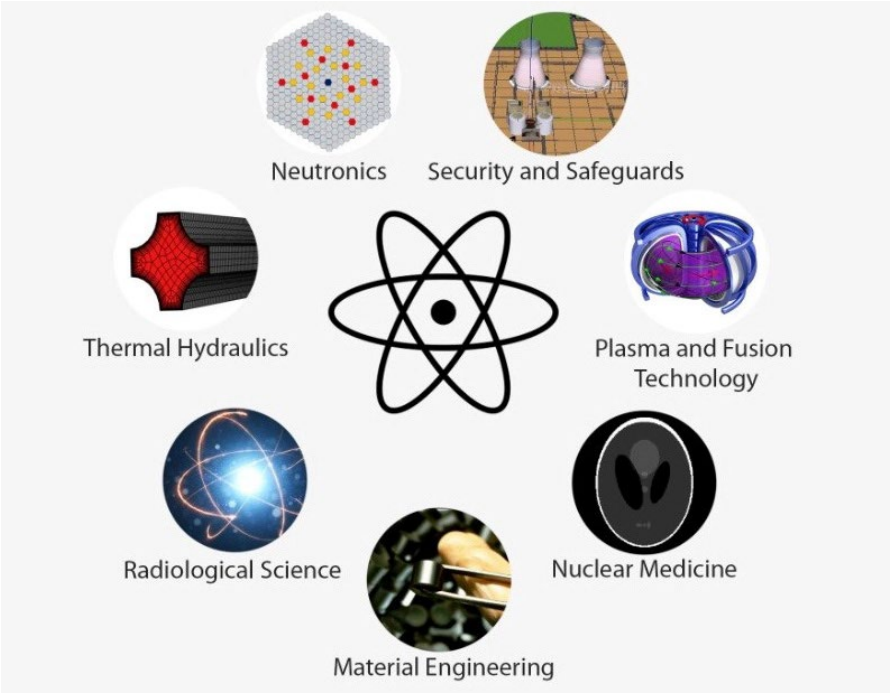

Syllabus
B.Sc. in Nuclear Engineering

Session 2022-2023 and onwards

Department of Nuclear Engineering
University of Dhaka
Dhaka-1000, Bangladesh

Syllabus

B.Sc. in Nuclear Engineering
Session 2022-2023 and onwards

Published by
Department of Nuclear Engineering
University of Dhaka

Published in 2023

Department of Nuclear Engineering
University of Dhaka

Department of Nuclear Engineering (NE)
University of Dhaka

About the Department:

In accordance with Dhaka University Ordinances and Regulations 1973 and recommendations of the Faculty of Engineering and Technology meeting on 25-07-2010 & 19-08-2010, the Dean's Committee meeting on 24-08-2010 and recommendations of the Academic Council meeting on 25-08-2010, the Syndicate of Dhaka University has established the Department of Nuclear Engineering in its meeting on 29-08-2010. The Department of Nuclear Engineering is one of the newest Departments of the University of Dhaka, which began its journey in January 2012. This Department is the first of its kind and is the pioneer in nuclear engineering education in Bangladesh.

The missions of the Nuclear Engineering Department are:

- To develop high-quality nuclear engineers and scientists from undergraduate through the doctorate level who are capable of contributing valuable engineering skills and knowledge toward the design, building, and running of Bangladesh's nuclear power plants.
- To be Bangladesh's center of excellence in nuclear engineering education and research, to lead Bangladesh's effort to develop its nuclear infrastructure, and to introduce nuclear power as a part of its energy mix.
- To perform services for industry, government, professional organizations, and the public in areas related to nuclear and radiological engineering.

The vision of the Nuclear Engineering Department of the University of Dhaka is to be recognized as an excellent higher-education nuclear engineering institution in the global arena for effective and peaceful applications of nuclear energy.

Degrees Offered:

B.Sc. : 4 years (Eight semesters) undergraduate program

M.Sc. : 1.5 years (Three semesters) postgraduate program

Ph.D. : 4 years in any related field

Research Areas:

The faculties and students in undergraduate and graduate studies conduct research activities in various nuclear engineering fields. The major research area

covers Neutronics, Thermal-Hydraulics, Computational Fluid Dynamics, Fuel Cycle and Waste Management, Radiation Damage to Materials, Plasma Physics and Fusion Technology, Nuclear Security and Safeguards, Radiological Science and Engineering, Nuclear Medicine.

Laboratories:

The department is enriched with well-equipped laboratories which cover practical aspects of physics, electrical and electronic engineering, heat transfer & fluid mechanics, thermal-hydraulics and reactor safety, radiation science & health physics, nuclear instrumentation & measurements, and computer programming & simulation.

Career Opportunities:

Graduated students will get a chance to work at Bangladesh Atomic Energy Commission (BAEC), Nuclear Power Plant Company Bangladesh Limited (NPCBL), and Bangladesh Atomic Energy Regulatory Authority (BAERA). In addition, graduates have opportunities to work at departments of nuclear engineering, physics departments, and related R&D organizations at home and abroad.

The Framework of The Semester System:

Program: B.Sc. in Nuclear Engineering

1. **Admission:** Students will be admitted to the department as per university rules.

2. **Duration of the Program:** 4 years.

3. **Total Semesters:** 4 × 2 = 8 (2 Semesters per year).

4. **Breakdown of each semester (**Duration of Six academic calendar months**):**

a. Class: Fifteen (15) active weeks

b. Preparatory Leave (PL): Two (2) weeks. No separate break for in-course examinations.

c. Semester Final Examinations: Two/Three (2/3) weeks

d. Evaluation of Scripts and Publication of Results: Within two months from the last date of the theory exam is desirable.

e. Vacation: No break between semesters; only the usual university vacations apply.

5. **Total Number of Credits in 8 semesters (4 years): 160**

Total credits to be completed for obtaining the degree of B.Sc. in Nuclear Engineering is 160.

Classes/Contact Hours for the Courses:

a. For each credit of a theory course, there will be 1 class per week of 1 hour duration.

b. Total number of classes in a semester for each credit of a theory course will be 15 (15 × 1).

c. Total Contact Hours in a semester for each 1.0 credit theory course: 15 × 1 = 15.

d. For each 1.5 credit lab course, there will be 1 class per week of 3.0 hours duration.

e. Total classes in a semester for each 1.5 credit lab course in 15 weeks: 15 × 1 = 15.

f. Total Contact Hours in a semester for each 1.5 credit lab course: 14 × 3.0 = 42.

Evaluation of the Courses: As per university rules.

Grading System:

The current University Grants Commission (UGC) approved grading system applies as per university rules.

Marks	Letter Grade	Grade Point
80% and Above	A+	4.00
75% to < 80%	A	3.75
70% to < 75%	A-	3.50
65% to < 70%	B+	3.25
60% to < 65%	B	3.00
55% to < 60%	B-	2.75
50% to < 55%	C+	2.50
45% to < 50%	C	2.25
40% to < 45%	D	2.00
Less Than 40%	F	0.00

	I	Incomplete
	W	Withdrawn

Marks Distribution:

For a Theory Course

Attendance	05%
Assignment/Presentation	05%
Mid-term Examination (Incourse)	20%
Final Examination	70%
Total	100%

If more than one in-course exam is taken final mark will be calculated by averaging all of them (the best one will not be allowed). Assignment/Presentation and Mid-term Examinations (Incourse) will be evaluated by the respective course teacher(s).

For a Laboratory Course

Attendance	10%
Continuous Assessment	50%
Final Exam (Experiment + Viva)	40% (20% + 20%)
Total	100%

For the Industrial Training

Viva/Presentation	20%
Written Examination	40%
Report	40%
Total	100%

For the Project

Continuous Assessment	10%
Presentation	40%
Report	50%
Total	100%

Guideline for Attendance Mark:

Attendance (%)	Marks (05)	Marks (10)
90 and Above	05	10
85 to 89	04	08
80 to 84	03	06
75 to 79	02	04
60 to 74	01	02
Less Than 60	00	00

Course Coordinator:

Each academic year will have a course coordinator. The coordinator will prepare class routines, monitor classes, arrange extra classes, if necessary, ensure smooth functioning of the academic activities, and help the Chairman (of the examination committee) hold examinations and publish results.

Class Representative:

Each batch/section of students will have two class representatives (one male and one female) to maintain liaison with the Course Coordinator regarding their class progress and problems.

Examination Committee:

a. The Academic Committee of the department will propose the examination committee consisting of 4 teachers.

b. There will be an examination committee for every academic year.

c. The committee will consist of a Chairman, two internal members, and an external member. The Course Coordinator should be one of the members of the committee.

d. The committee may have the external member from DU or outside DU.

e. The Chairman of the examination committee, with the help of the committee members, will be responsible for getting questions from the respective course teachers, moderating the questions and printing them, holding examinations, and publishing results.

Tabulators:

a. The examination committee will appoint two tabulators.

b. Course teachers/examiners will submit their grade sheets in detail.

c. The tabulators will enter the marks given by each course teacher/examiner in the tabulation sheets independently and process the examination results.

d. The controller's office will publish the examination results at the end of every semester and issue the transcripts.

Promotion to the Next Academic Year and Requirements for the Award of the B.Sc. in Nuclear Engineering Degree:

a. The minimum Cumulative Grade Point Average (CGPA) required for promotion to the next year:

1st year to 2nd year	: 2.00
2nd year to 3rd year	: 2.25
3rd year to 4th year	: 2.50

b. $\text{CGPA}=\frac{\sum G_i \cdot C_i}{\sum C_i}$, where, G_i is the grade point obtained in course i and C_i is the corresponding credit.

c. The minimum Grade Point (GP) of 2.00 in each theory course and an overall CGPA of 2.5 will be required for the award of the B.Sc. in Nuclear Engineering Degree without "F" grade in any course.

d. The Degree must be earned within the limit of 12 semesters, i.e., 6 academic years from the date of admission to the 1st semester.

e. There will be no option for grace.

Requirement to Sit for Course Final Exam

Students having 75% or more attendance on average is eligible to sit for the semester final examinations. Students having attendance 60-74% will be considered to sit for the examination as per the University rules. Students having attendance below 60% will not be eligible to appear at the examination but may seek re-admission to the program.

Improvement Examination:

a. To clear "F" grade/grades of any course/courses, a student will get two consecutive academic years complying with the time required for the degree. The best grade that the student can be awarded is "B+" (B plus).

b. A student may sit for the improvement examination in two consecutive academic years for any course/courses complying with the time required for the degree where the grade obtained is less than or equal to "C+" (C plus) and the best grade that a student can be awarded is "B+" (B plus). However, if the grade is not improved, the previous grade will remain valid.

Re-admission and Drop Out:

a. A student may be allowed re-admission for a maximum of two times to complete the B.Sc. in Nuclear Engineering program.

b. A student may seek re-admission provided he or she has at least 30% attendance in the previous semester.

c. A student failing to get the minimum required CGPA even after taking re-admission twice will be dropped out of the program.

Course Identification:

Every course has a unique course code. The letter prefix in any course code indicates the field or the discipline of the course, i.e.,

ACC	Accounting
CSE	Computer Science and Engineering
EEE	Electrical and Electronic Engineering
HUM	Humanities
MATH	Mathematics
ME	Mechanical Engineering
MSE	Materials Science and Engineering
NE	Nuclear Engineering
PHY	Physics
STAT	Statistics

The digits in the course code have the following meaning:

1st Digit – Represent year of the offered course, 2nd Digit – Represent semester of the offered course 3rd and 4th Digit – Represent offered course number (odd for theoretical course and even for laboratory or sessional course)

Semester-Wise Course and Credit Distribution of Different Years:

Year	Courses (Credits)	
First Year	First Semester: Theory Courses: 6 (3×5+2 Credits) Lab Courses: 2 (1.5×2 Credits) **Total: 20.0 Credits**	Second Semester: Theory Courses: 6 (3×5+2 Credits) Lab Courses: 2 (1.5×2 Credits) **Total: 20.0 Credits**
Second Year	First Semester: Theory Courses: 6 (3×5+2 Credits) Lab Courses: 2 (1.5×2 Credits) **Total: 20.0 Credits**	Second Semester: Theory Courses: 7 (3×6+2 Credits) Lab Courses: 1 (1.5 Credits) **Total: 21.5 Credits**
Third Year	First Semester: Theory Courses: 6 (3×5+2 Credits) Lab Courses: 2 (1.5×2 Credits) **Total: 20.0 Credits**	Second Semester: Theory Courses: 6 (3×5+2 Credits) Lab Courses: 2 (1.5×2 Credits) **Total: 20.0 Credits**
Fourth Year	First Semester: Theory Courses: 6 (3×5+2 Credits) Lab Courses: 1 (1.5 Credits) Industrial Training: 1 (2 Credits) **Total: 20.5 Credits**	Second Semester: Theory Courses: 4 (3×4 Credits) Lab Courses: 1 (2 Credits) Project: 1 (4 Credits) **Total: 18.0 Credits**
Grand Total: 160 Credits		

Syllabus for B.Sc. in Nuclear Engineering

List of Courses in Different Semesters

First Year First Semester

Course Code	Course Title	Credit Hour
NE 1101	Introduction to Nuclear Science and Engineering	3.0
PHY 1101	Mechanics, Waves & Oscillations, and Properties of Matter	3.0
MATH 1101	Differential and Integral Calculus	3.0
MATH 1103	Linear Algebra	3.0
STAT 1101	Theory of Probability and Statistics	3.0
HUM 1101	English for Professional Communication	2.0
ME 1102	Engineering Drawing Lab	1.5
ME 1104	Engineering Workshop Lab	1.5
	Total	**20.0**

First Year Second Semester

Course Code	Course Title	Credit Hour
NE 1201	Nuclear and Radiochemistry	3.0
PHY 1201	Electricity and Magnetism	3.0
ME 1201	Engineering Thermodynamics	3.0
MATH 1201	Ordinary Differential Equations	3.0
MATH 1203	Three-Dimensional Geometry and Vector Analysis	3.0
HUM 1201	Sociology and Engineering Ethics	2.0
PHY 1202	Physics Lab	1.5
NE 1202	Nuclear and Radiochemistry Lab	1.5
	Total	**20.0**

Second Year First Semester

Course Code	Course Title	Credit Hour
NE 2101	Radiation Science and Health Physics	3.0
NE 2103	Nuclear Technology for Non-power Applications	3.0
ME 2101	Heat and Mass Transfer	3.0
MATH 2101	Multi-variable Calculus and Partial Differential Equations	3.0
CSE 2101	Structured Programming	3.0
ACC 2101	Principle of Accounting	2.0
NE 2102	Radiation Science and Health Physics Lab	1.5
ME 2102	Thermal Engineering Lab	1.5
	Total	**20.0**

Second Year Second Semester

Course Code	Course Title	Credit Hour
NE 2201	Nuclear Fuel Cycle and Radioactive Waste Management	3.0
NE 2203	Nuclear Power Plant Economics	2.0
ME 2201	Fluid Mechanics and Machineries	3.0
ME 2203	Engineering Mechanics and Strength of Materials	3.0
EEE 2201	Electrical and Electronics Engineering	3.0
MATH 2201	Applied Mathematics for Engineering Physics	3.0
CSE 2201	Object Oriented Programming	3.0
EEE 2202	Electrical and Electronics Engineering Lab	1.5
	Total	**21.5**

Third Year First Semester

Course Code	Course Title	Credit Hour
NE 3101	Reactor Theory and Analysis I	3.0
NE 3103	Thermal Hydraulics of Nuclear Reactors	3.0
NE 3105	Nuclear Power System Engineering	3.0
MSE 3101	Materials Science	3.0
EEE 3101	Digital Electronics & Microprocessor	3.0
EEE 3103	Electrical Power Transmission and Distributions	2.0
NE 3102	Thermal Hydraulics Lab	1.5
EEE 3102	Digital Electronics & Microprocessor Lab	1.5
	Total	**20.0**

Third Year Second Semester

Course Code	Course Title	Credit Hour
NE 3201	Reactor Theory and Analysis II	3.0
NE 3203	Numerical Methods in Reactor Engineering Analysis	3.0
NE 3205	Materials for Nuclear Engineering Applications	3.0
NE 3207	Instrumentation and Measurement	3.0
NE 3209	Quantum Mechanics for Nuclear Phenomena	2.0
EEE 3201	Automation and Control Engineering	3.0
NE 3202	Instrumentation and Measurement Lab	1.5
NE 3204	Nuclear Design Project	1.5
	Total	**20.0**

Fourth Year First Semester

Course Code	Course Title	Credit Hour
NE 4101	Nuclear Disaster Management	3.0
NE 4103	Nuclear Power Plant Design and Features	3.0
NE 4105	Fusion Power Engineering	3.0
NE 4107	Security and Safeguards	3.0
NE 4109	Research Methodology, Scientific and Technical Writing	2.0
NE 4109	NEOP–1	3.0
NE 4102	Nuclear Simulation Lab	1.5
NE 4104	Industrial Training	2.0
	Total	**20.5**

Fourth Year Second Semester

Course Code	Course Title	Credit Hour
NE 4201	Advanced Nuclear Reactors Design and Features	3.0
NE 4203	Risk and Safety Analysis	3.0
NE 4205	Radiation Transport and Shielding	3.0
NE 4207	NEOP–2	3.0
NE 4200	Project Work	4.0
NE 4202	Reactor Operation and Experiments Lab	2.0
	Total	**18.0**

Optional Courses (NEOP)

Course Code	Course Title	Credit Hour
NEOP	Monte Carlo Methods for Nuclear System	3.0
NEOP	Computational Fluid Dynamics Analysis	3.0
NEOP	Nuclear Chemical Engineering	3.0
NEOP	Decommissioning Procedure and Management	3.0
NEOP	Plasma Physics	3.0
NEOP	Radiation Imaging	3.0
NEOP	Beams and their Applications	3.0
NEOP	Nanotechnology and its Applications	3.0
NEOP	Theory of Machines	3.0

First Year First Semester

NE 1101	Introduction to Nuclear Science and Engineering	Credits: 3.0 3.0 Hours/week

Properties of Atomic Nucleus: Concept of fundamental particles, fundamental forces, constituents of atom & nucleus, nuclear nomenclature, chart of nuclides, N-Z plot, magic nuclei, conservation of mass-energy, binding energy & separation energy, semi empirical mass formula.

