ANNEXURE - III

M. TECH.

NUCLEAR SCIENCE AND ENGINEERING

COURSE STRUCTURE AND SCHEME OF THE PROGRAMME

DEPARTMENT OF PHYSICS
DR B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY
JALANDHAR – 144011

PREFACE

Department of Physics started initially its functioning as Department of Applied Sciences in the year 1989, in the very first year of inception of Dr B R Ambedkar National Institute of Technology, Jalandhar (erstwhile Dr B R Ambedkar Regional Engineering College, Jalandhar). Later on the department of Applied Sciences was separated as three independent departments of Physics, Chemistry and Mathematics. Since inception the department has catered the needs of budding engineers by developing the basic skills of engineering. The department started its M.Tech (Part-Time) in Material Science and Technology in the year 2001 and M.Sc./Ph.D program from the academic session 2006-2007. Now Department of Physics intent to start M. Tech program in Nuclear Science and Engineering from the next academic session 2014-2015. M. Tech Nuclear Science and Engineering program is interdisciplinary and specifically designed for the development of the country in the 21st century. The challenges that lie ahead in designing the next generation of fission based power plants and to meet rather difficult conditions is in the actual fusion reactor for meeting the future energy needs.

The curriculum is sufficiently focused on the development of practical knowledge to make the students productive in several laboratories under the Department of Atomic Energy. It also provides the necessary theoretical fundamentals to prepare the students to undertake research programmes in the area of nuclear physics and radiation physics.

(Dr H M Mittal)
Chairman, Board of Studies
Head, Department of Physics
Dr B R Ambedkar National Institute of Technology
Jalandhar – 144011

General Information

- The M.Tech course in Nuclear Science and Engineering will be conducted by the Department of Physics.
- The duration of the course is four semesters. However, students will be required to undergo teaching/training in the summer vacations during the two years of the programme.
- The number of seats for the course are 20.
- The detailed syllabus of the course can be accessed at the institute website: http://www.nitj.ac.in

Minimum Eligibility Conditions

For a candidate to be eligible for M.Tech. programme:

- A candidate must have a valid GATE Score in either current year or previous year.
- Eligibility criteria to M.Tech. Admission will be 6.5 CGPA (on a 10-point scale) or 60% for OC/OB whereas 6.0 CGPA (on a 10-point scale) or 55% in case of SC/ST candidates in the qualifying degree. For PD candidates the eligibility criterion will apply to the category they belong to (OC/OB /SC/ST).
- In case of result of qualifying degree is awaited, provisional admission is permitted to a student subject to meeting above benchmark latest by 15th September of the current year of admission.
- Conversion from CGPA to percentage or vice versa given by individual institute will not be considered/allowed.
- The candidate would be eligible only if they have taken Maths as a main subject in 10+2 (Class XII).

Academic System

The academic system at NIT, Jalandhar is framed on a credit based semester examination system. The credit system envisages a continuous evaluation of student's performance, and provides flexibility for academic progress based on individual ability and convenience, subject to the constraint of the minimum requirements for continuation of the academic programme.

The students are awarded a letter grade from the prescribed grading system in each course registered by them. For each pass grade, the students accumulate the course credits as earned credits. The academic performance of the students is indicated in terms of the number of credits that he/she earns and the weighted grade point average. A specified minimum number of credits should be acquired on semester or session basis in order to qualify for continuation in the academic programme and for the award of degree.

Credits

Each lecture/tutorial of one hour duration per week in a semester is assigned one credit. Each laboratory hour per week in a semester is assigned half credit. However, some courses are preparatory in nature and have half the credit weightage of a normal course. The courses without credit are termed as noncredit (NC) courses.

Grades

In a grading system, the evaluation in terms of marks is replaced by the award of letter grades. The structure and guidelines for the award of grades is given below:

Structure of Grading System

Grade	Points	Description of performance	Recommended Cut off marks*
S	10	Outstanding	90
A	09	Excellent	80
B	08	Very Good	70
C	07	Good	60
D	06	Average	50
E	05	Marginal	40
I	-	Incomplete	-
U	-	Unsuccessful	-
W	-	Withheld due to shortage of attendance or withdrawal	-
NP	-	Audit Pass	-
NF	-	Audit Fail	-

**Subject to confirmation based on standard deviation, if the sample size is greater than 20, and is flexible to the recommendation of the individual course coordinator with proper justification.*

The grades will be awarded to a student in each registered course including a laboratory course, based on his/her performance evaluated through a prescribed scheme of evaluation. The credits for the courses in which a student has obtained "E" (minimum passing grade for a course) or a higher grade will be considered as credits earned by him/her. In addition, the course in which a M Tech student to gets NP grade, will also count towards his/her earned credits but to the maximum extent of 8 credits. Any course in which a student has obtained "W" or "NF" grade will not be counted towards his/her earned credits.

