparison between grounding and shielding. Cabling for radiation environment. Topologies for noise reduction.

Reactor Thermal Hydraulics (PG/NuE/T/129F)

Reactors: Explanation of the basic components of thermal energy removal process in different types of reactors, Analysis of neutron flux distribution in different reactor configurations, Relationship between reactor power and neutron flux, axial and radial power distribution, reactor heat generation parameters, power peaking factor.

Heat Transfer inside fuel element: Heat conduction in fuel matrices - Mathematical treatment in Cartesian, Cylindrical and Spherical co-ordinates. Derivation of the temperature distribution in different fuel elements (flat fuel plate, cylindrical rod and spherical fuel pellet with clad and gas gap) for constant and varying flux. Assignments on determination and analysis of temperature distribution in different fuel geometries.

Heat transfer by fluid flow: Explanation of the mechanism of heat transfer between fuel and coolant, heat exchange between primary coolant and secondary coolant (steam generator with pre-heater).

Single Phase Flow. Definition and derivation of dimensionless numbers, Determination of pressure drop in rod bundles, spacers and channels. Review of Convective heat transfer correlations in rod bundles. Derivation of Axial temperature distribution in fuel and coolant in a fuel channel for cosine power distribution. Orificing concept in nuclear reactors, flow distribution in channels, determination of orifice loss coefficients in channels.

Two Phase flow: Introduction to two phase flow. Basic concepts and definitions of pool boiling, nucleate and film boiling. Identification of DNB and boiling crisis and interpreting its significance in the context of reactor safety.

Hot Spot Factor: Classification and determination of subfactors, multiplicative and statistical methods for combining subfactors.

Sub-channel analysis: Definition of subchannel, mixing mechanisms, mixing parameters, governing equations and solution procedure, effects of spacers.

Flow Loops: Determination of operating point in forced and natural convection systems, Loss of flow accident, decay heat generation and flow coast down, transition to thermosyphon cooling, steady state, transient and stability behaviour of thermosyphon loops.

LOCA Heat Transfer: Types of LOCA, Thermohydraulic description of LOCA in BWR, PWR, PHWR. Critical flow models for single and two-phase critical flow. Explanation of events during blowdown, heat transfer behaviour from fuel to coolant during blowdown in PWR and BWR, cold water injection from emergency core cooling systems, refilling, sputtering, steam binding, reflooding, natural circulation heat removal during LOCA with loss of station power, reflux condensation cooling.

Thermal Hydraulics In Severe Accidents: Definition of severe accident, Outline of events leading to core melt down accident in LWRs and PHWRs, molten corium formation and its corium composition, molten pool formation in lower head of PWR and BWR, pool stratification, radiation cooling in nuclear reactors, fuel coolant interaction, steam explosion, failure of lower head, molten corium-concrete interaction, quenching of molten pool, debris formation and its characterization, debris bed coolability, containment pressurization, containment cooling using spray and passive cooling devices.

Liquid Metal Thermal Hydraulics: Outline of natural circulation in FBRs, Identification of heat transfer correlation for liquid metal coolants.

Nuclear materials (PG/NuE/T/1210A)

- In-core material: Fuels, Cladding and other structural materials.
- Nuclear material for thermal reactor, fast reactor, fusion reactor and high temperature reactor.
- Materials: Aluminum and Zirconium alloys, swelling resistant stainless steel for fast reactor, high temperature material (refractory metals) for high temperature and fusion reactor applications. Fuel, metallic fuel and ceramic fuels.
- Fabrication and processing of nuclear structural components and fuels.

Real Time Embedded System (PG/PE/T/1210A)
Offered by the Department of Power Engineering

Introduction: (Defining real time systems, Embedded real time systems, special characteristic of real time systems, a brief evolutionary history). Hardware Architecture of real time systems. Software Architecture (concepts of interrupt driven activation, need for real time monitor, pseudo parallelism). System Development life cycle (Phases, separate HW and software design tracks, Hybrid, co design, difficulty of debugging without target hardware etc., Available development methodologies. Specifying a real time system (complexities and difficulties, mention of formal specification languages – no details). Software Design. Introduction: Characteristics of Real Time Software Design Methodologies and life cycle. Overview of ward & Mellor methodology: Ward & Mellor Life Cycle, The Essential Model Step, The Implementation model, Real time Extensions to DFD. Environment Model: Context Diagram, The Event list. Behavioral Model: Expanding the contest diagram, Disambiguation of Transformation schema, describing the data schema, describing the data transform and control transforms, state transition diagrams. Implementation model steps: Processor Environment Model, Software environment model, code organization model, Translating STD's to structure charts, Translating data Transform based schema's to structure charts. Developing testing and evaluation of real time systems. System Development and Implementation. Real time programming language-issues and Ada. Real time O/S (facilities, UNIX/VENIX/POSIX, IRMX (historical reasons), concepts of processes and threads, communication among processes, kernel services). Development systems (Options, ICE, emulators, Section 15 of existing syllabus). External World Interfacing Issues: (Standard buses, connectors, isolation of signals from EMI/EMC).

Micro-scale Heat Transfer (PG / ME / T/ 1210E)
Offered by the Department of Mechanical Engineering

Basic concepts of microscale flows; Governing equations and models for different classes of microflows; Thermal effects in microscale flows; Electrokinetically driven and thermomagnetic microflow and heat transfer; Overview of different solution techniques for microscale flows and transport; Non-Fourier heat conduction

Term Paper Leading to Thesis (PG/NuE/S/121)

Each student will be given a Thesis / Project problem at the beginning of the second Semester. He/She will work on the literature survey, set scope of work, find stages of completion, experimental setup required and constraints which should be satisfied and submit a report / dissertation.

Seminar (PG/NuE/S/122)

Each Student is required to present a seminar along with a report on any advanced topic related to Nuclear Engineering.

PG Thesis & Viva-voce (3rd & 4th Semester)