Radioactivity: Nuclear stability and radioactive decay, decay law, half-life, mean life, decay constant, activity, types of decay, decay series, energetics of radioactive decay, decay dynamics, secular and transient equilibrium, measurement of half-life, Radiometric dating. Sources of radiation, Dosimetric quantities.

Nuclear Process: Concept of scattering and nuclear reaction, types of nuclear reaction, examples of binary nuclear reaction, parameters conserved in nuclear reaction, energetics of nuclear reaction, Q-values, reaction threshold energy.

Neutron Interaction and Nuclear Fission: Classification of neutron based on energy, modes of neutron's interaction of with matter, reaction cross section, energy dependence of cross section, calculation of cross section, neutron flux and reaction rate. Concept of nuclear fission, explanation of nuclear fission based on liquid drop model, schematic development of fission process, energy released in fission process, mass and energy distribution of fission products, neutron yield, energy spectra of fission neutrons, prompt and delayed neutron, delayed neutron emission scheme.

Fission Chain Reaction: Critical energy of fission, fissile and fertile materials, nuclear chain reaction, neutron multiplication factor, neutron life cycle in thermal and fast reactor, four factor and six factor formula, subcritical, critical and super critical state of nuclear reactor, concept of reactivity and reactivity coefficients.

Nuclear Power Development: Pros and Cons of different energy sources, energy scenario (global and Bangladesh perspectives), nuclear power as a substitute for fossil fuels, early history of reactor development, national nuclear energy program, worldwide development of nuclear power.

Nuclear Power and Research Reactor: Working principle of nuclear power plant (NPP), components of NPP, properties of nuclear fuel, moderator, coolant,

control materials, cladding and structural materials, basics of energy conversion, classification of nuclear reactor, characteristics of power reactors from Gen I to latest design (evolutionary and innovative design, small modular reactors), details of safety system, overview of major reactor accidents, types and characteristics of research reactor, applications of research reactor, space nuclear reactor, marine nuclear propulsion reactor, basics of fusion technology.

Recommended Readings

A. Fundamentals of Nuclear Science and Engineering, J. Kenneth Shultis, Richard E. Faw, Kansas State University Manhattan, Kansas, U.S.A. ISBN: 0-8247-0834-2, 2002.
B. Introduction to Nuclear Engineering, John R. Lamarsh, Anthony J. Baratta, 3rd Edition, ISBN 0-201-82498-1.
C. Nuclear Engineering Handbook, Kenneth D. Kok, Section II, ISBN 978-1-4200-5390-6
D. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307.
E. Raymond L. Murray, Nuclear Energy: An Introduction to the Concepts, Systems, and Applications of Nuclear Process, Sixth Edition, Elsevier Inc. 2009. ISBN: 978-0-12-370547-1.
F. David Bodansky, Nuclear Energy: Principles, Practices, and Prospects, Second Edition, Springer-Verlag New York, LLC, 2004. ISBN: 0-387-20778-3.

PHY 1101	**Mechanics, Waves & Oscillations, and Properties of Matter**	**Credits: 3.0** **3.0 Hours/week**

Introduction: The nature of physics, standards and units, unit conversions, overview of vectors.

Kinematics: Speed and velocity, constant velocity motion, acceleration, constant acceleration problems, acceleration of gravity, projectile motion, circular motion (uniform and non-uniform), relative velocity

Newton's Laws of Motion: Force and interactions, Newton's first, second and third laws, free body diagram, application of first law: particles in equilibrium, application of second law: dynamics of particles, working principle of satellites, frictional forces, dynamics of circular motion, fundamental forces of nature

Work and Energy: Work by constant and varying forces, kinetic energy- work energy theorem, power, gravitational potential energy, elastic potential energy,

conservative and non-conservative forces, force and potential energy, energy diagram

Momentum: Momentum and impulse, conservation of momentum, collisions: elastic and non-elastic, center of mass, energy of a system of particles, 2d-elastic collisions, ballistic pendulum.

Rotation of Rigid Bodies: Angular velocity, acceleration and momentum, relation between angular and linear kinematics, parallel axis theorem, moment of inertia, torque\rigid body rotation about a moving axis.

Oscillations: Periodic phenomena (oscillations and waves), spring-mass system, simple harmonic motion (SHM), energy in SHM, simple pendulum, physical pendulum, torsional pendulum, small angle approximation, simple harmonic oscillation, periodic phenomena (oscillations and waves), spring-mass system, simple harmonic motion, energy in SHM, simple pendulum, physical pendulum, torsional pendulum, damped oscillation, forced oscillation and resonance.

Recommended Readings

A. Young, Hugh, Lewis Ford and Roger Freedman. University Physics. Reading, MA: Addison-Wesley, 2003. ISBN: 0321500628.
B. David Halliday, Robert Resnick and Jearl Walker. Principle of Physics. Extended, 9th ed. Wiley, 2010, ISBN: 978-0-470-56158-4.
C. Serway, Raymond A., and John W. Jewett. Physics for Scientists and Engineers (with PhysicsNOW and InfoTrac). Belmont, CA: Thomson-Brooks/Cole, 2003. ISBN: 9780534408428.
D. Ohanian, Hans C. Physics. Vol. 1. 2nd ed., expanded. New York, NY: Norton, 1989. ISBN: 9780393957501.
E. Ohanian, Hans C., and John T. Markert. Physics for Engineers and Scientists. Vol. 1. 3rd ed. New York, NY: Norton, 2007. ISBN: 9780393930030.
F. French, A. P. Vibrations and Waves. New York, N.Y.: W.W. Norton & Company, January 1, 1971. ISBN: 9780393099362.
G. Tipler, Paul A., and Gene Mosca. Physics for Scientists and Engineers: Extended Version. New York: W.H. Freeman, 2003. ISBN: 9780716743897.
H. Giancoli, Douglas C. Physics for Scientists and Engineers with Modern Physics. Upper Saddle River, NJ: Pearson Education, 2007. ISBN: 9780130215192.
I. Resnick, Robert, David Halliday, and Kenneth S. Krane. Physics. New York, NY: Wiley, 2001. ISBN: 9780471401940.

MATH 1101	Differential and Integral Calculus	Credits: 3.0 3.0 Hours/week

Functions and Models: Functions, ways of representing a function, catalogue of essential functions, new functions from old functions, families of functions, inverse functions, and inverse trigonometric functions, exponential and logarithmic functions.

Limits and Continuity: The limit of a function, computing limits, precise definition of limit, continuity, limits at infinity, horizontal asymptotes, continuity of trigonometric, exponential and inverse functions, parametric equations and polar coordinates.

The Derivatives: Tangent lines and rates of change, the derivative function, and introduction to techniques of differentiation, the product and quotient rules, derivatives of trigonometric functions, the chain rule.

Differentiation Rules: Implicit differentiation, exponential growth and decay, derivatives of logarithmic functions, derivatives of exponential and inverse trigonometric functions, related rates, local linear approximation, differentials, hyperbolic functions, L'hospial's rule, indeterminate forms.

Applications of Differentiation: Increase, decrease and concavity of functions, absolute maximum and minimum values, relative extrema, graphing polynomials, rational functions, cusps and vertical tangents, rectilinear motion, Rolle's theorem, the mean-value theorem.

Integration: The indefinite integral, indefinite integrals and the net change theorem, integration by substitution, the definition of area as a limit-sigma notation, the definite integral, areas and distances, the substitution rule, integration by parts, trigonometric integrals, trigonometric substitution, integration of rational functions by partial fractions, strategy for integration, gamma and beta functions, improper integrals.

Applications of Integrals: Arc length, area between two curves, volume by slicing disks and washers, volumes by cylindrical shells, length of a plane curve, area of a surface of revolution, work, moments, centers of gravity and centroids, fluid pressure and force, hyperbolic functions and hanging cables.

Recommended Readings

A. Calculus: Early Transcendentals, James Stewart, 6th Edition, Thomson learning Inc., Belmont, CA 94002, USA, 2008.

B. Calculus: Early Transcendentals, Howard Anton, IrlBivens and Stephen Davis, 10th Edition, John Willy & Sons, Inc., NJ 07030, USA, 2012.
C. Calculus and Analytic Geometry, George B. Thomas and Ross L. Finney, 9th Edition, Addison-Wesley publishing company, Inc., USA, June 1998.
D. University Calculus: Early Transcendentals, Joel Hass, Maurice D. Weir, George B. Thomas, 2nd Edition, Addison-Wesley, 2012. ISBN: 9780321753878.
E. Thomas' Calculus: Global Edition /Matlab and Simulink Student Version 2012A, Mathworks The, George B. Thomas, Jr., Maurice D. Weir, Joel Hass, Frank R. Giordano, 12th Edition, Revised, Pearson Education, Limited, 2012. ISBN: 9781447935513.

MATH 1103	**Linear Algebra**	**Credits: 3.0** **3.0 Hours/week**

Review of Geometric Vectors: Review of geometries castors in R^2 and R^3 space, vectors in R^n, inner product, Euclidean inner product, norm and distance in R^n.

Matrices and Determinants: Notion of a matrix, types of matrices, matrix operations, laws of matrix algebra, transpose and inverse of a matrix, quadrate forms, adjoin matrix, tridiagonal matrix, block matrix, properties of determinants, types of determinants, minor, cofactors, expansion and evaluation of determinants, elementary row and column operations, row reduced echelon metrics.

System of Linear Equations: Linear equations, system of linear equations (homogeneous and non-homogeneous) and their solutions, linear dependence and independence of vectors, rank of a matrix, application of matrices and determinates for solving system of linear equations.

Transformations: Linear transformations, kernel and image of a linear transformation and their properties, matrix representation of linear transformations, change of bases.

Eigenvalues and Eigenvectors: Eigenvalues and eigenvectors, characteristic polynomial, diagonalization, clayey Hamilton theorem, applications.

Recommended Readings

A. H. Anton, and C. Rorres, Linear Algebra with Applications, 10th Edition.
B. B. Kolman & D. R. Hill, Elementary Linear Algebra with Applications, 9th Edition.

C. S. Lipshutz, Linear Algebra, Schaum's Outline Series.
D. David C. Lay, Linear Algebra and its Applications, 4th Edition.
E. W. K. Nicholson, Linear Algebra with Applications, 3th Edition.

STAT 1101	Theory of Probability and Statistics	Credits: 3.0 3.0 Hours/week

Introduction: Definition of statistics; population and sample; descriptive and inferential statistics; parameter and statistic; variables - categorical, discrete and continuous; measurement scales - nominal, ordinal, interval and ratio.

Processing Data: Frequency tables; graphs; histograms.

Summarizing Data: Measures of central tendency, dispersion and skewness.

Correlation and Regression: Pearson's correlation coefficient, simple and multiple linear regressions.

Probability: Axioms of probability; conditional probability; Bayes' theorem; independence of events

Random Variable: Probability distributions; joint, marginal and conditional distributions; independence of random variables.

Mathematical Expectation: Expectations of discrete and continuous random variables and their functions.

Basic Distributions: Binomial; Poisson; hypergeometric; uniform; exponential; normal.

Sampling Distribution: Basic idea; distributions of mean and proportion.

Estimation: Point estimation; confidence intervals.

Test of Hypothesis: Basic concepts, t test.

Recommended Readings

A. Ross, Sheldon. Introduction to Probability and Statistics for Engineers and Scientists.5th Edition. Academic Press, 2014.
B. Hossein Pishro-Nik. Introduction to Probability, Statistics, and Random Processes. Kappa Research, 2014. ISBN: 0990637204
C. Douglas C. Montgomery. Engineering Statistics, 5th Edition. John Wiley & Sons, 2010. ISBN: 978-0990637202

HUM 1101	English for Professional Communication	Credits: 2.0 2.0 Hours/week

Introduction: English as a language of science and technology communication.

Grammar: Tense, preposition, subject verb agreement, construction of sentences, transformation of sentences: active and passive transformation. Reported speech, grammatical error, conditionals.

Rhetoric: Introduction to rhetoric, rhetoric for technical communication and persuasive writing.

Developing Writing Skills: Principles of effective writing, pre-writing and writing process.

Letter and E-Mail Writing: Formal and informal, precis writing, following netiquette in e-mail writing.

Report Writing: Defining a report, classification of reports, structure of a report and writing reports.

Developing Reading Skills: Strategies of reading: skimming, scanning, inferencing, analyzing and interpreting variety of texts and text types.

Developing Listening Skills: Active listening skills, note-taking strategies, comprehending lectures, interviews and conversation. Practicing listening by using audio visual aids.

Developing Speaking Skills: Practicing situational dialogues; role play, narrating stories debates, interview sessions, extempore speech, effective oral presentation.

Critical Thinking and Analytical Skills: Analyzing and interpreting data, synthesizing information for reports and presentations, problem-solving through effective communication, developing logical arguments.

Recommended Readings

A. A Practical English Grammar, A. J. Thomson and A. V. Martinet, Oxford University Press.
B. Effective reading, G. Simon and M. Swan, Cambridge University Press.
C. Most Common mistakes in English Usage, T. J. Berry, McGraw-Hill.
D. Practicing Faster Reading, G. Mosback and V. Mosback, McGraw-Hill.
E. From Paragraph to Essay, M. Imhoof, H. Hudson, Harlow Longman.

ME 1102	Engineering Drawing Lab	Credits: 1.5 3.0 Hours/week

Introduction to mechanical drawing, instrument and their uses, first and third angle projections, orthographic drawings, missing lines and views, sectional views and conventional practices, auxiliary views, isometric views, surface development, computer aided drawing (CAD).