In case of other (elective) courses in which U or W grade has been obtained, the student may take the same course or any other course from the same category when it is offered next. Further, "U" grade secured in any course stays permanently on the grade card. The weightage of these grades is not counted in the calculation of the SGPA and CGPA (Please refer for information 3.3.4)

An "I" grade denotes incomplete performance in any course due to absence at the end of semester. Upon completion of all course requirements, the "I" grade is replaced by a regular grade.

The grades NP and NF are awarded in a course that the student opts to audit. Audit applications are allowed during the first four weeks of a semester. The audit pass (NP) grade is awarded if a minimum "E" grade is obtained in the course and attendance is above 75% in the classes. If either of these requirements is not fulfilled, the audit fail (NF) grade is awarded. In courses, where NP grade is obtained, the corresponding course credits are counted towards earned credits. The grades obtained in an audit course are not considered in the calculation of SGPA or CGPA.

A "W" grade is awarded in a course where the student has opted to withdraw from the course. Withdrawal from a course is permitted until one week after the class test-I.

Grade Point Averages

The performance of a student will be evaluated in terms of two indices, viz., the Semester Grade Point Average (SGPA) which is the Grade Point Average for a semester and Cumulative Grade Point Average (CGPA) which is the Grade Point Average for all the completed semesters at any point of time. The SGPA is calculated on the basis of grades obtained in all courses, except audit courses, registered for in the semester:

$$\text{SGPA} = \frac{\Sigma(\text{Course credits} \times \text{Grade point}),\ \text{except audit courses, obtained during a semester}}{\Sigma(\text{Course credits}),\ \text{except audit courses, obtained during a semester}}$$

The CGPA is calculated on the basis of all pass grades, except audit courses, obtained in all completed semesters.

$$\text{CGPA} = \frac{\Sigma(\text{Course credits} \times \text{Grade point})\ \text{of courses with pass grade except audit courses upto a specific semester}}{\Sigma(\text{Course credits})\ \text{of courses with pass grade except audit courses upto a specific semester}}$$

Attendance Requirement

i) All students must attend every lecture, tutorial and practical class. The Institute desires 100% attendance with a provision for consideration for absence on account of late registration, sickness or other such contingencies. The attendance requirement of 75% of the scheduled classes in course is needed for appearing in the examination.

ii) A student with less than 75% attendance in a course during a semester will be awarded 'W' grade in that course irrespective of his/her performance in the tests. The Course Coordinator, while awarding the grades, will take into account the consolidated attendance record for the whole semester.

iii) In order to maintain the attendance record of a particular course, a roll call will be taken in every scheduled lecture, tutorial and practical class.

iv) For the purpose of attendance, every scheduled practical class will count as one unit irrespective of the number of contact hours.

v) The Course Coordinator will consolidate the attendance record for the course from the beginning of the semester till the end of the semester. The teacher offering the course shall notify the students having less than 75% attendance with an intimation of the same to the concerned Head of the Department and Dean Academic / Deputy Registrar(Academics).

vi) Every faculty offering a course will take attendance till three calendar days before the last instruction day in the semester. The percentage of attendance, calculated up to this instruction day, will be indicated in a code number/letter as follows:

Attendance rounded to	Code No/letter
95% and above	H
85% to 94%	9
75% to 84%	8
Below 75%	L

A student who has attendance code letter L will not be allowed to sit for end semester examination in the course in which the shortfall exists.

Registration:

A full time M.Tech. student should earn minimum 12 successful credits in the first semester and 28 successful credits at the end of 2nd semester. In case an M. Tech student does not satisfy these requirements, he/she will have to leave the programme.

For continuation in the programme, an M. Tech. student should have a minimum CGPA of 5.0. While calculating the CGPA for eligibility to continue in the programme, only cases successfully completed upto the point under consideration by the concerned student will be taken into account. If the CGPA of any student, calculated in this manner, falls below 5.0 the student will be issued a warning and in case he/she again obtain a CGPA less than 5.0 in the following semester, then he/she will be disqualified from the programme.

Degree Requirements:

An M. Tech. student will be eligible for the award of M. Tech. degree:

1. if he/she has successfully completed all the courses, practical, seminar, dissertation work and any other requirement of the curriculum as required by the Institute Senate.

2. If he/she has obtained a minimum CGPA of 6.0 in the entire course.

3. If he/she has paid all the institute dues including hostel dues, library dues, etc.

4. No disciplinary action is pending against him/her.

5. Character certificate is issued by his/her supervisor/Head of Department.

Scheme of Teaching and Examinations for M.Tech.

(Nuclear Science and Engineering)

Semester-I

Course Code	Course	Hours/week			Credits
		L	T	P	
PH-571	Quantum Mechanics & Electrodynamics	3	1	0	4
PH-573	Radiation Technology and its Applications	3	1	0	4
PH-575	Mathematical and Numerical Methods in Nuclear Engineering	3	1	0	4
PH- ###	Elective-I	3	0	0	3
PH-591	Computational Programming and Simulation Laboratory	0	0	3	2
PH-593	Nuclear Physics Laboratory	0	0	3	2
Total Credits					**19**

Semester-II

Course Code	Course	Hours/week			Credits
		L	T	P	
PH-572	Plasma Physics and Applied Thermodynamics	3	1	0	4
PH-574	Accelerator Physics & Technology	3	1	0	4
PH-576	Nuclear Radiation Detection and Analytical Tools	3	1	0	4
PH-578	Nuclear Radiation Safety and Waste Management	3	0	0	3
PH-592	Nuclear Measurement Laboratory	0	0	3	2
PH-594	Plasma Laboratory	0	0	3	2
Total Credits					**19**

Semester-III

Course Code	Course	Hours/week			Credits
		L	T	P	
PH-###	Elective-II	3	0	0	3
PH-###	Elective-III	3	0	0	3
PH-601	Seminar	-	-	-	3
PH-600*	Dissertation Phase-I	-	-	-	6
Total Credits					**15**

Semester-IV

Course Code	Course	Hours/week			Credits
		L	T	P	
PH-600	Dissertation Phase-II	-	-	-	12
Total Credits					**12**

LIST OF ELECTIVES

S. No.	Course Code	Course Title
1.	PH-577	Nuclear and Computational Sciences
2.	PH-579	Structure and Material of Nuclear Reactor
3.	PH-580	Nuclear Power Engineering
4.	PH-581	Plasma Physics & Nuclear Fusion Reactor

M.Tech. Nuclear Science and Engineering

1st SEMESTER

PH-571 Quantum Mechanics & Electrodynamics

Quantum Mechanics

Quick recap-Motivation for QM: Experimental need (spectra etc), Schrodinger equation, One-dimensional potential problems, 3-dimentional potential problems. Schrodinger & Heisenberg picture, Heisenberg equation of motion, classical limit solution of Harmonic oscillator problem using operator method.

Hilbert space and linear operator approach: linear vector space; inner product and probability; dual space, linear operator, basis. Heisenberg picture, Simple Harmonic Oscillator in detail (use of raising and lowering operators etc).
Angular momentum, Spin, L-S coupling.
Approximation methods: Perturbation Theory, Variational Methods, WKB Approximation, Scattering theory; some calculations.

Electrodynamics

Quick review of Maxwell's equations, Scalar and vector potentials, Gauge transformation and gauge invariance, Coulomb and Lorentz gauges.

Quick recap of special theory of relativity, Transformation properties of electric and magnetic fields, Field tensor, Maxwell's equations in covariant form.

Relativistic charged particle in an electromagnetic field, Motion in uniform electric and magnetic fields and combinations thereof, Non-uniform static magnetic field.

Green's function for wave equation (relativistic),Radiation from localized moving charges, Multipole expansion, Dipole and quadrupole radiation, Radiation from accelerated charge.

Power radiated by point charge, Larmor’s formula, Angular distribution of power.

Lagrangian formulation: Free relativistic particle, Charged particle in electromagnetic field, Free electromagnetic field, Energy-momentum tensor and conservation laws.

Electrodynamics of particle accelerators, cavity mode etc.

Suggested Reading:

1. L. I. Schiff, *Quantum Mechanics,* 3rd edition, McGraw Hill Book Co., New York (1968).

2. E. Merzbacher, *Quantum Mechanics, 3rd* edition, John Wiley *and* Sons, Inc (1997).

3. J.L. Powell & B. Crasemann, *Quantum Mechanics,* Addison-Wesley Pubs.Co., (1965).

4. A. Ghatak & S. Lokanathan, *Quantum Mechanics.- Theory and Applications,* 5th Edition, Macmillan India (2004).

5. E. M. Lifshitz and L. D. Landau, *Quantum Mechanics: Non-Relativistic Theory (Course of Theoretical Physics, Vol 3), 3rd* Edition, Butterworth- Heinemann (1981).

6. *J.*D. Jackson, *Classical Electrodynamics,* 3rd Edition, Wiley, New York (1998).

7. E. M. Lifshitz and L. D. Landau, *Quantum Electrodynamics (Course of Theoretical Physics),* 2nd Edition, Pergamon Pr; (1981).

8. David J. Griffiths, *Introduction to Electrodynamics,* 3rd edition, Benjamin Cummings (1998).

PH-573 Radiation Technology and its Applications

Radiation sources — alpha, beta, gamma sources, neutron sources, spontaneous fission source and synchrotron radiation source.

Interaction of gamma rays, charged particles and neutrons with matter — photoelectric absorption, Compton scattering, pair production, electromagnetic shower in high energy photon and electron interaction with matter; energy loss of heavy charged particles in matter, electronic stopping power (Bohr, and Bethe-Bloch formulae), Cerenkov radiation; energy loss of electrons and positrons, electronic stopping and energy loss by bremsstrahlung radiation. Neutron elastic scattering, inelastic scattering, radiative capture, (n, p), (n, 2n), (n, a), (n, fission) reactions.

Radiation shielding for neutrons, photons and charged particles. Design of radiation shields, including neutrons, photons and charged particles. Dosimetric quantities,materials selection and energy deposition in shields. Techniques for dose estimation including buildup factors, neutron removal cross-sections.