ME 1104	Engineering Workshop Lab	Credits: 1.5 3.0 Hours/week

Foundry: Introduction to foundry, tools and equipment; Patterns: function, pattern making; Molding: molding materials sand preparation, types of molds, procedure; Cores: types, core making materials; Metal melting and casting; Inspection of casting and casting defects.

Machine Tools: Introduction about different types of tools; hand tools, power tools, Safety rules for workshop practices

Practices on Machine Tools: Lathe machine, drilling machine, shaper machine, milling machine, grinding machine.

Metal Joints: Riveting, grooving, soldering.

Welding Practice: Electric arc welding, spot welding, pressure Welding, TIG, MIG.

First Year and Second Semester

NE 1201	Nuclear and Radiochemistry	Credits: 3.0 3.0 Hours/week

Introduction: Atom, atomic nucleus, atomic masses, mass defect, nuclear binding energy, nuclear stability, atomic models.

Radioactive Decay and Nuclear Reactions: Radioactive decay, decay modes, decay series, Transient and Secular Equilibrium, radio-dating. Nuclear reaction, types of nuclear reactions, Q value of reaction.

Elements of Radiation Chemistry: Interaction of ionizing radiation with matter, Units for measuring radiation absorption and radiation energy, Radiolysis of water and aqueous solutions.

Applications of Radiation & Radioisotopes: General principles of using radioisotopes, radio techniques of radioisotopes production, application of ionizing radiation for environmental protection, food irradiation, sterilization of medical products and drugs. applications of radiotracers in trace analysis of elements and compounds, neutron activation analysis, isotope dilution analysis. Glass chemistry, radiation chemistry of polymers, biological polymers, solvent extraction and ion exchange in radiochemistry.

Reactor Coolant Chemistry: Effects of radiation on coolant chemistry, chemistry parameters (e.g., pH, conductivity, dissolved oxygen, total gas content, chlorides), reasons and means of control of chemistry parameters, activation and corrosion product transport in coolant system.

Nuclear Fuel Cycle Chemistry: Uranium and plutonium compounds and their properties, chemistry of uranium mining, milling, conversion, and fuel fabrication, nuclear waste reprocessing methods- Aqueous (e.g., Purex Process) and pyro processing.

Trans-uranium Elements: Production of transuranium nuclides, separation of transuranium elements, solid-state properties of transuranium metals and compounds.

Recommended Readings

A. Attila Ve´rtes, Sa´ndor Nagy, Zolta´n Klencsa´r, Rezso˝ G. Lovas, Frank Ro¨sch, Handbook of Nuclear Chemistry, Second Edition, ISBN 978-1-4419-0719-6.

B. Benedict, M., T. H. Pigford, and H. W. Levi. Nuclear Chemical Engineering. 2nd ed. Chapter 3-5, Columbus, OH: McGraw-Hill, 1981. ISBN: 9780070045316.
C. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307.
D. Essentials of Nuclear Chemistry, H.J Arnikar, Revised Fourth Edition, 2004.
E. Fundamentals of Nuclear Science and Engineering, J. Kenneth Shultis, Richard E. Faw, Kansas State University Manhattan, Kansas, U.S.A. ISBN: 0-8247-0834-2, 2002.
F. Introduction to Nuclear Engineering, John R. Lamarsh, Anthony J. Baratta, 3rd Edition, ISBN 0-201-82498-1.

PHY 1201	Electricity and Magnetism	Credits: 3.0 3.0 Hours/week

Electric Field: Introduction to electric field, math review related to electric field, electric fields and discrete charge distributions, electric fields and continuous charge distributions, electric field line and electric dipole.

Gauss's Law: Charge and electric flux, calculating electric flux, Gauss's law, application of gauss's law, charges on conductors.

Electric Potential: Electric potential energy, electric potential, calculating electric potential, equipotential surfaces, potential gradient.

Capacitors: Conductors and insulators, conductors as shields, capacitors and capacitance, capacitors in series and parallel, energy storage in capacitors and electric field energy, capacitors and dielectrics, Gauss's law in dielectric.

Circuits: Current, current density, resistance and Ohm's law, resistivity, batteries and circuit elements, electromotive force and circuits, energy and force in electric circuit, DC circuits, DC circuits with capacitors.

Magnetic Fields and Force: Magnetic field, magnetic field lines and magnetic flux, motion of charge particles in magnetic field, applications of motion of charged particles, magnetic force on a current carrying conductor, force and torque on a current loop.

Sources of Magnetic Field: Magnetic field of a moving charge, magnetic field of a current element, magnetic field of straight current carrying conductors, Biot-Savart law, ampere's law and their applications.

Electromagnetic Induction and Inductance: Faraday's law, Lenz's law, motion of electromotive force, induced electric field, eddy currents,

displacement current and maxwell's equation, pointing vector, mutual and self-inductance, magnetic field energy, RL circuit.

Oscillating circuit: Undriven RLC circuits, driven RLC circuits.

Electromagnetic Waves: Maxwell's equations and electromagnetic waves generation, plane electromagnetic waves and speed of light, sinusoidal electromagnetic waves, energy and momentum in electromagnetic waves, dipole radiation.

Recommended Readings

A. Young, Hugh D., and Roger A. Freedman. University Physics with modern Physics. San Francisco, CA: Addison-Wesley, 2003. ISBN: 9780805386844.
B. David Halliday, Robert Resnick and Jearl Walker. Principle of Physics. Extended, 9th ed. Wiley, 2010, ISBN: 978-0-470-56158-4.
C. Serway, Raymond A., and John W. Jewett. Physics for Scientists and Engineers (with Physics NOW and InfoTrac). Belmont, CA: Thomson-Brooks/Cole, 2003. ISBN: 9780534408428.
D. Ohanian, Hans C. Physics. Vol. 1. 2nd ed., expanded. New York, NY: Norton, 1989. ISBN: 9780393957501.
E. Ohanian, Hans C., and John T. Markert. Physics for Engineers and Scientists. Vol. 1. 3rd ed. New York, NY: Norton, 2007. ISBN: 9780393930030.
F. Physics, David Halliday, Robert Resnic, Part-II ISBN 0 85226 355 4, Second edition.
G. Physics, David Halliday, Robert Resnic, Kenneth S. Krane, Volume-II, 5th edition.

ME 1201	Engineering Thermodynamics	Credits: 3.0 3.0 Hours/week

Introduction and Basic Concepts: Scope and relevance of Engineering Thermodynamics, thermodynamic systems, macroscopic and microscopic descriptions, properties and state of a system, thermodynamic equilibrium, processes and cycles, zeroth law and temperature, pressure and specific volume.

Work, Energy, and First Law: Quasi-equilibrium expansion or compression processes, work and internal energy, energy conservation and the first law of thermodynamics, applications of the first law in closed and open systems, polytropic process, enthalpy, specific heats.

Properties of Pure Substances: Definition and classification of pure substances, Phases and Phase-Change Processes of Pure Substances, Thermodynamic Property Diagrams and Property Tables, Equations of State.

First Law Applied to Flow Processes: Control volume, mass and energy balance in steady flow processes, steady-flow analysis: nozzles and diffusers, turbines and compressors, throttling devices, heat exchanges.

Second Law and Entropy: Heat engines, heat pumps, and refrigerators, statements of the second law of thermodynamics, Carnot cycle and its efficiency, entropy and its properties, entropy change in reversible and irreversible processes, availability and exergy.

Thermodynamic Relations: Maxwell's equations, relations among thermodynamic properties, Joule-Thomson effect, Clausius-Clapeyron equation, relationships involving specific heats.

Thermodynamic Analysis of Energy Conversion Processes: Vapor power cycles: Rankine cycle and its Efficiency, Reheat and Regenerative Rankine Cycles, Nuclear power plant cycle analysis, Gas power cycles: Reciprocating Engines, Otto and Diesel Cycles, Gas Turbines, Brayton cycle and its modifications, Refrigeration Cycles: fundamentals of refrigeration, Vapor compression and vapor absorption.

Recommended Readings

A. Çengel, Y. A., & Boles, M. A. (2020). Thermodynamics: An Engineering Approach (9th ed.). McGraw-Hill Education. ISBN: 978-1259822674
B. Nag, P. K. (2017). Engineering Thermodynamics (6th ed.). McGraw Hill. ISBN: 978-9339204045
C. Moran, M. J., Shapiro, H. N., Boettner, D. D., & Bailey, M. B. (2020). Fundamentals of Engineering Thermodynamics (9th ed.). John Wiley & Sons. ISBN: 978-1119721437
D. Potter, M. C., Somerton, C. W., & Ganesan, V. (2021). Schaum's Outline of Thermodynamics for Engineers (5th ed.). McGraw Hill. ISBN: 978-1264253536.
E. Rajput, R. K. (2007). A Textbook of Engineering Thermodynamics (3rd ed.). Laxmi Publications. ISBN: 978-0763782726
F. Zohuri, B., & McDaniel, P. (2015). Thermodynamics in Nuclear Power Plant Systems. Springer International Publishing AG. ISBN: 978-3319231255.

MATH 1201	Ordinary Differential Equations	Credits: 3.0 3.0 Hours/week

Differential Equations and Their Solutions: Concepts of variables parameter etc. Classifications of differential equations methods of solution initial value problem, boundary value problems.

First Order Differential Equations: Exact differential equations and integrating factor, separable equations and their solving methods, linear and Bernoulli equations, differences between linear and nonlinear equations.

Second and Higher Order Differential Equations: Homogeneous and no-homogeneous equations, reduction of order, undetermined coefficient methods, variation of parameter, Cauchy-Euler equations.

Series Solutions of Linear Equations: Review of power series, series solutions near an point, Euler equations, regular singular points, series solutions near a regular singular point, Bessel's equation, convergence and divergence series.

Systems of First Order Linear Differential Equations: Differential operators, linear system in normal form, homogeneous linear systems with constant coefficients, nonhomogeneous linear systems.

Application of Differential Equations: Orthogonal and oblique trajectories, problems in mechanics, vibration of mass on spring, free, damped motion, forced motion, electric circuit problems, problems in nuclear sectors.

Approximate Methods of Solving 1st Order Equations: Successive approximation methods.

Recommended Readings

A. Differential Equations, 3rd Edition, Shepley L. Ross, John Wiley & Sons, Inc., USA, 2011
B. Elementary Differential Equations and Boundary Value Problems, 9th Edition, William E. Boyce and Richard C. DiPrima, John Wiley & Sons, Inc., USA, 2009.
C. Differential Equations: An Introduction to Modern Methods and Applications, 2nd Edition, James R. Brannan and William E. Boyce, John Wiley & Sons, Inc., USA, 2011.
D. Elementary Differential Equations, 6th Edition, C. Henry Edwards, David E. Penney and David Calvis, Pearson Education, Inc., Upper Saddle River, New Jersey, USA, 2008.

E. Differential Equations: Crash Course, Richard Bronson and Erin J. Bredensteiner, Schaum's Outline Series, The McGraw-Hill Companies, Inc., USA, 2003.
F. Differential Equation Demystified: A Self Teaching Guide, Steven G. Krantz, Demystified Series, The McGraw-Hill Companies, Inc., USA, 2005.

MATH 1203	Three-Dimensional Geometry and Vector Analysis	Credits: 3.0 3.0 Hours/week

Coordinate Systems and Vectors: Three-dimensional coordinate systems, Vectors in three dimensions, The dot and cross products of two and more vectors, Transformation of coordinates from Cartesian to cylindrical and spherical coordinates, volume elements, planar angle and solid angle, Laplacian operator in cylindrical and spherical coordinate systems.

Planes and Straight Lines: Difference between two points, Section formula. Projections, Direction cosines, equations of planes and straight lines.

Different Types of Solids: Equations of spheres, ellipsoids, hyperboloids, paraboloids, cones, cylinders (basic definitions and properties only).

Vector Functions: Vector functions and space curves, derivatives and integrals of vector functions, arc length and curvature, motion in space: velocity and acceleration, planetary motion and satellite.

Vector Calculus: Vector fields, line integrals, the fundamental theorem for line integrals, independence of path, conservative vector fields. Gradient, divergence and curl. Parametric surfaces and their areas. Surface integrals, applications of surface integrals. Green's, Stokes' and divergence theorems. Applications of Green's, Stokes' and Divergence theorems for solving engineering problems.

Applications: Applications of Navier-Stroke's Equations, Stoke's Equations, Green's Theorems, Divergence theorem for solving engineering problems.

Recommended Readings

A. Kreyszig, E. (2011). Advanced Engineering Mathematics. John Wiley & Sons. ISBN: 9780471154969.
B. Anton, I.C. Bivens and S. Davis, Calculus: Early Transcendentals (10th Edition), Wiley.
C. J. Stewart, Calculus (6th Edition), Thomson Learning.
D. R.T. Smith, R. B. Minton, Calculus (4th Edition), McGrawHill

E. R. Larson, B. H. Edwards, Calculus: Early Transcendentals (5th Edition), Cengage Learning
F. G.B. Thomas, M.D. Weir and J. Hass, Thomas' Calculus (12th Edition) Addison Wesley.

HUM 1201	Sociology and Engineering Ethics	Credits: 2.0 2.0 Hours/week

Socialization and Deviance: Socialization, life course, and aging, social interaction in everyday life, groups, networks, and organizations, crime and deviance.

Social Stratification: inequality, global inequality, gender inequality, Race and ethnicity.

Socialization and Culture: Families and intimate relations, education, religion, politics, economics and work organizations, health, illness, and sexuality, urbanization & population.

Sociology and Environment: Environment, globalization and social change.

Engineering Ethics: The importance of ethics in science and engineering, moral analysis, the role of codes of ethics, virtues and the psyche, habits and morals; distinguishing exterior and interior morality, hierarchy of moral values, truth in actions and words, withholding truth and spreading truth, whistle blowing, privacy issues, recognition from scientific publication, plagiarism, conflict of interest, ethics in the global engineering profession - fairness in supervising, fairness in contracting; intellectual property and society, resource allocation by merit.

Recommended Readings

A. Mitchell Duneier, Richard P. Appelbaum, Introduction to Sociology, Deborah Carr, 8th Edition, W.W. Norton & Company Incorporated, 2011. ISBN: 9780393912289.
B. Anthony Giddens et al. Essentials of Sociology, 4th Edition. W W Norton & Company Incorporated, 2013. ISBN: 9780393137453.
C. Diana Kendall. Sociology In Our Times: The Essentials. 9th Edition. Cengage Learning, 2011. ISBN: 9781111831578.
D. Hughes, Michael and Carolyn L. Kroehler. Sociology: The Core, 8th edition, McGraw-Hill, 2008. ISBN: 007-0299636-6.
E. Edition, Pearson College Division, 2008. ISBN: 9780205672486.

F. Theodor W. Adorno, Introduction to Sociology, Stanford University Press, 2002.ISBN: 9780804746830.
G. Seebauer, E. G. and R. L. Barry, Fundamentals of Ethics for Scientists and Engineers, 1st Edition, Oxford University Press, 2001.
H. Davis, M., ed. Engineering Ethics. Burlington, VT: Ashgate Publishing Co., 2005. ISBN: 0754625249.

PHY 1202	**Physics Lab**	**Credits: 1.5** **3.0 Hours/week**

Laboratory based on PHY 1101, PHY 1201.

NE 1202	**Nuclear and Radiochemistry Lab**	**Credits: 1.5** **3.0 Hours/week**

Laboratory based on NE 1201.

Second Year and First Semester

NE 2101	Radiation Science and Health Physics	Credits: 3.0 3.0 Hours/week

Basics of Radiation: Atomic & nuclear radiation, ionizing & non-ionizing radiation, properties of various charged and uncharged radiation particles, natural & man-made sources.

Interaction of Radiation with Matter: Interaction of charged particles (alpha, beta) with matter: mechanism of energy loss, energy transfer, range–energy relationship, stopping power, slowing down time, theory of bremsstrahlung. Phenomena associated with charged-particle tracks- delta rays, restricted stopping power, specific ionization, linear energy transfer, energy straggling, range straggling, multiple coulomb scattering. Interaction of electromagnetic radiation (gamma & X-ray) with matter: Attenuation of neutral particle beams, attenuation coefficients, half value and tenth value thickness. Interaction mechanisms of photons- photoelectric effect, Compton scattering, pair production, photonuclear reactions, energy-transfer and energy-absorption coefficients. Interaction of neutrons with matter- Interaction mechanisms and cross sections.