Industrial applications — tracing, gauging, material modification, sterilization, food preservation and other applications.

Medical applications — Projection imaging, imaging with external radiation and internal radiation, computerized tomography, positron emission tomography, magnetic resonance imaging, radiation therapy — using photons and electrons, radionuclides, neutrons and heavy charged particles.
Biological effects of radiation — direct and indirect physical damage, indirect chemical damage, dose, dose rate and dose distributions, Dose limits, Regulatory requirement, Damage to critical tissues — complex molecules, nucleic acids and damage repair. Human exposure to radiation, radiation in environment, evaluation of dose — external radioactive source and inhaled and ingested radioactivity, risk assessment, risk to occupationally exposed workers, radiation protection and measurement.

Suggested Reading:

1. David W. Anderson, *Absorption of Ionizing Radiation,* University Park Press — Baltimore (1984).
2. Frank H. Attix, *Introduction to Radiological Physics and Radiation Dosimetry,* John Wiley & Sons (1986).
3. S.H. Chen and M. Kotlarchyk, *Interaction of Photons and Neutrons with Matter,* World Scientific (1997).
4. James Turner's *Atoms, Radiation and Radiation Protection, 2nd* edition, Wiley & Sons, Inc. (1995).
5. William R. Leo, *Techniques for Nuclear and Particle Physics Experiments: A How- to Approach, 2nd* revised edition, Springer-Verlag, New York Inc. (1994).
6. John Lilley, *Nuclear Physics, Principles and Application,* John Wiley (2002).

PH-575 Mathematical and Numerical Methods in Nuclear Engineering

Computational methods used to analyze nuclear reactor systems described by various differential, integral, and integro-differential equations. Numerical methods include: finite difference, finite elements, discrete ordinate, and Monte Carlo, Examples from neutron and photon transport, heat transfer and thermal hydraulics. An overview of optimization techniques for solving the resulting discrete equations on vector and parallel computer systems. Develop numerical problem solving using case studies of problems encountered in nuclear engineering. Numerical methods employed may include differentiation and quadrature, root solving, linear algebra, eigenvectors and eigenvalues, initial and boundary value problems in ordinary differential equations, and partial differential equations. Examples of typical problems studied are: temperature of a plasma given its energy density (iteration or root solving), radionuclide decay chains (initial value problem, system of ODE's), 1-d spatial dependence of radiation diffusion (boundary value ODE eigenvalue/eigenfunction problem), transient heat diffusion(PDE's).

Suggested Reading:

1. Richard L. Burden and J. D. Faires, *Numerical Analysis, 8*th Edition, Brooks Cole (2004).

2. Elmer E. Lewis and Warren F. Miller, Jr., *Computational Methods of Neutron Transport,* John Wiley & Sons Inc. (1984); Wiley-Interscience; Reprint edition (1993).

PH-591 Computational Programming and Simulation Laboratory

List of Experiments:

1. **Determination of Roots:**
   a) Biseciton Method
   b) Newton Raphson Method
   c) Secant Method
   d) Coupled non-linear equations

2. **Matrix Manipulation:**
   a) Matrix Multiplication
   b) Determinant
   c) Gauss Elimination
   d) Matrix Inversion
   e) Gauss Jordan

3. **Interpolation:**
   a) Forward interpolation, Backward interpolation
   b) Lagrange's interpolation
   c) Least square method

4. **Integration:**
   a) Trapezoidal Rule
   b) Simpson 1/3 and Simpson 3/8 rules
   c) Multiple integral

5. **Differential Equations:**
   a) Euler's method
   b) Runge Kutta Method
   c) Coupled first order differential equations
   d) Solution of partial differential equation

PH-593 Nuclear Physics Laboratory

List of Experiments:

1. To study the characteristics of G.M. counter.
2. To determine the dead time of G.M. counter.
3. To study absorption of beta particles is matter.
4. To study Gaussian distribution using G.M. counter.
5. Source strength of a beta-source using G.M. counter.
6. Study of Poisson distribution.
7. To investigate the statistics of radioactive measurements.
8. Determination of Planck's constant using Photocell and Interference filters.
9. Analysis of pulse height of gamma ray spectra.

2nd SEMESTER

PH-572 Plasma Physics and Applied Thermodynamics

Plasma phenomena relevant to energy generation by controlled thermonuclear fusion and to astrophysics. Coulomb collisions and transport processes. Motion of charged particles in magnetic fields; Adiabatic invariance, Invariant Torroi. Integral systems,Stochastic and Chaotic Orbits, KAM Theory. Plasma confinement schemes. N1HD models; simple equilibrium and stability analysis. Two-fluid hydrodynamic plasma models; wave propagation in a magnetic field; RF plasma heating. Introduction to kinetic theory; Vlasov plasma model; fluid model from kinetic model; electron plasma waves and Landau damping. Linear waves and instabilities in magnetized plasma; solutions of Vlasov-Maxwell equations in homogeneous and inhomogeneous plasmas; conservation principles for energy and momentum.

Laws of Applied thermodynamics: Zeroth law of thermodynamics, heat and work, first law of thermodynamics, non-flow and steady flow energy equations, second law, Camot's theorem, entropy in various processes for ideal gases.

Air Compressors: Single and multistage compression of air Steam: Properties of steam, use of steam tables and Mollier diagram study of Cochian and locomotive and Babcock and *Wilcox boilers, boiler* mountings and accessories, draft systems, operation of reciprocating steam engine.

Refrigeration: Vapour compression, refrigeration cycle, basic components of refrigeration plant, psychometry, properties of air vapour mixtures, use of tables and charts. I.C. Engines: Working of four stroke and two stroke I.C. engines, study of components of I.C. Engines and testing of engines.

Suggested Reading:

1. F. F.Chen, *Introduction to Plasma Physics.* 2nd edition, Plenum Press, (1984).
2. R. J.Goldston, and P. H. Rutherford. *Introduction to Plasma Physics.* 10P Publ. (1995).
3. R.D.Hazeltine, and F. L. Waelbroeck. *The Framework of Plasma Physics.* Cambridge, MA: Perseus Books (1998).
4. P. C.Clemmow, and J. P. Dougherty. *Electrodynamics of Particles and Plasmas.* Reading, MA: Addison-Wesley (1969).
5. L.Spitzer, Jr. *Physics* of *Fully Ionized Gases.* 2nd ed. New York, NY: Interscience-John Wiley (1962).
6. G.Schmidt, *Physics of High Temperature Plasmas.* 2" edition Burlington, MA: Academic Press (1979).
7. R.Dendy, *Plasma Physics.* Cambridge, UK: Cambridge University Press, (1993). (Recommended for specific chapters on space and plasmas and on industrial plasmas).

PH-574 Accelerator Physics & Technology

Historical development of accelerators and their past and present application.

DC accelerators; Cockcroft-Walton, Van de Graaf, and Tandem; linacs; cyclotrons; synchrotrons; intersecting storage rings;

The emphasis will be shared between hadron and lepton accelerators.

The basic concepts of magnet design will be introduced, along with discussions of machine lattice design, radiofrequency cavities and particle beam optics.

Longitudinal and transverse beam dynamics will be explored, including synchrotron and betatron particle motion.

A number of additional special topics will be reviewed, including, synchrotron radiation, injection techniques, and collective effects and beam instabilities.

Beam physics topics in these accelerators include particle motion dynamics, beam confinement and guidance, and beam acceleration.

RF linacs: Introduction to linacs

Propagation of electromagnetic waves through matter (relevant to linacs only); reflection of waves in bounded media.

Phase velocity; group velocity; wave equation; continuity theorem; Brilliouin diagram for empty cavity, etc.

Generation of modes in a cavity/waveguide; TEM,TE,TM modes; mode creation and identification, boundary conditions.

Generation of an electric field in an empty cavity; dispersion relation; frequency and mode evaluation, etc.

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.

Transit time factor and the energy gained in a linac.

Longitudinal stability; stability criteria; separatrix; synchronous oscillation with small and large amplitudes; longitudinal wave vector; time period; phase damping; acceleration through v-c traveling wave linac and damping phenomena; acceleration conditions therein, etc.

Transverse stability; stability criteria; impulse due to radial field; focal strength of a radial defocusing impulse.

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 structures; superconducting structures (SC);

general advantages of SC systems over room temperature ones.

High Power DC and pulsed electron accelerators

Electron emission processes; thermionic cathodes; field emission; explosive field emission.

Pulse power systems; Marx generators; Tesla transformer, transmission line spark gaps; induction linac.

Relativistic electron beam generation, propagation and applications in generation of microwaves, neutrons, ion beams and X-rays. Beam diagnostics.

Industrial DC electron accelerators; Dynamitron. Application of industrial electron accelerators; comparison with X-ray sources.

Accelerator Driven Systems.

Suggested Reading:

1. J.J.Livinghood, *Principles of Cyclic Particle Accelerators,* D.Van Nostrand Company. Inc (1964).

2. T.P. Wanger, *RF Linear Accelerators,* John Wiley & Sons Inc. (1998).

3. R. Miller, *An Introduction to the Physics of Intense Charged Particle Beams,* Ist edition, Springer (1982).

4. S.Shiller, U.Heisig and S.Panzer, *Electron Beam Technology,* John Wiley & Sons Inc.(1982).

5. W. Scharf, *Particle Accelerators and Their Uses (Accelerators and Storage Rings), Portland Part II,* Gordon and Breach (1991).

7. E.Wilson, *An Introduction to Particle Accelerators.* Oxford University Press (Oxford) (2001).

8. K. Wille, *The Physics of Particle Accelerators: an Introduction,* Oxford University Press (Oxford) (2001).

9. S.Y. Lee, *Accelerator Physics,* World Scientific, Singapore (1999).

10. D.A. Edwards and M.J. Syphers, *An Introduction to the Physics of High Energy Accelerators,* John Wiley and Sons, New York (1993).