Radiation Dosimetry: Quantities and units- exposure, absorbed dose, equivalent & effective dose, dose conversion factor, measurement of exposure and absorbed dose, dose calculations, kerma, microdosimetry, specific energy, linear energy.

Chemical and Biological Effects of Radiation: Time frame for radiation effects, chemical stage, effects on biological cell, interaction with DNA, biological effects, acute radiation syndrome, delayed somatic effects, genetic effects, deterministic & stochastic effects, dose–response relationships, latent period, factors affecting dose response.

Radiation Detection and Monitoring: Necessity of radiation measurements, radiation effects used in the detection and measurement, Particle-counting instruments- gas-filled particle counters (ionization chambers, proportional and Geiger-Muller counters), scintillation counters, semiconductor detectors, gamma-ray spectroscopy, Cerenkov detectors. Neutron measurements-detection reactions, neutron counting with a proportional counter, long counter, proton recoil counter. Dose-measuring instruments: pocket dosimeters, film-badge dosimeters, thermoluminescent dosimeters, albedo neutron dosimeter,

optically stimulated luminescence, electronic dosimeters, chemical dosimeters, neutron dosimetry, radiation survey meters.

Counting Statistics: Probability distributions (Binomial, Poisson, Normal), standard deviation, coefficient of variation, standard error of the difference between means, counting radioactive sample, minimum detectable activity, optimization of counting time, reliability of a counting system: chi-square, instrument response.

Radiation Protection: Objective of radiation protection, principles for control of external and internal exposures, limits on intake, ICRP safety criteria, radiation safety guides.

Recommended Readings

A. Cember. H. and Johnson. E. T. Introduction to Health Physics. 4th Ed.
B. James E. Turner, Atoms, Radiation, and Radiation Protection, John Wiley&Sons, Inc. (2008), ISBN: 9783527616985.
C. Shultis. K. J. and Faw. E. R. Fundamentals of Nuclear Science and Engineering, J. Kenneth Shultis, Richard E. Faw, Kansas State University Manhattan, Kansas, U.S.A.ISBN: 0-8247-0834-2, 2002.
D. Knoll G. F. Radiation Detection & Measurements, 3rd Ed., John Wiley, 2005.
E. Lamarsh, J. R. Introduction to Nuclear Engineering, 3rd Edition, Addison-Wesley, 2001.
F. Edward L. Alpen, Radiation Biophysics, 2nd Edition, Academic Press (1998), ISBN: 9780080540207.
G. Faiz M. Khan, The Physics of Radiation Therapy, 4th Edition, Lippincott Williams & Wilkins, 2012, ISBN: 9781451149135.
H. Frank Herbert Attix, Introduction to Radiological Physics and Radiation Dosimetry, John Wiley & Sons, 2008, ISBN: 9783527617142

NE 2103	Nuclear Technology for Non-power Applications	Credits: 3.0 3.0 Hours/week

Nuclear Technology in Industry and Research: Production of Radioisotopes, Tracer Applications of Radioisotopes**:** leak detection, flow rate measurements, labeling of chemical reagents with radionuclides to study complex chemical reactions, etc., Tracer Dilution Techniques: blood volume measurement, mixing time of two fluid, residence times. Application of the effects on radiation by matter: Radiography: X-ray and gamma- ray radiography, neutron radiography, beta radiography, thickness gauging, density gauges, liquid level gauges etc. Application of the effects in matter by radiation**:** food preservation, sterilizing,

insect control, etc. Neutron activation analysis, Neutron Scattering, Nondestructive testing (NDT): nuclear material testing and inspection, Technology of Hydrogen Production and Water desalination.

Nuclear Medicine: Diagnostic Techniques: Use of X-rays**,** SPECT imaging**,** PET imaging, Hybrid Imaging: SPECT/CT and PET/CT, NMR, MRI, diagnostic uses of radioisotopes**,** Therapeutics: fundamental radiobiology and its applications to radiation oncology, X-rays therapy, hadron therapy, brachytherapy, quality assurance, computers in treatment planning, in vitro applications: RIA, molecular biology techniques using radionuclide methods**.**

Accelerators in Applied Research and Technology: Accelerator based fundamental research, application of accelerator in medical and industry.

Applications in Agriculture and Food Processing: Pest control, Crop Production Enhancement, Improving Animal Health, Food Processing, Food Irradiation, Sterilization, Eradication of Pests.

Geological aspects of Nuclear Materials: Mineralogy of nuclear materials, Geographical distribution of nuclear minerals in world, Exploration & exploiting of nuclear minerals, Geochemical analysis and their interpretation, mining and economics of commercial exploration of nuclear deposits, radiation safety aspects of mining and environment.

Recommended Readings

A. J. Kenneth Shultis & Richard E. Faw, Fundamentals of Nuclear Science and Engineering, Kansas State University Manhattan, Kansas, U.S.A.
B. Simon R. Cherry, James A. Sorenson &Michael E. Phelps, Physics in Nuclear Medicine, 4th edition, Elsevier, ISBN: 978-1-41605198-5
C. Yves Lemoigne & Alessandra Caner, Radiotherapy and Brachytherapy, European Scientific Institute Site d'Archamps France, Spriger, ISBN 978-90-481-3096-2 (PB)
D. Namira Negm, Transfer of Nuclear Technology under International Law, ISBN 9789004175273
E. Lamarsh, John R., and Anthony J. Baratta. Introduction to Nuclear Engineering. 3rd ed. Englewood Cliffs, NJ: Prentice Hall, 2001. ISBN: 9780201824988.
F. B H Brown, R H Smallwood, D C Barber, P V Lawford and D R Hose, Medical Physics and Biomedical Engineering, Institute of Physics Publishing, Dirac House, Temple Back, Bristol BS1 6BE, UK, ISBN: 0750303670 (hbk),

G. Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt Jr., John M. Boone, The Essential Physics of Medical Imaging, Third Edition, Lippincott Williams & Wilkins, ISBN-13: 978-0781780575
H. Manson Benedict, Thomas H. Pigford, Hans Wolfgang Levi, Nuclear Chemical Engineering, 2nd Edition

ME 2101	Heat and Mass Transfer	Credits: 3.0 3.0 Hours/week

Introduction to Heat and Mass Transfer: Definition and significance of heat and mass transfer, modes of heat transfer: conduction, convection, radiation; introduction to mass transfer, basic equations and principles of heat and mass transfer, Dimensionless Numbers in Heat Transfer (Reynolds Number, Nusselt Number, Prandtl Number, Grashof Number, Rayleigh Number)

Conduction Heat Transfer: Fourier's law of heat conduction; one-dimensional steady-state conduction; thermal resistance concept; extended surfaces and fins, two-dimensional and transient conduction.

Convection Heat Transfer: Convection mechanisms: forced and natural convection; boundary layer concepts, heat transfer coefficients and correlations, external and internal flow heat transfer.

Radiation Heat Transfer: Blackbody radiation and Stefan Boltzmann law; radiation properties and behavior of surfaces; radiation exchange between surfaces; radiative heat transfer in participating media. Radiation shields and enclosures.

Heat Exchangers: Classification and types of heat exchangers; analysis and design of shell-and-tube heat exchangers; finned tube heat exchangers; compact heat exchangers.

Mass Transfer: Diffusion and Fick's law; mass transfer coefficients; mass transfer in fluids. Mass transfer with chemical reaction.

Heat and Mass Transfer with Phase Change: Evaporation and condensation; boiling and condensation heat transfer; solidification and melting

Heat and Mass Transfer in Industrial Processes: Heat transfer in combustion processes, heat transfer in manufacturing and processing industries, mass transfer in separation processes (e.g., distillation, absorption).

Numerical Methods in Heat and Mass Transfer: Finite difference methods; finite element methods; analytical solutions and approximate methods, computer-aided analysis and simulations.

Recommended Readings

A. Frank P. Incropera, David P. DeWitt, Theodore L. Bergman, and Adrienne S. Lavine, Introduction to Heat Transfer, 6th Edition, John Wiley & Sons, 2019
B. J.P. Holman, Heat Transfer, 10th Edition, McGraw-Hill Education, 2009
C. W.M. Kays, M.E. Crawford, and B.A. Weigand, Convective Heat and Mass Transfer, 4th Edition, McGraw-Hill Education, 2005.
D. Sadik Kakac, Hongtan Liu, and Anchasa Pramuanjaroenkij, Heat Exchangers: Selection, Design, and Construction, 2nd Edition, CRC Press, 2012.
E. Michael F. Modest, Radiative Heat Transfer, 3rd Edition, 2013.

MATH 2101	Multi-variable Calculus and Partial Differential Equations	Credits: 3.0 3.0 Hours/week

Functions of Several Variables: Graphs of functions of two variables, limits and continuity, partial derivatives, differentiability, linearization and differentials, the chain rule, partial derivatives with constrained variables.

Extreme Values of a Function: Extrema of functions of several variables, Lagrange multipliers.

Multiple Integrals: Double integrals and iterated integrals, area as a double integral, triple integrals, volume as a triple integral.

General Multiple Integrals: General multiple integrals, change of variables in multiple integrals, Jacobians.

Concept and Solution of First Order Equations: First order equations, complete integral, general solutions, method of characteristics for linear equations.

Second Order Equations: Second order equations, classifications, reduction to canonical forms, characteristic curves**.**

Fourier Series: Fourier series, Fourier sine and cosine series, applications.

Separated Variables Solutions: Boundary value problems related to linear equations, separated variables solutions of wave, heat, diffusion and Laplace's equation.

Special Functions: Solution of the practical problems involving cylindrical and spherical symmetry, boundary value problems involving special functions.

Recommended Readings

A. Differential Equations, 3rd Edition, Shepley L. Ross, John Wiley & Sons, Inc., USA, 2011
B. Elementary Differential Equations and Boundary Value Problems, 9th Edition, William E. Boyce and Richard C. DiPrima, John Wiley & Sons, Inc., USA, 2009.
C. Differential Equations: An Introduction to Modern Methods and Applications, 2nd Edition, James R. Brannan and William E. Boyce, John Wiley & Sons, Inc., USA, 2011.
D. Elementary Differential Equations, 6th Edition, C. Henry Edwards, David E. Penney and David Calvis, Pearson Education, Inc., Upper Saddle River, New Jersey, USA, 2008.
E. Differential Equations: Crash Course, Richard Bronson and Erin J. Bredensteiner, Schaum's Outline Series, The McGraw-Hill Companies, Inc., USA, 2003.
F. Differential Equation Demystified: A Self Teaching Guide, Steven G. Krantz, Demystified Series, The McGraw-Hill Companies, Inc., USA, 2005.

CSE 2101	Structured Programming	Credits: 3.0 3.0 Hours/week

Review of basics: Basic i/o, data type, conditional logic, switch case, character, ascii value, reading and writing character, integer to character conversion

Operators: Arithmetic, relational, logical and bitwise operators, operator precedence and associativity, arithmetic expression evaluation, short cut operator.

Functions- i: Basic functions, void functions with no parameters

Loops: Looping basic, necessity of loops, while loop, loop condition, body, initialization, increment, for loops, part of for loops, do while loop, entry-controlled loops, exit controlled loops, example, formulating problems using loops.

Formatted i/o: Specifying width using format specifier in printf and scanf in details.

Nested Loop: Nesting of two loops, example, nesting of independent loops inside one, example, nesting of more than two loops.

Functions - ii: Functions with return type and trivial parameters, local and global variables, call by value, library functions/header files concept.

Arrays: Basics of array, necessity, declaration, accessing through indices, accessing using loops, initialization, example, two dimensional arrays, declaration, initialization, accessing through loops, example, multidimensional arrays, example.

Functions - iii: Passing arrays in a function as parameter, call by reference, recursion, scope visibility and lifetime of variable.

Strings: Basics, difference between string and character array, i/o, basic operations without using library functions, array of strings

String Library: Basic string operations, length, compare, concatenate, substring, reverse.

Structures: Basics, necessity, declaration, accessing, initialization, array of structures.

Pointers: Basics, uses, pointer operation, call by reference using pointers, pointer for 1d/2d/3d array, structure, pointer expression, array of pointers, function returning pointers.

Dynamic Memory Allocation: Basics, uses, malloc, free, calloc, realloc.

File operation: Basics, uses, file opening, closing, file i/o

Recommended Readings

A. Kernighan, Brian, and Dennis Ritchie. The C Programming Language. 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1988. ISBN: 9780131103627.
B. Schildt. Teach Yourself C++, Tata McGraw-Hill Education, 1998. ISBN: 9780074638705.
C. Perry, Greg, C Programming Absolute Beginner, 3rd Edition, Que Publishing; 3 edition (August 17, 2013), ISBN-10: 0789751984.
D. Problem Solving and Program Design in C - Jeri R. Hanly, Elliot B. Koffman, Pearson; 8 edition (February 27, 2015) 8th Edition, ISBN-10: 0134014898.
E. Programming in Ansi C- Balaguruswamy, Third Edition, McGraw-Hill; 7th edition (December 9, 2017), ISBN-10: 9789339219666.

ACC 2101	Principle of Accounting	Credits: 2.0 2.0 Hours/week

Introduction: A study of accounting as an informational system, fundamental accounting concepts and principles used to analyze and record business transactions.

Recording System: Double-entry book keeping and accounting, accounting equation, measuring and recording business transactions.

Accounting Cycle: Journal, ledger, trail balance, preparation of financial statements considering adjusting and closing entries.

Financial Statements analysis and Interpretation: Ratio analysis – tests for profitability, liquidity, solvency and overall measure.

Cost in General: Objectives and classifications. Overhead costs: Allocation and apportionment. Product costing: Cost sheet under job costing, process costing, costing by products and joint products.

Marginal Costing: Tools and techniques; Cost-volume-profit analysis: Meaning, break-even analysis, contribution margin technique, sensitivity analysis, designing the optimal product mix.

Relevant Costing: Analysis, profitability within the firm.

Guidelines for Decision-Making: Short-run decisions. Long run planning and control: Capital budgeting; the master budget, flexible budget and standard cost, variance analysis.

Recommended Readings

A. Accounting Principles- Jerry J. Weygandt, Donald E. Kieso, and Paul D. Kimmel Publisher: Wiley;
B. Cost Accounting: Theory and Practice- Bhabatosh Banerjee; Publisher: Prentice-Hall of India Pvt. Ltd;
C. Cost and Management Accounting- Duncan Williamson; Publisher: Prentice Hall.
D. Introduction to Management Accounting- Charles T. Horngren, Gary L. Sundem, William O. Stratton, and Jeff Schatzberg; Publisher: Prentice Hall;
E. Managerial Accounting 10/e Update Edition- Ray; Noreen, Eric Garrison; Publisher: McGraw-Hill.
F. Fundamental Accounting Principles- Kermit Larson, John Wild, and Barbara Chiappetta; Publisher: McGraw-Hill/Irwin

NE 2102	**Radiation Science and Health Physics Lab**	**Credits: 1.5 3.0 Hours/week**

Laboratory based on NE 2101.

ME 2102	**Thermal Engineering Lab**	**Credits: 1.5 3.0 Hours/week**

Laboratory based on ME 1201 and ME 2101.

Second Year and Second Semester

NE 2201	Nuclear Fuel Cycle and Radioactive Waste Management	Credits: 3.0 3.0 Hours/week

Fission Fuel Cycle: Characteristics of nuclear fuel, viable fuel materials, concept &steps of nuclear fuel cycle (NFC), types of NFC, fuel cycle steps of various power reactors. Front end of the fuel cycle: classification of uranium ore body, methods of uranium mining, milling process, uranium purification and conversion, methods of enrichment, reconversion process, fuel pellet fabrication, fabrication process of fuel rod & assembly, fuel assemblies of various reactors. Back end of the fuel cycle: different steps, characteristics of spent nuclear fuel (SNF), possible SNF management strategies, characteristics of various interim dry & wet storage option, design consideration of spent fuel pool, spent fuel shipping cask and safety during shipment, methods of spent fuel reprocessing- aqueous processes, pyro-processes, and possible disposal options.