PH-576 Nuclear Radiation Detection and Analytical Tools

Gas-filled ionization detectors-Ionization chambers, proportional counters and GM counters. Pulse height spectra and energy resolution.

Semi-conductor detectors — Working of a p-n junction detector, partially and totally depleted detectors, surface barrier detectors, Lithium drifted Silicon detectors (Si(Li)), high-purity Germanium(HPGe) gamma detectors, typical gamma-ray spectrum with an HPGe detector. Particle identification and time of flight technique.

Scintillation detectors- scintillation mechanism in inorganic crystal scintillators and organic scintillators. Characteristics and operation of alkali halide scintillators with details of NaI (Tl), Photomultiplier tubes. Pulse height spectrum using a monoenergetic gamma ray source.

Production and detection of neutrons-typical neutron sources, slow neutron detection, BF3 counter, boron-lined proportional counter, boron loaded scintillators, Lithium containing slow neutron detectors, He proportional counters, fission counters.

Reactor Instrumentation — general considerations — Reactor Nuclear Instrumentation systems — an overview — pressurized water nuclear instrumentation, boiling water reactor nuclear instrumentation, Encore detectors, self powered detectors, detectors based on beta decay, detectors based on secondary electrons from gamma decay.

Measurement Techniques — measurement of voltage current, charge and frequency. Timing measurements, leading edge and constant fraction discriminators, coincidence measurements, time to amplitude converter. Single and multi channel analyzers, data acquisition system

Vacuum techniques — elements of a vacuum system, molecular and viscous flow, pumping speed, displacement and containment pumps, diffusion pump, turbo molecular pump, sputter ion pump, getter ion pump, cryogenic pump, high and ultrahigh vacuum systems, vacuum measurement gauges, leak detection techniques.

Nuclear techniques for materials analysis — basic principles of materials analysis, basic requirements for the technique, nuclear techniques for elemental analysis, main nuclear processes useful for materials analysis, the quantitative estimate, Rutherford back scattering (RBS) and elastic recoil detection analysis(ERDA). Nuclear reaction analysis — principle of the technique and required instrumentation, nuclear reactions suitable for nuclear reaction analysis, neutron activation analysis. PIXE and XRF techniques.

Suggested Reading:

1. G.F.Knoll, *Radiation Detection and Measurement,* 3rd Edition, John Wiley and Sons (2000).

2. S.S.Kapoor and V.S.Ramamurthy, *Nuclear Radiation Detectors,*Wiley Eastern Limited, New Delhi (1986).

3. K.M.Varier, A.Joseph and P.P.Pradyurnan, *Advanced Experimental Techniques in Modern Physics,* Pragati Prakashan, Meerut (2006).

4. John Lilley, *Nuclear Physics, Principles and Application,* John Wiley (2002).

PH – 578 Nuclear Radiation Safety and Waste Management

Nuclear Fuel Cycle: In-depth technical and policy analysis of various options for the nuclear fuel cycle. Topics include uranium supply, enrichment fuel fabrication, in-core physics and fuel management of uranium, thorium and other fuel types, reprocessing and waste disposal. Principles of fuel cycle economics and the applied reactor physics of both contemporary and proposed thermal and fast reactors are presented. Control and transient problems, release of radioactivity from reactors.
Nuclear Radiation Safety: Integration of reactor physics and engineering sciences into nuclear power plant design. Topics include materials issues in plant design and operations, aspects of thermal design, fuel depletion and fission-product poisoning, and temperature effects on reactivity. Safety considerations in regulations and operations, such as the evolution of the regulatory process, the concept of defense in depth, General Design Criteria, accident analysis, probabilistic risk assessment, and risk-informed regulations.
Nuclear Waste Management: Introduces scientific and engineering aspects of the management of spent fuel, reprocessed high-level waste, low-level wastes, and decommissioning wastes. Characteristics and classification of nuclear wastes and waste forms. Fundamental processes and governing equations of radionuclide transport in the environment. Discussion of performance assessment for repositories. Design principles and evaluation methods for geologic waste disposal systems.

Suggested Reading:

1. Robert G. Cochran and Nicholas Tsoulfanidis, *The Nuclear Fuel Cycle: Analysis and Management,* 2nd Edition, American Nuclear Society (1999).
2. H. W. Graves, *Nuclear Fuel Management,* John Wiley and Sons, New York (1979).
3. Ronald A. Knief, *Nuclear Criticality Safety: Theory and Practices,1st* Edition, American Nuclear Society (1985).
4. Edward L. Alpen, *Radiation Biophysics,* 2nd edition, San Diego: Academic Press (1998).
5. P. D. Wilson, ed. *The Nuclear Fuel Cycle: from Ore to Wastes,* Oxford University Press (1996).
6. W. Marshall„ ed. *Nuclear Power Technology Fuel Cycle. Vol.* 2. Clarendon Press, (1983).
7. R. L. Murray. *Understanding Radioactive Waste,* 4th edition, Battelle Press, (1994).

PH-592 Nuclear Measurement Laboratory

List of Experiments:

1. Recording and calibrating a gamma ray spectrum by scintillation counter.
2. Detecting gamma radiation with a scintillation counter.
3. To study absorption of gamma radiation by scintillation counter.
4. Identifying and determining the activity of weakly radioactive samples.
5. Recording a beta spectrum using a scintillation counter.

PH-594 Plasma Laboratory

List of Experiments:

A.C. Plasma:

1. Study of Plasma parameters such as Electron density, ion density, Electron temp, floating potential, Plasma Potential etc. using Langmuir probe.

2. Verification of Paschen curve.

3. Study of Plasma coating of different materials on substrate.

4. Study of Plasma cleaning of substrate surfaces.

D.C. Plasma:

1. Study of Plasma parameters such as Electron density, ion density, Electron temp, floating potential, Plasma Potential etc. using Langmuir probe.

2. Verification of Paschen curve.

3. Study of Plasma coating of different materials on substrate.

4. Study of Plasma cleaning of substrate surfaces.

PH-577 Nuclear and Computational Sciences

Nuclear Science

Basic properties of the nucleus and nuclear radiations. Quantum mechanical calculations of deuteron bound-state wave function and energy. n-p scattering cross section, transition probability per unit time and barrier transmission probability.

Nuclear reactions — Kinematics, Direct and Compound Nucleus Reactions. Binding energy and nuclear stability. Radioactive decays. Energetics and general cross section behavior in nuclear reactions. Details of Nuclear Models and Nuclear Fission.

Computational Physics

General remarks regarding Computer Programming, High Level Languages, Familiarization with DOS and WINDOWS, computer arithmetic, FORTRAN-77 statements and implementation on PCs, Sample assignments to write programs of scientific computation. Highlights of FORTRAN-90 programming language.

Introduction to C, C+, Unix, Dialects of C, Functions and Program structure, Basic Data Types, Arrays, Strings Expressions and Operators, Precedence of C Operators, C Preprocessors, Control Statements, Pointers, Pointer Arithmetic, Arrays handling with Pointers, Functions in detail

Input and Output Operations and C File Handling Operations. Structures & Unions in C, Dynamic memory Allocation, Macro definitions, Compilation and Execution of C program, Fortran to C linking procedures, Introduction to Parallel Processing, Grid Computing, Introduction, Applications & Architecture.

Overview of accuracy, precision and errors in scientific computations. Solution of non-linear equations. Solution of linear systems and eigen value problems. Curve fittings of given data. Numerical integration. Solution of ordinary differential equations. Solution of partial differential equations. Solution of integral equations.
Assignments of real life Physics problems and computations based on these and other methods using FORTRAN-77

Suggested Reading:

1. Kenneth S. Krane, *Introductory Nuclear Physics.* Hoboken: John Wiley & Sons, Inc. (1987).
2. V. Rajaraman, *Computer Programming in Fortran* 77, 4th Edition, Prentice-Hall of India (1997).
3. *V.* Rajararnan, *Computer Programming in Fortran 90 and 95,* Prentice-Hall of India (2002).
4. W.H. Press et.01., *Numerical Recipes in Fortran/F-90/C,* Cambridge Univ. Press (1996).

5. P.L. DeVries, *A First Course in Computational Physics,* John Wiley & Sons (1993).

6. *J.H.* Ferziger, *Numerical Methods of Engineering Application,* 2nd edition, WileyInterscience (2001).

7. G. Golub and *I* .M. Ortega, *Scientific Computing,. An Introduction to Parallel Computing,* Academic Press (1993).

8, Pierre Marmier., and Eric Sheldon. *Physics of Nuclei and Particles.* San Diego: Academic Press, (1986).

9. Walter E. Meyerhof, *Elements of Nuclear Physics.* New York: McGraw-Hill, (1967).

10. Bernard L. Cohen, *Concepts of Nuclear Physics.* New York: McGraw-Hill, (1971) (Background reading).

PH-579 Structure and Material of Nuclear Reactor

Core Physics: criticality, control rod calculations, excess reactivity computations, enrichment requirements, fuel bum-up and fission product formation.

Radiation and shielding: radioisotope decay, interaction of radiation with matter and shielding (thickness, material, cooling).

Thermal Hydraulics: convective and/or boiling heat transfer at fuel element surface, conductive heat transfer inside elements, pressure drops, heat exchanger calculations, thermodynamic cycle efficiency, steam turbine reheat and regeneration, preheating and inlet sub-cooling.

Materials: selection of fuel and cladding, corrosion, pressure vessel materials. Pressure Vessel: stress calculations, materials selection/thicknesses, ASIvIE codes. Safety: Safety design principles, Safety in operation, temperature and void coefficients, emergency cooling, hazards considerations.

Thermal limits on reactor performance, thermal converters, and fast breeders.