In-core Fuel Management: Objectives of fuel and poison management, material balance in the nuclear fuel cycle, nuclear fuel demand, supply of nuclear fuel, nuclear fuel performance, cycle burnup, discharge burnup, cycle length, fuel cycle management in breeder reactors viz conversion ratio & breeding ratio, breeding gain, doubling time etc. single and multi-batch refueling, various refueling methods.

Waste Management: Definition and characteristics of radioactive waste, sources of radioactive waste, classification of radioactive waste, waste generated from different steps of NFC, solid, liquid & gaseous waste of nuclear reactors, objectives and principles of radioactive waste management (RWM), different steps of RWM, details of predisposal activities, waste characterization, waste treatment and conditioning. Design of nuclear waste package, fabrication and monitoring of nuclear waste package, materials for waste immobilization, materials for waste containers, backfills and seals, methods considered for permanent disposition of nuclear waste, host medium of geological disposal, candidate rock types for geological repository, development of geological repository. regulatory requirements & methods of transportation, burial & surveillance of waste.

Advanced Fuel Cycle: Innovative fuel cycles, fuel cycle options for innovative reactors, partitioning and transmutation (P&T), transmutation devices & process for the advanced fuel cycle, thorium fuel cycle, relative waste arising from alternative nuclear fuel cycles.

Recommended Readings

A. Nuclear Waste Management, Science, Technology, and Policy, Man-Sung Yim, Springer Nature B.V. 2022, ISBN 978-94-024-2106-4
B. Nuclear Engineering Handbook, Kenneth D. Kok, Section II, ISBN 978-1-4200-5390-6
C. Introduction to Nuclear Engineering, John R. Lamarsh, Anthony J. Baratta, Third Edition, Chapter 4, ISBN 0-201-82498-1.
D. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307.
E. Introduction to Nuclear Power, Hewit & Collier, 2nded.
F. Applied Reactor Technology, Henryk Anglart, 2011, Chapter 7
G. Nuclear Reactor Enginering, Glasstone and Sesonske, Third ed. Chapter 7
H. Benedict, M., T. H. Pigford, and H. W. Levi. Nuclear Chemical Engineering. 2nd ed. Chapter 3-5, Columbus, OH: McGraw-Hill, 1981. ISBN: 9780070045316.
I. Driscoll, M. J., T. J. Downar, and E. E. Pilat. The Linear Reactivity Model for Nuclear Fuel Management. La Grange Park, IL: American Nuclear Society, 1991. ISBN: 9780894480355.

NE 2203	Nuclear Power Plant Economics	Credits: 2.0 2.0 Hours/week

Fundamentals of Economics: Definition of economics, Micro vs Macro Economics, Positive vs. Normative Economics, Economic Models; Circular Flow Diagram and Production Possibilities Frontier, Ten Principles of economics, Market, Competition, Supply and Demand, Keynesian economics, Keynesian multiplier effect, Business-As-Usual (BAU) model.

Basic Parameters of Power Plant Economics: Capital expenditures (CAPEX), Operational expenditures (OPEX), O&M costs; Fixed costs and variable costs, Relationship between OPEX and O&M costs, Components under CAPEX and OPEX, Weighted Average Cost of Capital (WACC), Plant capacity factor, Plant utilization factor, Based load plant

Financial and Economic Parameters of Power Plants: Financial parameters, Economic parameters, Financial vs Economic analysis of a power plant project, Discount rate, Discounting formula, Overnight construction costs, Interest during construction (IDC), Project profitability parameters; Net Present Value (NPV), Internal Rate of Return (IRR), Benefit Cost Ratio (BCR), and Pay Back Period (PBP), Different types of cost concepts, Engineering, procurement, and

construction (EPC) project cost, Turnkey cost, Levelized cost of electricity generation (LCOE)

Solving Financial and Economic Analysis of a Power Project: Calculation and analysis of LCOE of NPPs both theoretical and modelling methods, Analysis of NPV, IRR, and PBP, BCR, Sensitivity analysis during construction and operational cases of a power plant

Variability Study: Variation of CAPEX, OPEX, Discount factor, and plant capacity factor over renewable, fossil fuel, and nuclear energy-based plants, Affect CAPEX, OPEX, Discount factor, plant capacity factor etc. over LCOE for different energy-based power plants.

Recommended Readings

A. Economics of Nuclear Power 1st Edition by Geoffrey Rothwell, Routledge.
B. Fundamentals of Power System Economics 2nd Edition by Daniel S. Kirschen and Goran Strbac, Wiley

ME 2201	Fluid Mechanics and Machineries	Credits: 3.0 3.0 Hours/week

Properties of Fluids: Fundamental concept of fluid as a continuum, Viscosity, Thermodynamic properties, Compressibility and bulk modulus, Surface tension and capillarity, No slip condition, System and Control volume, Engineering software packages.

Pressure and its Measurement: Fluid pressure at a point, Pascal's law, pressure variation in a fluid at rest, Types of pressure, Measurement of pressure, Simple manometers, Differential manometers, Pressure at a point in compressible fluid.

Hydrostatic Forces on Surfaces: Centre of pressure, Vertical plane surface sub-merged in liquid, Horizontal plane sub-merged in liquid, curved surface sub-merged in liquid.

Buoyancy and Flotation: Buoyancy, Centre of buoyancy, Meta-center, Meta-centric height, Analytical method for meta-center height, Conditions of equilibrium of a floating and sub-merged body.

Kinematics of Flow: Types of fluid flow, Lagrangian and Eulerian, pathline, streakline.

Ideal Flow: Streamline, Timeline, Reynold's transport theorem, Continuity equation, Continuity equation in three-dimension, Velocity potential and stream function, Types of motion, Vortex flow.

Dynamics of Fluid Flow: Conservation of mass, Euler's equation, Bernoulli's equation, Conservation of linear momentum – Cauchy's equation, the Navier-Stokes equation.

Notches and Weirs: Discharge over a rectangular, triangular, and trapezoidal Notch or weir.

Orifices and Mouthpieces: Classification of Orifices, flow through an orifice and a mouthpiece, hydraulic coefficients, flow through large orifice, flow through a convergent-divergent mouthpiece.

Viscous Flow: Flow of viscous fluid through circular pipe, Flow of viscous fluid between two parallel plates, kinetic energy correction and momentum.

Turbulent Flow: Frictional loss in pipe flow.

Flow Through Pipe: Loss of energy in pipes, loss of energy due to friction, Minor energy losses.

Hydraulic Machines: Turbine (with emphasis on steam turbine), Centrifugal pumps, Reciprocating pumps, compressors, Fans, and Blowers.

Recommended Readings

A. Yunus A. Cengel, Dr., John M. Cimbala, Fluid Mechanics Fundamentals and Applications, McGraw-Hill Education
B. Victor L. Streeter, Fluid Mechanics, Mcgraw-Hill Book Company
C. Dr. R.K. Bansal, A Textbook of Fluid Mechanics and Hydraulic Machines (SI units), Pearson

ME 2203	Engineering Mechanics and Strength of Materials	Credits: 3.0 3.0 Hours/week

Introduction to Force Analysis: Fundamental concepts and principles in mechanics of rigid and deformable bodies; review of basic concepts of forces, moments and couples; free-body diagrams and equilibrium of rigid bodies in two and three dimensions; friction and its applications.

Analysis of Structures: Simple trusses; analysis of trusses by the methods of joints and sections; analysis of frames and machines.

Distributed Forces: Types of distributed forces; centroids and center of gravity of simple and composite bodies; moment of inertia of areas and composite sections.

Introduction to Strength of Materials: Stress and strain; tensile, compressive, and shear stresses; deformation and elongation; elasticity, plasticity, and yield strength; modulus of elasticity and Poisson's ratio.

Axial Loading and Torsion: Normal stress and strain in axially loaded members; Ssaint-Venant's principle; force method of analysis; thermal stresses; torsional deformation shafts; angle of twist; statically indeterminate problems.

Bending and Shear Stresses in Beams: Types of beams and loadings; analysis of beams under bending; shear and bending moment diagrams; flexural stress.

Stresses in Pressure Vessels and Pipes: Analysis of cylindrical shells; analysis of spherical shells.

Deflection of Beams: Deflection of beams under transverse loading; equation of the elastic curve; moment-area methods; statically indeterminate beams;

Columns and Stability: Buckling and stability of columns; Euler's formula and critical loads.

Recommended Readings

A. Hibbeler, R. C. (2017). Statics and Mechanics of Materials (5th ed.). Pearson Education, Prentice Hall Inc. ISBN: 9780134382890.
B. Beer, F. P., Johnston, E. R., DeWolf, J. T., & Mazurek, D. F. (2021). Statics and Mechanics of Materials (3rd ed.). McGraw-Hill Higher Education. ISBN: 9781260226751.
C. Limbrunner, G. F., & Spiegel, L. (2015). Applied statics and strength of materials (6th ed.). Pearson Education. ISBN: 9780133840544.
D. Rajput, R. K. (2015). A Textbook of Strength of Materials (6th ed.). S. Chand Publishing. ISBN: 9789352533695

EEE 2201	Electrical and Electronics Engineering	Credits: 3.0 3.0 Hours/week

Electrical Components and Sources: Introduction to Resistor, Capacitor and Inductor and their series and parallel combinations, Transient response of RC circuit, series and parallel resonant circuits, D.C. voltage and D.C current sources, dependent and independent sources.

Networks Theorems: Superposition theorem, Thevenins theorem, Nortons theorem, maximum power transfer theorem for DC circuits.

Fundamental of AC and its Application: Basics of AC voltage and AC current, average and RMS value, power in AC circuits, real and reactive power, and power factor, Analysis of AC circuits- Series and parallel RLC circuits (resonant circuits).

Poly Phase Systems: The three-phase generator, Y-connected and delta-connected generators and loads. Advantage of three-phase systems, line-to-line voltage and phase voltage.

Band Theory of Solids: Energy band diagram of conductor, insulator and semiconductor, classifications of semiconductor materials, drift and diffusion of charge carriers.

PN Junction Diodes: P-N Junction Diode construction and characteristics, the ideal diode and real diode, P-N junction diode as a circuit element, load Line analysis of a diode circuit, Zener diodes, photo diodes, LED half-wave and full wave rectifier, capacitor filter, Zener diode voltage regulator, basic clippers and clamper.

Bipolar Junction Transistor (BJT): PNP and NPN transistors constructions, principles of operation, DC load line, Q-point, transistor biasing (emitter-feedback and voltage divider), effect of temperature on transistors, stability factor of basing circuits. CE amplifier, AC load Line, small signal analysis, r_e-model of CE amplifier, power amplifiers.

Field Effect Transistor (FET): Construction of JFET and MOSFET, their operations and I-V characteristics, self-bias and voltage divider bias for CS amplifier. determination of load-line and operating point, application of FETs as switches.

Operational Amplifiers and Applications: Characteristics of ideal and practical op-amps, inverting and non-inverting amplifiers, gain, input and output impedances, summing amplifier and its applications- DAC, weighted gain amplifier.

Recommended Readings

A. Introductory Circuit Analysis, 12th Edition, Robert L. Boylested, Pearson Education, 2010.
B. Fundamentals of Electric Circuits, 5th Edition, Charles K. Alexander and Matthew N. O. Sadiku, McGraw-Hill Higher Education, 2013.

C. Electrical and Electronic Principles and Technology, 3rd Edition, John Bird, Elsevier Ltd., Jordan Hill, Oxford, UK, 2007.
D. Foundation of Analog and Digital Electronic Circuits, AnantAgarwal and Jeffrey H. Lang, Morgan Kaufmann Series, Elsevier Inc., San Francisco, USA, 2005
E. Electronic Devices & Circuits, 5th Edition, David A. Bell, Oxford University Press, ISBN: 978-0195693409.
F. Electronic Devices & Circuit Theory, 10th Edition, Robert L. Boylestad and Louis Nashelsky, Prentice Hall, Inc., New Jersey, USA, 2009.
G. Microelectronic Circuits, 6th Edition, Adel S. Serda, Kenneth Carless Smith, Oxford University Press, Incorporated, 2010. ISBN: 9780195323030.
H. Operational Amplifiers and Linear Integrated Circuits, 6th Edition, Robert F. Coughlin, Frederick F. Driscoll, Prentice Hall, Pearson Education International, 2001. ISBN: 9780131224568.

MATH 2201	Applied Mathematics for Engineering Physics	Credits: 3.0 3.0 Hours/week

Functions of a Complex Variables: Complex numbers, powers and roots, sets in the complex plane, functions of a complex variable, Cauchy-Riemann equations, exponential and logarithmic functions, trigonometric and hyperbolic functions, inverse trigonometric and hyperbolic functions.

Integration in the Complex Plane: Contour integrals, Cauchy-Goursat theorem, independence of the path, Cauchy's integral formulas

Series and Residues: Sequences and series, Taylor series, Laurent series, zeros and poles, residues and residue theorem, evaluation of real integrals.

Conformal Mappings: Complex functions as mappings, conformal mappings, linear fractional transformation.

Laplace Transformation: Definition of Laplace transformation, notation, Laplace transformations of some elementary functions, the inverse Laplace transformation and transforms of derivatives, translation theorems, additional operational properties, the Dirac delta function, applications to differential equations

Fourier Transformation: Fourier integral, Fourier transforms, sine and cosine transform, transform of derivatives, application to boundary problem.

Special Functions: Bessel function and their prosperities modified Bessel function. Legendre polynomials and properties, green's function, Kronecker delta, concept of tensor.

Recommended Readings

A. Dennis G. Zill& Warren S. Wright, Advanced Engineering Mathematics, Fifth Edition, 2014.
B. Saff, Edward B., and Arthur David Snider.Fundamentals of Complex Analysis with Applications to Engineering, Science, and Mathematics. 3rd ed. Upper Saddle River, NJ: Prentice Hall, 2002.
C. J.E. Marsden, M.J. Hoffman,Basic complex analysis, 3rd ed. Freeman and Company, ISBN: 0-7167-2877X.
D. Ahlfors, Lars V. Complex Analysis: An Introduction to the Theory of Analytic Functions of One Complex Variable. 3rd ed. New York, NY: McGraw-Hill, 1979. ISBN: 9780070006577.

CSE 2201	Object Oriented Programming	Credits: 3.0 3.0 Hours/week

Introduction: Object oriented programming overview.

Object Oriented Concepts: Modeling problems using object-oriented concepts. Encapsulation, Inheritance and Polymorphism. Object Oriented vs. Procedural programming, Basics of Object-Oriented Programming language.

Objects and Classes: Attributes and functions, constructors and destructors, functions or methods, overloading methods, access control, special considerations in different languages.

I/O: Stream and files. Inheritance: Inheriting classes, subclass, super class, access control, inheritance hierarchy, overriding, dynamic binding, abstract class, inner classes, special considerations in different languages, multiple inheritance, interface

Exception and Exception Handling: Exception handling fundamentals, exception types, chained exception, creating own exception subclasses. Designing Template Classes.

Package/Namespace: Understanding and implementing package/namespace.

Recommended Readings

A. Schildt, H, Teach Yourself C++, Tata McGraw-Hill Education, 1998. ISBN: 9780074638705.
B. Flanagan, David. Java™ in a Nutshell. 5th ed. Cambridge, MA: O'Reilly, 2005. ISBN: 0596007736.
C. Flanagan, David, and Brett McLaughlin. Java™ 1.5 Tiger: A Developer's Notebook. Cambridge, MA: O'Reilly, 2004. ISBN: 0596007388.
D. Schildt, H: Turbo C/C++: The complete reference, Second Edition, September 1st 1992 by Osborne Publishing, ISBN-10: 9780078817762.
E. N. Barkakati: Object Oriented Programming with C++, 1st edition, ISBN-10: 0672228009, Sams; 1st edition (July 1, 1991).
F. Balagurusamy, EISBN-10: 9352607996: Object Oriented Programming with C++, 7th Edition, McGraw Hill India; 7th edition (July 1, 2017).
G. B. Stroustrap: The C++ programming Language, 4th Edition, Addison-Wesley Professional; 4 edition (May 19, 2013), ISBN-10: 0321563840.
H. D. Ravichandran: Programming with C++, Programming With C++ 3rd Edition, ISBN-10: 0070681899.

EEE 2202	**Electrical and Electronics Engineering Lab**	**Credits: 1.5** **3.0 Hours/week**

Laboratory based on EEE 2202.

Third Year and First Semester

NE 3101	Reactor Theory and Analysis I	Credits: 3.0 3.0 Hours/week

Neutron Physics Background: Types of neutron interaction, neutron cross sections, energy and temperature dependence of cross sections, neutron attenuation & mean free path, fission spectra. Nuclear Data- classification, energy discretization, homogenization and group collapsing, nuclear data processing codes, nuclear data library, JANIS cross sections.

Slowing-Down Theory: Differential scattering cross sections, energy transfer probability and transfer cross section, energy loss, angle of scattering in Lab and CM frame, neutron lethargy, transport mean free path. Macroscopic slowing down power, moderating ratio, effect of inelastic scattering. Slowing-down densities, slowing-down time, infinite medium slowing down equation (IMSDE), moderation of neutrons without absorption in hydrogen and in other moderators (A>1), slowing down flux, slowing down in mixture of nuclides, space-dependent slowing down, neutron moderation with absorption and fission, effective resonance integral, NI & NRIM approximation, narrow and widely spaced resonance.

Thermal Spectra: Energy dependence of thermal flux, thermal group constant, chemical binding and scattering kernels, effect of nonequilibrium perturbation on neutron spectra, coupling to higher energy sources, neutron spectrum in thermal and fast reactors.

Neutron Transport & Diffusion Theory: Introductory Concepts: Neutron Density, Scalar & Angular Neutron Flux, Collision Frequency, Neutron Current Density, and Partial Current Density. Space-dependent conservation law for neutrons: Equation of Continuity. Fick's Law. Neutron Diffusion Equation, Boundary Conditions for the Steady-State Diffusion Equation. Elementary Solutions of the Diffusion Equation for different sources in finite and infinite media, Multiregion problem, The albedo problem. Time-dependent neutron diffusion equation and its solution. Neutron diffusion equation with a fission source. Criticality and k-eff. Eigenvalue problems. Analytic solution for 1D bare reactor. Diffusion parameters. Multi-group Diffusion Theory: Inadequacy of the one-group model, Multi-group Diffusion Equations, generation of group constant, Multi-group Collapsing to One & Two Group, Numerical criticality-finite difference equations, generalized eigenvalue problem, inverse power method. Inner and outer iterations. Neutron Transport Theory: Assumptions in

the neutron transport theory. Derivation of neutron transport equation (NTE). Different forms of divergence operator. Time-independent transport equation: Fixed source problem, k-eigenvalue problem. Boundary conditions for solving the neutron transport equation. Common Simplification to the Neutron Transport Equation.

Nuclear Reactor Models: One-group Reactor Equation, Solution of reactor equation for different Reactors, Maximum-to-Average Flux and Power. One-group Critical Equation (Relating k to the Criticality Condition). Material & Geometrical Buckling. Analytical Solution of reactor equation for the Transient case. Numerical Criticality Searches. Two Group Criticality Calculations. Calculations of Critical Mass &Critical Size. Solution of reactor equation for Reflected Reactors. Reflector Savings. Heterogeneous effects. Spatial self-shielding factor. Escape probability. Dancoff factor.

Recommended Readings

A. Duderstadt, James J., and Louis J. Hamilton. Nuclear Reactor Analysis. 1st ed. New York: Wiley, 1976. ISBN: 9780471223634.
B. Bahman Zohuri, Neutronic Analysis for Nuclear System, Springer, 2019, Second Edition, ISBN 978-3-030-04905-8
C. Lamarsh, John R., and Anthony J. Baratta. Introduction to Nuclear Reactor Theory, New York University
D. S.E. Liverhant., "Elementary Introduction to Nuclear Reactor Physics". Second edition
E. Lamarsh, John R., and Anthony J. Baratta. Introduction to Nuclear Engineering. 3rd ed. Englewood Cliffs, NJ: Prentice Hall, 2001. ISBN: 9780201824988.
F. Lee: Nuclear Reactor Physics and Engineering, J. C. Lee, John Wiley & Sons, 2020
G. George I. Bell and Samuel Glasstone, Nuclear Reactor Theory, 1970,Van Nostrand Rainhold Ltd.
H. Lewis, Elmer E. Fundamentals of Nuclear Reactor Physics. Burlington, MA: Academic Press, 2008. ISBN: 9780123706317.
I. Weston M. Stacey, Nuclear Reactor Physics, 2007 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, ISBN 978-3-527-40679-1

NE 3103	Thermal Hydraulics of Nuclear Reactors	Credits: 3.0 3.0 Hours/week

Introduction: Concept of thermal-hydraulics, objectives of nuclear reactor thermal hydraulics, thermal-hydraulics as a part of the nuclear reactor analysis chain.

Reactor Heat Generation, Distribution: Energy deposition in nuclear reactor, heat removal steps from nuclear reactors, transfer parameters, relation between heat flux, volumetric heat generation, and core power, figures of merit for core thermal performance, heat generation in fuel, heat generation after reactor shut-down.

Heat Conduction Analysis in Fuel Elements: Mode of heat transfer (fundamental equations), heat conduction equation (derivation, special case),1D steady-state conduction in plane wall & radial system, convective heat transfer & overall heat transfer coefficient, heat conduction in plate fuel element, heat conduction in fuel rod element of nuclear reactor (e.g. PWR, BWR, VVER), heat conduction in pebble fuel element (e.g. HTGR).

Single Phase Fluid Flow and Heat Transfer in Reactor Fuel Subchannel: Reactor coolant path, coolant subchannel in rod bundle, hydraulic diameter, subchannels for square & hexagonal arrays, 1-D mass, energy and momentum equation of fluid flow in subchannel, pressure drop in reactor fuel subchannel, minor pressure loss of components, heat transfer in reactor fuel subchannel, thermal analysis of reactor fuel subchannel.

Two Phase Fluid Flow and Heat Transfer in Reactor Fuel Subchannel: Classification of two-phase flow, flow regimes/patterns (vertical & horizontal flow), flow regimes transition, nucleation superheat, boiling heat transfer (pool boiling & flow boiling), boiling crises in LWRs (DNB, Dryout), flooding and flow reversal, one-dimensional two-phase flow parameters, averaging operators for two-phase flow, void-quality-slip relation, homogenous equilibrium model, drift-flux model, two-fluid model, two-phase heat transfer analysis.

Thermal Hydraulic Design: Objectives of thermal-hydraulic design, thermal-hydraulic design flow, thermal-hydraulic constraints, hot channel factors, heat flux related, limitation in LWR, safety margins, various components of safety margins.

Integral System Analysis: Material volume, control volume & control surface, system balance laws, Reynolds transport theorem, integral mass balance equation (primary circuit of PWR, BWR), integral energy balance equation (reactor vessel, pump system, heat exchanger, turbine), Rankine cycle, energy balance in primary & secondary system, mass balance during LOCA.

Recommended Readings

A. Neil E. Todreas, Mujid S. Kazimi, Nuclear Systems I, Thermal Hydraulic Fundamentals, Taylor & Francis
B. Lamarsh, John R., and Anthony J. Baratta. Introduction to Nuclear Engineering. 3rd ed. Chapter 8
C. Duderstadt, James J., and Louis J. Hamilton. Nuclear Reactor Analysis. 1st ed, Chapter 12
D. Glasstone, S., and A. Sesonske, Nuclear Reactor Engineering, 3rd ed. 1994, Chapman& Hall, Chapter 6
E. Henryk Anglart, Applied Reactor Technology, 2011, Chapter 4
F. Henryk Anglart, Thermal-Hydraulics in Nuclear Systems, 2010.
G. Daniel Kolak, John Symons, Nuclear Engineering Handbook, CRC Press, Taylor & Francis, Chapter 20 & 21
H. Tong, L. S., and J. Weisman, Thermal Analysis of Pressurized Water Reactors, 3rd ed. La Grange Park, Ill.: American Nuclear Society, 1996.
I. Lahey, R. T., and F. J. Moody, The Thermal Hydraulics o f a Boiling Water Nuclear Reactor, 2nd ed. La Grange Park, Il l.: American Nuclear Society, 1993.

NE 3105	Nuclear Power System Engineering	Credits: 3.0 3.0 Hours/week

Overview of Nuclear Power Plants: Overview and classification of NPPs, overview of nuclear and turbine islands, plant layout.

Thermodynamics of Nuclear Power Plants: Coolants, working fluids, and their functions, basic parameters of thermodynamic cycles, thermal efficiency coefficient, initial and final parameters of working fluids, principles of heat regeneration, optimal distribution by stages, features of the water-chemical regime in nuclear power plant circuits.

Primary circuit and auxiliary systems: Overview and layout of the primary systems, reactor internals, main circulation pipelines, MCP and related systems, pressurizer system, chemical and volume control system, steam generator with its blowdown and drain system, residual heat removal system.

Safety systems: Emergency core cooling system, boron injection system, emergency feedwater system, passive heat removal system, containment system.

Turbine-Generator and Related Systems: In-depth study of steam turbine, main generator, and their components. examination of main steam supply system and reheaters, feed water system, deaeration system, condensate system, condenser cooling system.

Instrumentation and Plant control systems: Overview of advanced control rooms, man-machine interface, process supervision, radiation monitoring systems, reactor protection, and control systems.

Fuel Handling and Waste Processing Systems: Study of fuel handling facilities, refueling equipment, and operation, maintenance & plant outages. Overview of liquid, gaseous, and solid waste processing systems.

Plant Operation and Safety Considerations: Overview of startup, normal operation, shutdown, maintenance, load follow capability, and emergency response. Discussion on safety defenses levels.

Other Auxiliary Systems: Discussion on backup power systems including diesel generators and inverter power supply. Analysis of circulating, service water, and spent fuel pool cooling systems.

Recommended Reading

A. Don Testa and A. Kunkle. The Westinghouse pressurized water reactor nuclear power plant." Westinghouse Electric Corporation Water Reactor Divisions, 1984.
B. Bereznai G. Nuclear power plant systems and operation. University of Ontario Institute of Technology, Oshawa. 2005.
C. Zorin V.M., Nuclear Power Plants, Moscow Power Engineering Institute, 2022.
D. Baklushin R.P. Operational Modes of Nuclear Power Plants, Institute for Physics and Power Engineering, 2009.
E. Daniel Kolak, John Symons, Nuclear Engineering Handbook, CRC Press, Taylor & Francis, Chapter 20 & 21.
F. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307.

MSE 3101	Materials Science	Credits: 3.0 3.0 Hours/week

Fundamentals: Introduction to material science and engineering, Classification of Materials, Materials Design and Selection. Atomic structure

and bonding, Crystal structures and their properties, crystal defects- Point Defects, Dislocations, Slip systems and slip planes, Grain Boundaries.

Mechanical Properties: Technological Significance, Terminology for Mechanical Properties, Stress and Strain Analysis, Elastic and plastic deformation behavior, Tensile Testing, Hardness and Impact Testing, Compression, Fatigue and Creep Behavior, Mechanical Properties of Engineering Materials.

Fracture Mechanics: Overview of fracture mechanics, Importance and applications in engineering, Microstructural Features of Fracture in Metallic Materials, Ceramics, Glasses, and Composites, Stress intensity factor (K) and its significance, Fracture Toughness and Fracture Criterion, Failure criteria (brittle, ductile, mixed mode), Crack Growth and Fatigue, Nondestructive Evaluation (NDE) Techniques, Failure analysis methodologies.

Phase Diagrams: Phases, Gibbs phase rule, solubility limit, phase equilibrium, interpretation of phase diagrams, unary phase diagrams, binary isomorphous systems, development of microstructure in isomorphous alloys, binary eutectic systems, and eutectic alloys, eutectoid and peritectic reactions, the iron–iron carbide (Fe–Fe3C) phase diagram and evolution of microstructure, influence of other alloying elements.

Phase Transformations: Basic concepts, the kinetics of phase transformations, metastable versus equilibrium states, isothermal transformation diagrams, continuous cooling transformation diagrams, mechanical behavior of iron–carbon alloys tempered martensite.

Applications and Processing of Metal Alloys: Introduction, ferrous alloys, nonferrous alloys, annealing processes, heat treatment of steels, Strain hardening and work hardening, precipitation hardening. Basics of Nano-materials.

Recommended Readings

A. W.D. Callister, Jr., Materials Science and Engineering – An Introduction, 8th Edition, John Wiley & Sons, Inc. 2007, ISBN: 0-471-73696-1
B. Essentials of Materials Science and Engineering, Second Edition, Donald R. Askeland, Pradeep P. Fulay, D. K. Bhattacharya, ISBN-13: 978-0-495-43850-2
C. Nuclear Reactor Enginering, Glasstone and Sesonske, Third ed.
D. Applied Reactor Technology, HenrykAnglart, 2011.
E. S. Was, Fundamentals of Radiation Materials Science: Metals and Alloys Springer, 2007, ISBN: Gary 978-3-540-49471-3.

EEE 3101	Digital Electronics & Microprocessor	Credits: 3.0 3.0 Hours/week

Number System and Arithmetic Operation: Decimal, binary, octal, hexadecimal, BCD number system and conversion; Grey and alphanumeric codes; parity method; signed numbers; 2's-complement system; digital arithmetic.

Logic Gates: OR, AND, NOT, NOR, NAND, universality of NOR/NAND gates, Ex-OR, Ex-NOR, alternate representations.

Boolean Algebra: Boolean constants and variables, truth tables, Boolean laws, DeMorgan's theorems.

Combinational Logic Operation: Sum-of-product (minterm) and products-of-sum (maxterm) forms; algebraic simplification, Karnaugh-map method, parity generator and checker;

Logic Circuits: NAND/NOR latch, flip-flops, counters, registers: S-R, J-K, D, T flip-flops; serial and parallel shift registers; asynchronous (ripple) and synchronous up and down MOD-2N counters; MOD-3, MOD-5, MOD-10/BCD counters; frequency dividers; decoder, encoder, multiplexer, demultiplexer.

Logic Families: TTL, ECL, PMOS, NMOS, and CMOS technology.

Memory Devices: Memory operation, CPU-memory interfacing, ROM, RAM

Arithmetic Circuits: Half-adder, full-adder, half-subtractor, full-subtractor, adder-subtracter; parallel adder; ripple/look-ahead carry; ALU.

Converter Circuits: Digital to analog converter (DAC): binary-weighted resistors type and R/2R ladder DAC; analog to digital converter (ADC): digital-ramp and successive-approximation ADC

PLD: Microprogrammed control, PLA, PAL, GAL, CPDL, FPGA, HDLA.

Microprocessor: Introduction to microprocessors; 8086 microprocessor: architecture, instruction set, interfacing; advanced microprocessors.

Recommended Readings

A. Digital Systems, Ronald J. Tocci, Neal S. Widmer, and Gregory L. Moss, 12th Edition, Pearson Education, Prentice Hall Inc.

B. Digital Design: With an Introduction to the Verilog HDL, VHDL, and SystemVerilog, M. Morris Mano, and Michael D. Ciletti, 6th Edition, Pearson Education, Prentice Hall Inc.
C. Digital Electronics: A Practical Approach with VHDL, William Kleitz, 9th Edition, Pearson Education, Prentice Hall Inc.
D. Digital Electronics: An Introduction to Theory and Practice, William H. Gothmann, 2nd Edition, Prentice Hall Inc.
E. Microprocessors and Microcomputer-Based System Design, M. Rafiquzzaman, 2nd Edition, CRC Press.
F. Microprocessors PC Hardware and Interfacing, N. Mathivanan, 1st edition, Prentice Hall of India.
G. Microprocessor Architecture, Programming, and Applications with the 8085, Ramesh S. Gaonkar, 6th Edition, Penram International Publishing.