Suggested Reading:

1. Richard T. Lahey and Frederick J. Moody, *The Thermal-Hydraulics of Boiling Water Reactors,* 2nd Edition, American Nuclear Society (1993).
2. Edited by O.C. Jones, *Nuclear Reactor Safety Heat Transfer,* Hemisphere Pub (1981).
3. A.E. Waltar, and A.B. Reynolds, *Fast Breeder Reactors,* Pergamon Press, New York (1981).
4. A.E. Bergles et al., *Two Phase Flow and Heat Transfer in the Power and Process Industries,* Hemisphere Publishing (1981).
5. J.C. Collier, *Convective Boiling and Condensation,* McGraw Hill (1972).
6. J.M. Delhaye et *at.. Therrnohydraulics of Two Phase Systems for Industrial Design and Nuclear Engineering,* Hemisphere Publishing (1981).
7. Y. Hsu and R. Graham, *Transport Processes in Boiling and Two Phase Systems,* Hemisphere Publishing (1976).
8. James H. Rust, *"Nuclear Power Plant Engineering",* Haralson Publishing Company, P.O. Box 20366, Atlanta, Georgia 30325 (1979).
9. Neil E. Todreas and Mujid S. Kazimi, *Nuclear Systems I, Thermal Hydraulic Fundamentals,* Hemisphere Publishing Corporation, (1990).

PH- 580 Nuclear Power Engineering

Principles of the conversion of nuclear energy to useful power, various types of nuclear power plants that have been designed, built and operated. Advanced future types of nuclear power plants that are in the design or developing stages. Reactor designs of power plants, their energy conversion principles, cycles and load-following characteristics, Economics of nuclear vs. other types of power plants. Power plant design and utility industries.

Problems involving core hydrodynamics of boiling-water reactors, their void and pressure coefficients, stability, and their effects on the design of the balance-of-plant. Detailed features of pressurized water reactor components, including steam generators, pressurizers and chemical-shim control systems. Problems related to features of gas- cooled reactor cycles and components, and compare/contrast those features with those of conventional LWRs. Examples include, but are not limited to, fuel geometries (hex vs rod vs pebble-bed), fuel type (uranium vs thorium) and coolant type (helium vs water). Solve problems related to conversion, breeding and doubling times of fast breeder reactors. Difference in neutron spectrum and fuel type between a fast reactor and a LWR affect fast reactor physics and performance. Examples include, but are not limited to, fast reactor kinetics, sodium void coefficients and designs to suppress reactivity excursions. Describe methods of direct nuclear energy conversion such as thermionic, thermoelectric, betavoltaic and fission-electric cells.

Economics of nuclear power plants. accounting for capital costs, fuel costs and O&M (operations and maintenance) costs,, as well as environmental aspects - sustainability, proliferation, safety. Compare and contrast the relative merits of different types of power plants.

Suggested Reading:

1. M. M. El-Wakil, *Nuclear Energy Conversion,* American Nuclear Society; Revised edition (1982)

2. John R. Lamarsh and Anthony J. Baratta, *Introduction to Nuclear Engineering,* 314 Edition, Prentice Hall (2001).

PH-581 Plasma Physics and Nuclear Fusion Reactors

Plasma phenomena relevant to energy generation by controlled thermonuclear fusion and to astrophysics.

Coulomb collisions and transport processes.

Motion of charged particles in magnetic fields; Adiabatic invariance, Invariant Torroi. Integral systems, Stochastic and Chaotic Orbits, KAM Theory.

Plasma confinement schemes.

N1HD models; simple equilibrium and stability analysis.

Two-fluid hydrodynamic plasma models; wave propagation in a magnetic field; RF plasma heating.

Introduction to kinetic theory; Vlasov plasma model; fluid model from kinetic model; electron plasma waves and Landau damping.

Linear waves and instabilities in magnetized plasma; solutions of Vlasov-Maxwell equations in homogeneous and inhomogeneous plasmas; conservation principles for energy and momentum.

Suggested Reading:

1. F. F.Chen, *Introduction to Plasma Physics.* 2nd edition, Plenum Press, (1984).

2. R. J.Goldston, and P. H. Rutherford. *Introduction to Plasma Physics,* IOP Publications (1995).

3. R.D.Hazeltine, and F. L. Waelbroeck. *The Framework of Plasma Physics.* Cambridge, MA: Perseus Books (1998).

4. P. C.Clemmow, and J. P. Dougherty. *Electrodynamics of Particles and Plasmas.* Reading, MA: Addison-Wesley (1969).

5. L.Spitzer, Jr. *Physics* of *Fully Ionized Gases.* 2nd ed. New York, Interscience ~ John Wiley (1962).

6. G.Schmidt, *Physics of High Temperature Plasmas.* 2nd Edition Burlington, MA: Academic Press (1979).

7. R.Dendy, *Plasma Physics.* Cambridge, UK: Cambridge University Press, 1993. (Recommended for specific chapters on space and plasmas and on industrial plasmas).