EEE 3103	Electrical Power Transmission and Distributions	Credits: 2.0 2.0 Hours/week

Introduction: Basics of nuclear power generation from NPPs, power requirements (stability, quality, and reliability), power transmission and distribution systems, emergency power supply system and power requirements in NPP, Circuit interruption and protection, Terminologies and general characteristics of relays and breakers. AC/DC converter.

Load Curves: Demand factor, diversity factor, load duration curves, energy load curve, load factor, capacity factor and plant factor.

Power Factor Improvement: Power factor, Power triangle, Disadvantage of low power factor, Causes of low power factor, Power factor improvement, Power factor improvement equipment, Calculation of power factor corrections, Importance of power factor improvement, most economical power factor,

Circuit Breakers: Control systems, arc extinction, and recovery voltage. Air, oil, air blast circuit breaker, vacuum, SF6 and high voltage DC circuit breakers, testing of circuit breakers

Relays: Over current, directional, differential, distance, sequence, pilot-wire and carrier-current protection. Busbar arrangement, grounding.

Unit Protection: Generator, motor, transformer, bus and line protection. Protective schemes, instrument transformers. Basic static and microprocessor-based relays.

Trip Circuits: Unit protection schemes: Generator, transformer, motor, bus bar, transmission and distribution lines, Instrument transformers: CT and PT

Grid System: Typical layout of a substation, High tension switch gear, Low tension switch gear, Transmission cables, Transmission tower, Corona, High voltage measurements and testing. Over-voltage phenomenon and insulation coordination. Lightning and switching surges, basic insulation level, surge diverters and arresters.

Recommended Readings

A. Principles of power system, V.K. Mehta, Rohit Mehta
B. Switchgear and Protection, Sunil S. Rao
C. High Voltage switch gear Analysis and Design, Chunikhin M. Zhavoronkov, 1st edition, 1989, Mir publishers Moscow
D. Switch gear and Finite Automata Theory, Kohavi, 2nd edition, 2005, Tata McGraw Hill.

NE 3102	**Thermal Hydraulics Lab**	**Credits: 1.5** **3.0 Hours/week**

Laboratory based on ME 2201 and NE 3103.

EEE 3102	**Digital Electronics & Microprocessor Lab**	**Credits: 1.5** **3.0 Hours/week**

Laboratory based on EEE 3101.

Third Year and Second Semester

NE 3201	Reactor Theory and Analysis II	Credits: 3.0 3.0 Hours/week

Methods of Solving Neutron Transport Equation: Brief introduction to the numerical solution to neutron transport equation (NTE), Eigenvalue problem and source iteration method, Overview of approximate solution for neutron transport equation: Discretization of energy variables (multigroup transport equation), Approximation of angular variable (spherical harmonic expansion approximation, Discrete ordinate method), Spatial variable discretization.P1 approximate methods in transport theory, derivation of the one-dimensional multi-group P_N equations.

Reactor Kinetics: Time dependent behavior of reactor, reactor with no delayed neutrons, delated neutron data, kinetics with delayed neutrons, point reactor kinetics equations (PKE), reactivity formulation, response of reactor to a step change in reactivity, reactor period, In-hour equation, one group of delayed neutron approximation of PKE, approximation with the constant delayed neutron generation rate, prompt jump and prompt drop approximation, prompt critical condition, kinetics in subcritical state, dynamic versus static reactivity, multigroup diffusion with delayed precursors, spatial effect in reactor kinetics, experimental measurement of kinetics parameters.

Reactivity Feedback and Reactor Dynamics: Mathematical description of feedback, temperature feedback model, simple feedbacks, multiple time constant feedbacks, Fuchs-Nordheim model, Fuchs-Hansen model, reactivity coefficient and reactivity defect, fuel temperature coefficient (doppler coefficient), reactivity coefficient of moderator and coolant, power defect of reactivity, reactivity coefficients of the fast reactor.

Reactivity Control: Effect of rod insertion on core multiplication, general expression of reactivity decrease, first order perturbation approximation, calculation of control rod worth for rod insertion and withdrawal, worth of a partially inserted control rod, worth of cluster control rod& cruciform control rod, reactivity worth of chemical shim. Temperature coefficients of reactor physics parameters, Effect of homogenous and heterogenous distribution of burnable poison, control requirements, excess reactivity & shutdown margin.

Burnup Analysis: Burnup chain from thorium and uranium, decay chain of fission products & burnable poison, nuclide transmutation and decay equation,

burnup equation for various fissile and fertile materials, solution of burnup equations, reactivity change due to fuel burnup, fission product poisoning and reactivity feedback, Xenon and Samarium poisoning- rate equation, solution at initial startup, equilibrium concentration, solution after shutdown, reactivity feedback, Xenon and Samarium transient with power level changes, Xenon spatial oscillation, core burnup with burnable poisons, fuel depletion dynamics & reactor model, linear reactivity model, calculation of fuel cycle length and discharge burnup.

Recommended Readings

A. Yoshiaki Oka and Katsuo Suzuki, Nuclear Reactor kinetics and Plant Control, Springer, 2013, ISBN 978-4-431-54194-3
B. Lamarsh, John R., and Anthony J. Baratta. Introduction to Nuclear Reactor Theory, New York University.
C. Karl O. Ott, Robert J. Neuhold - Introductory Nuclear Reactor Dynamics, 1985, American Nuclear Society. ISBN: 0-89448-029-4
D. Nuclear Reactor Design, Oka.Yoshoaki, Springer, 2014, ISBN 978-4-431-54897-3
E. Bahman Zohuri, Neutronic Analysis for Nuclear System, Springer, 2019, Second Edition, ISBN 978-3-030-04905-8
F. Duderstadt, James J., and Louis J. Hamilton. Nuclear Reactor Analysis. 1st ed. New York: Wiley, 1976. ISBN: 9780471223634.
G. Lamarsh, John R., and Anthony J. Baratta. Introduction to Nuclear Engineering. 3rd ed. Englewood Cliffs, NJ: Prentice Hall, 2001. ISBN: 9780201824988.
H. S.E. Liverhant., "Elementary Introduction to Nuclear Reactor Physics". Second edition
I. Driscoll, M. J., T. J. Downar, and E. E. Pilat. The Linear Reactivity Model for Nuclear Fuel Management. La Grange Park, IL: American Nuclear Society, 1991. ISBN: 9780894480355.

NE 3203	Numerical Methods in Reactor Engineering Analysis	Credits: 3.0 3.0 Hours/week

Introduction: Overview of Computational Science/Engineering; Preliminaries of Computing-round-off errors, floating point arithmetic, Convergence.

Numerical Solution of Nonlinear Equations: Bisection method, fixed-point iteration, Newton's method, Error analysis for Iterative Methods, Computing roots of polynomials.

Numerical Methods for ODE: Numerical solution of the 1st order ODE: Initial value problems; Numerical solution of the 2nd order ODE: Finite difference method; Numerical solution of the 2nd order ODE: Finite element/ Nodal methods; Diffusion equation in two or more dimensions; Diffusion theory codes.

Numerical Integration and Differentiation: Trapezoidal rule, etc., Gaussian quadrature and Euler-Maclaurin formula.

Types of Equations in Radiation Transport: Integro-differential and Integral form neutron transport equation (NTE); Diffusion approximation to NTE; Time-dependent forms of NTE; Computational Methods: Probabilistic and Deterministic.

Numerical Methods for PDE - Integro-Differential Form of NTE: Time, energy, angle and spatial discretization; Discrete-ordinates (S_N) methods in one spatial dimension; Multidimensional discrete ordinates (S_N) methods; Discrete-ordinates computer codes. Optimization for vector and parallel processing; Spherical harmonics (P_N) method; Transport theory codes.

Integral Form of NTE: Collision Probability Method: Traditional collision probability method in one and two dimensions; Collision/transfer probability method in arbitrary 2D/3D geometries; Ray tracing in arbitrary geometry; Discrete integral transport; Interface coupling methods; Optimization of integral transport methods for parallel processing; CP codes. **Method of Characteristics (MOC):** Method of characteristics in two dimensions; Choice of Angles; Choice of boundary conditions; Ray tracing in arbitrary geometry for MOC; Linearly anisotropic scattering in MOC; Approximate methods for solving 3D MOC Problems; Coupled MOC/CFD; MOC Codes.

Probabilistic Numerical Method: Random numbers; Probability density function; Cumulative PDF; Analog Monte Carlo; Nonanalog Monte Carlo; Importance sampling; Variance reduction methods; Error estimates; Monte Carlo neutron and photon transport simulation; All-particle Monte Carlo simulation; Parallel Monte Carlo; Monte Carlo codes.

Recommended Readings

A. E. Lewis,W. E. Miller Jr., " Computational Methods of Neutron Transport," J. Wiley&Sons (1992)
B. J. Duderstadt & L. J. Hamilton, "Nuclear Reactor Analysis," Wiley (1976)

C. I. Bell and S. Glasstone, "Nuclear Reactor Theory," U.S. Atomic Energy Commission (AEC) (1970). (Out of print, free at http://www.osti.gov/scitech/biblio/4074688).
D. Y. Azmy and E. Sartori, Eds., "Nuclear Computational Science: A Century in Review," Sringer (2010).
E. Spanier and E. M. Gelbard, "Monte Carlo Principles and Neutron Transport Problems," Dover Publications, Inc., 2008 (Reprinted from 1969 edition)
F. Hebert, "Applied Reactor Physics," Presses Internationales Polytechnique (2009).
G. Pozrikidis, "Numerical Computation in Science and Engineering," Oxford University Press, NY (1998).
H. Linear Algebra: Gil Strang's lectures and materials, http://ocw.mit.edu/courses/mathematics/18-06-linear-algebra-spring-2010/
I. Eigenvalues: http://mathworld.wolfram.com/Eigenvalue.htmlLinks to an external site.
J. Iterative Methods: Two books by Yousef Saad are here: http://www-users.cs.umn.edu/ saad/books.html.
K. Method of Characteristics: https://mit-crpg.github.io/OpenMOC/index.html

NE 3205	Materials for Nuclear Engineering Applications	Credits: 3.0 3.0 Hours/week

Materials for Nuclear Applications: Steels, Superalloys, Refractory Alloys, Zirconium Alloys, Intermetallics, Nano-Structured Materials, Ceramic Materials, Coatings.

Plant Components: Properties of nuclear reactor materials (fuel, coolant, moderator and control material), structural materials of different components-Reactor Internals Piping and Steam Generator, Intermediate Heat Exchanger, Energy Conversion Systems.

Production of Plant Components: Production Techniques, Powder Metallurgy, Fiber Reinforced Materials, Fusion Procedures: Submerged Arc and Gas Tungsten Arc Welding, Defects in Welds, Other Bonding Methods. Coatings and Surface Treatment: Lining, Chemical Vapor Deposition CVD, Physical Vapor Deposition, Thermal Spray, Other Surface Treatments.

Irradiation Damage: Early Stage of Radiation Damage, Influence of Temperature, Lattice Type and Chemical Composition on Point Defects Created During Irradiation, Radiation Induced Segregation (RIS), Irradiation Induced (Coherent) Precipitation, Amorphization, Production of Foreign Atoms, Void

Swelling, Radiation Creep. Radiation Effects at High Temperatures, Influence of Radiation on Mechanical Properties, Radiation Damage in Non-Metallic Structural Materials. Irradiation Damage of Components in Light Water Reactors (LWRs) and advanced reactors.

Environmental Damage in Nuclear Plants: Basic Aspects of Corrosion: electrochemical considerations, corrosion rates, prediction of corrosion rates, forms of corrosion, Stress Corrosion Cracking (SCC), Corrosion and Fatigue Loading, corrosion prevention. High Temperature Effects. Environmental Effects in LWRs and advanced reactors. ageing mechanism of different components and their mitigation.

Design and Life-Time: Codes and Design Rules, Loads and Stresses in Components, Non-Destructive Testing/Evaluation, Plant Life Management and Plant Life Extension.

Recommended Readings

A. Wolfgang Hoffelner, Materials for Nuclear Plants, Springer, 2011, ISBN 978-1-4471-2914-1.
B. G.S. Was, Fundamentals of Radiation Materials Science: Metals and Alloys Links to an external site., Second Edition, Springer, New York, 2017.
C. W.D. Callister, Jr., Materials Science and Engineering – An Introduction, 8th Edition, John Wiley & Sons, Inc. 2007, ISBN: 0-471-73696-1
D. Essentials of Materials Science and Engineering, Second Edition, Donald R. Askeland, Pradeep P. Fulay, D. K. Bhattacharya.
E. Nuclear Reactor Enginering, Glasstone and Sesonske, Third ed.
F. Applied Reactor Technology, Henryk Anglart, 2011.

NE 3207	Instrumentation and Measurement	Credits: 3.0 3.0 Hours/week

Data Analysis: Causes and types of experimental errors, uncertainty analysis and propagation of uncertainty, evaluation of uncertainties for complicated data reduction, statistical analysis of experimental data, probability distributions, the gaussian or normal error distribution, standard deviation of the mean

Pressure Measurement: Introduction, mechanical pressure-measurement devices, dead-weight tester, bourdon-tube pressure gage, diaphragm and bellows gages, low-pressure measurement, the mcleod gage, Pirani thermal-conductivity gage, the Knudsen gage, the ionization gage

Flow Measurement: Positive-displacement methods, flow-obstruction methods, the sonic nozzle, flow measurement by drag effects, hot-wire and hot-film anemometers, the laser doppler anemometer (LDA)

Temperature Measurement: The ideal-gas thermometer, temperature measurement by mechanical effects, electrical effects and radiation, effect of heat transfer on temperature measurement, thermocouple compensation

Thermal and Transport-Property Measurements: Thermal-conductivity measurements, thermal conductivity of liquids and gases, measurement of viscosity, gas diffusion, calorimetry, convection heat-transfer measurements, humidity measurements, heat-flux meters, pH measurement

Reactor Instrumentation: Overview of reactor systems, out-core sensors: source, intermediate and power range neutron sensor, log count rate meter, period meter, startup rate meter, in core sensors: fission chamber, b-10 lined ion chamber, self-powered neutron detector (SPND), travelling and moving sensor, thermocouple, RTD, TTFM, N-16 power monitoring system, sensor performance and reliability test, calibration, process instrumentation, signal conditioning, control rod drives and indicating systems; power supplies, installation of instrumentation systems; quality assurance and reliability

Plant Control: Reactor kinetics, transfer function, transfer function measurement systems, range of reactor control, reactor protection system, primary & secondary control desk, pressure, temperature, flow, water level control in NPP, reactor control loop, turbine follows reactor and reactor follows turbine principles.

Plant Radiation Monitoring: Function, continuous area monitoring system (CAM), fixed filter CAM and moving filter CAM, process radiation monitoring instrumentation, radiation monitoring instrumentation for accident situation, HEPA filter, charcoal filter, compensated ion chamber, personnel dosimeters.

Recommended Readings

A. Experimental Methods for Engineers (Eighth Edition) by J. P. Holman. Mac Graw hill publications.
B. Theory and Design for Mechanical Measurements (Fifth Edition) by Richard S. Figliola and Donald E. Beasley. John Wiley & Sons, Inc
C. Doe fundamentals handbook: Instrumentation and Control, U.S. Department of Energy
D. Nuclear Power Reactor Instrumentation Systems Handbook, Joseph M. Harrer and James G. Beckerley, Vol 1 & 2, 1973.

NE 3209	Quantum Mechanics for Nuclear Phenomena	Credits: 2.0 2.0 Hours/week

Introduction to Quantum Mechanics: Historical development and motivation for quantum theory, Classical mechanics versus quantum mechanics, Basic concepts and postulates of quantum mechanics.

Wave-Particle Duality: The wave equations, wave function & its physical interpretation wave function for particles having a definite momentum, wave packets, the Heisenberg uncertainty principle & complementarity.

The Schrödinger Equation: The Time-dependent Schrödinger Equation, conservation of probability, expectation values- operators, The Ehsenfest Theorem, The time independent Schrödinger Equation, Stationary States, Energy Quantization, The Schrödinger Equation in Momentum Space.

Quantum Mechanics of Simple Systems: Quantum harmonic oscillator, The Free Particle-Box Quantization, The Rectangular Potential Step, The Potential Barrier, The Infinite potential Well, The Square Well, tunneling phenomena.

Nuclear Models: Shell model, collective model, and optical model. The deuteron.

Recommended Readings

A. David J. Griffiths, Introduction to Quantum Mechanics, Third edition, Cambridge University Press, 2018. ISBN: 9781107189638.
B. H. Bransden and C. J. Joachain, Quantum Mechanics, 2nd edition, Prentice Hall, 2000. ISBN: 9780582356917.
C. Ramamurthy Shankar, Principles of Quantum Mechanics, 2nd edition, Springer, 1994. ISBN: 978-1-4757-0576-8.
D. Krane Kenneth S and David Halliday. Introductory Nuclear Physics. Wiley 1988. ISBN: 9780471805533.
E. S. N. Ghoshal, "Nuclear Physics," S. Chand & Company Limited, New Delhi, 2006. ISBN: 978-8121904131.
F. Elements of Nuclear Physics, Walter E. Meyerhof, McGraw-Hill, ISBN 0-07-100221-9.

EEE 3201	Automation and Control Engineering	Credits: 3.0 3.0 Hours/week

Introduction: System, control system, input, output, Elements of a general control system, examples of control system, System configuration (Open-loop and closed loop), Design process.

Modeling in the Frequency Domain: Review of Laplace transform, impulse, step and ramp functions, Electrical, mechanical, rotational, electromechanical systems

Modeling in the Time Domain: State space representation, Converting a transfer function to state space

Time Response: First order system, General second order system, Underdamped second order systems, System response with additional poles, zeros, Laplace solution of state equation, Time domain of state equation

Reduction of Multiple Orders: Block diagrams, Analysis and design of feedback systems, Mason's rule, Signal flow graphs of state equations

Manipulators: Classification of robot example of robot application, Identification of manipulator components and terminology; joints classification.

Kinematics: Kinematic description of multi-degree of freedom manipulators, Joint coordinates, task coordinates, transformation coordinate system, Kinematic model, dynamic equation of six degree of freedom robot arm, Introduction to Jacobians and dynamic performance, Automation strategy, Role of automation in industries, benefits of automation, Introduction to automation tools, programmable logic control (PLC), microcontroller, relay etc.

Recommended Readings

A. Norman S. Nise, Control System Engineering, 6th addition,2016. ISBN: 9780470547564
B. Francis H. Raven, Automatic Control, 5th Edition, McGraw Hill, 1994. ISBN: 0070513414.
C. Richard C. Dorf, Modern Control System, 11th Edition, Prentice Hall, 2007. ISBN: 0132270285.
D. B. B. Kuo, Automatic Control Systems, 9th Edition, Wiley, 2009. ISBN: 0470048964.
E. D. Roy Choudhury, Modern Control Engineering, Illustrated Edition, PHI Learning Pvt. Ltd., 2005. ISBN: 9788120321960.

F. Katsuhiko Ogata, Modern Control Engineering, Prentice Hall, 2010. ISBN: 9780136156734.
G. U. A. Bakshi, V. U. Bakshi, Control System Engineering, Technical Publications, 2008. ISBN: 9788184314632.
H. L. C. Westphal, Handbook of Control Systems Engineering, Illustrated Edition, Springer, 2001. ISBN: 9780792374947.

NE 3202	Instrumentation and Measurement Lab	Credits: 1.5 3.0 Hours/week

Laboratory based on NE 3207.

NE 3204	Nuclear Design Project	Credits: 1.5 3.0 Hours/week

Design project based on NE 3105.

Fourth Year First Semester

NE 4101	Nuclear Disaster Management	Credits: 3.0 3.0 Hours/week

Concepts of Reactor Accident: Operational States of NPP; Concept of Nuclear Accident and Incident; Initiating Events; Classification of Nuclear Accident; INES Scale; Design Basis and Beyond Design Basis Accidents in NPP.

Introduction to Nuclear Disasters: Definition and types of nuclear disasters, Historical case studies of nuclear disasters, Three Mile Island, Chernobyl and Fukushima Daiichi Nuclear disaster. International legal frameworks and regulations for nuclear safety.

Nuclear Emergency Planning and Preparedness: Development of emergency response plans, Roles and responsibilities of various agencies and stakeholders, Risk assessment and hazard analysis, Emergency planning zones and evacuation strategies, Emergency response plans and protocols.

Radiation Monitoring and Environmental Impact: Radiation monitoring techniques and equipment, Environmental monitoring and assessment, Radioactive contamination and decontamination procedures, Health effects of radiation exposure. Radiation exposure and dose assessment, Radiation protection and safety measures, public information and education campaigns.

Emergency Response and Recovery: Incident command system and emergency response organization, Communication and coordination among response agencies, medical management and triage of radiation injuries, Decontamination procedures and waste management, Strategies for environmental remediation, Long-term management of contaminated areas, Psychosocial support and community resilience.

International Cooperation and Lessons Learned: International organizations and their roles in nuclear disaster management, Case studies of international cooperation during nuclear emergencies, Lessons learned from past nuclear disasters and their application, Collaboration and sharing of best practices.

Ethical, Legal, and Social Issues: Ethical considerations in nuclear disaster management, Legal frameworks and regulations related to nuclear emergencies, Social and cultural implications of nuclear disasters, public perception and risk communication strategies.

Recommended Readings

A. Sehgal, B.R. (Editor), Nuclear Safety in Light Water Reactors. Severe Accident Phenomenology, 1st edn., (2012).
B. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307
C. International Atomic Energy Agency, Method for the Development of Emergency Response Preparedness for Nuclear or Radiological Accidents, IAEA-TECDOC-953, Vienna (1997).
D. International Atomic Energy Agency, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards, General Safety Requirements No. GSR Part 7, Vienna (2015).
E. International Atomic Energy Agency, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards, General Safety Guide No. GSG-2, Vienna.
F. Nuclear Energy Agency - OECD, Implementation of Defence in Depth at Nuclear Power Plants. Lessons Learnt from the Fukushima Daiichi Accident, NEA No. 7248 (2016).
G. International Nuclear Safety Advisory Group, Defence in Depth in Nuclear Safety, INSAG-10, IAEA, Vienna (1996).
H. United States Environmental Protection Agency, PAG Manual: Protective Action Guides and Planning Guidance for Radiological Incidents, EPA-400/R-17/001, Washington DC (2017).

NE 4103	Nuclear Power Plant Design and Features	Credits: 3.0 3.0 Hours/week

Design Aspects of Nuclear Power Plant: Principles of nuclear reactor design, history and survey of reactor design, general aspects of core design, core design objectives, core design constraints and variables, nuclear design, thermal hydraulic design, mechanical/material design, design of reactor shielding and reflector.

Design of Light Water Reactor: General core design, core design set-up, lattice physics and whole core analysis, design of fuel lattice and assembly, characteristics of reactivity, reactivity feedback, control of power distribution, core management, fuel management, economics of reactor.

Design of High Temperature Gas-Cooled Reactors: Core, fuel, and control rod designs, method of achieving high outlet coolant temperature, nuclear and thermohydraulic design codes and process flow, process flow of cell

calculation, thermal-hydraulic design, mechanical design, annular core design, principle of keeping low fuel temperature of annular core at accident.

Operation and Control of Nuclear Power Plant: Plant startup- types, startup from cold zero power to hot full power, pressure, temperature, reactivity control during startup, limiting conditions for startup, startup sequence, operational issues during startup, safety issues during startup, synchronization of the generator. Normal plant operating parameters, reactor cooling in power operation, plant shutdown shut down cooling., plant heat balance & the steam cycle, steady-state thermal hydraulic analysis, thermodynamics of Power Conversion cycles

Plant Simulators: Approach to criticality, ascension to full power, normal operation, transient analysis, accident analysis.

Recommended Readings

A. Nuclear Reactor Design, Oka.Yoshoaki, Springer, 2014, ISBN 978-4-431-54897-3
B. Nuclear Reactor Analysis, James J. Duderstat and Louis J. Hamilton, 1st ed. New York: Wiley, 1976. ISBN: 9780471223634
C. Neutronic Analysis for Nuclear System, Bahman Zohuri, Springer, 2019, Second Edition, ISBN 978-3-030-04905-8
D. Nuclear Reactor Enginering, Glasstone and Sesonske, Third ed.
E. Nuclear Engineering Handbook, Kenneth D. Kok, ISBN 978-1-4200-5390-6
F. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307.
G. Applied Reactor Technology, HenrykAnglart, 2011
H. Neil E. Todreas, Mujid S. Kazimi, Nuclear Systems I, Thermal Hydraulic Fundamentals, Taylor & Francis.
I. Introduction to Nuclear Engineering, John R. Lamarsh, Anthony J. Baratta, Third Edition, ISBN 0-201-82498-1.

NE 4105	Fusion Power Engineering	Credits: 3.0 3.0 Hours/week

Fundamentals of Fusion Engineering: The role of fusion energy, fusion reactions, difficulty of fusion reaction, fusion in sun and stars, fusion fuel cycles, energy partition in fusion reaction, thermonuclear conditions; Lawson and ignition criteria, basic concept about plasma formation, start-up and burning plasma analysis, Magnets: superconductivity.

Fusion Power Generation: Concept of cross section, mean free path, and collision frequency, reaction rate, distribution functions, fusion cross sections, fusion power density and radiation losses.

Power Balance in a Fusion Reactor: 0-D conservation of energy relation, general power balance in magnetic fusion, steady state power balance, power balance in the plasma, power balance in a reactor, time dependent power balance in a fusion reactor.

Fusion Confinement: Necessity of confinement, Material confinement, gravitational confinement, electrostatic confinement, inertial confinement: Energy balance, compression energy, laser and particle beam drivers; magnetic confinement: energy and particle flow in magnetic field, linear mirror fusion concept, tandem mirror, tokamak concept and stellator concept.

Fusion Blanket: Blanket concept, first wall loading, plasma wall interactions, wall impurity effects, blanket neutronics and energetics, tritium inventor, methods of recovery, tritium breeding induced radioactivity, radiation damage to material: influence on design.

Design of a Simple Magnetic Fusion Reactor: Generic fusion reactor, critical reactor design parameter, design goals, and basic engineering and nuclear physics constraints, design of the reactor, Fission-fusion hybrids reactor, prospect of ITER.

Recommended Readings

A. Plasma Physics and Fusion Energy, Jeffrey P. Freidberg, 2007.
B. Principles of Fusion Energy, A.A. Harms, K.F. Schoepf, G.H. Miley, D.R. Kingdon, ISBN 981-02-4335-9
C. Francis F. Chen, Introduction to Plasma Physics and Controlled Fusion. Springer; 2nd Ed., 1984
D. Introduction to Nuclear Power, Geoffery F. Hewitt, Jhon G. Collier, 2nd edition, Chapter-9.
E. John Wesson, Tokamaks, Oxford Univ. Press, USA, 4th edition, 2011
F. Mitsuru Kikuchi, Karl Lackner, and Minh Quang Tran, Fusion Physics, IAEA, Vienna 2012
G. Leslie C. Woods, Theory of Tokamak Transport, Wiley-VCH Verlag GmbH & Co. KGaA, 2006.
H. Dwight Nicholson, Introduction to Plasma Theory, John Wiley & Sons, 1983.

NE 4107	Security and Safeguards	Credits: 3.0 3.0 Hours/week

Security: Definition of nuclear security; Threat, Theft, sabotage, Nuclear attacks, Historical developments, International Protocols, UNSCR-1373, 1540, IAEA nuclear security document Series and Hierarchy, Member state's obligations towards nuclear security, Legal and Non-legal binding instruments for member states, Legislative and regulatory framework for nuclear security, Physical protection regime and layers, graded approach, Category of nuclear material, Physical Protection System (PPS) designs for protection of nuclear material, radiation and associated facilities, Design Basis Threat (DBT) analysis, Detection architecture (Boarder, Airport, Sea port), Regulation for nuclear material and radioactive sources in storage and transport, Export and import control, Assessment methodology for nuclear security cultures, Insider threats analysis, cyber security, Nuclear security event response and neutralization.

Safeguards: History of nuclear nonproliferation, NPT, IAEA Safeguards systems, Evolving safeguards implementation, Safeguards agreements, additional protocol agreements, National regulatory framework for safeguards policy and regulation, nuclear material facility inspection guidance, State-level and integrated safeguards concepts, state systems accounting for and control (SSAC) of nuclear material, Safeguards reporting system, Safeguards information system, Safeguards verification systems, NDAs and DAs, Safeguards challenges for fuel fabrication, enrichment and reprocessing facilities, Safeguards R&D for advanced nuclear fuel cycles.

Recommended Readings

A. The Oxford Handbook of Nuclear Security Get access Arrow, Christopher Hobbs (ed.), Sarah Tzinieris (ed.), Sukesh K. Aghara (ed.)
B. Nuclear Security Briefing Book 2014 Edition, King's College London, UK.
C. IAEA NSS No.20, Nuclear Security Fundamentals, Objective, and Essential Elements of a State's Nuclear Security Regime
D. IAEA NSS No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)
E. IAEA NSS No.10, Implementing Guide, Development, Use and Maintenance of the Design Basis Threat
F. NPT Briefing Book, 2015 Edition, King's College London, UK.
G. Nuclear Material Accounting Handbook, IAEA Services Series No.15.
H. IAEA safeguard standard series

NE 4109	Research Methodology, Scientific and Technical Writing	Credits: 2.0 2.0 Hours/week

Foundation of Research: Definition of research, Significance of research, Objectives of Engineering research, Motivation in Engineering research, Types of engineering research, Fundamental research, applied research, Descriptive research, Analytical research, Research methods versus methodology.

Literature Review: Developing a systematic literature search, Search techniques, Advanced literature search, Broadening or narrowing your search, Bibliographic databases (Web of Science, Google Scholar, Scopus), Citations: functions and attributes, Knowledge flow through citation, Styles for citations, Reference management software like Mendeley/Zotero.

Data and Error Analysis: Data preparation, Primary data, Secondary data, making effective charts (bar, pie), Graphs, Tables, Error in scientific/experimental measurement, Importance of knowing the uncertainties, how to report and use uncertainties, Propagation of uncertainties, Statistical tools for error analysis.

Research Misconduct and Ethics: Understand the research misconduct; Types of research misconduct, Ethical issues in conducting research, Fabrication, Falsification, Plagiarism and self-plagiarism, Plagiarism detection software like iThenticate, Ethical issues related to authorship, Academic dishonesty, Conflicts of Interest (CoI),

Structure of Thesis/Scientific Manuscript/Report: Ways of writing your thesis, Typical format of thesis, Types of manuscripts, IMRAD structure, Contents of scientific manuscript, Acknowledgements, Keywords, Highlights, Graphical abstract.

Reading, Writing, and Communicating your Research: How to read scientific publication, Critical and Creative reading, taking notes while reading, writing strategies or approach, Language skills and writing style, Poster presentation, Oral presentation, Process of publishing your research, how to write research proposal (purpose, plan, and method), Time management and developing Gantt Charts.

Recommended Readings

A. C.R. Kothari, Research Methodology (Methods and Techniques), Second revised edition, New Age International (P) Limited, Publishers, India, 1990.

B. Dipankar Deb, Rajeeb Dey, and Valentina E. Balas, Engineering Research Methodology: A Practical Insight for Researchers, 1st edition, Singapore: Springer, 2018.
C. David V. Thiel, Research Methods for Engineers, 1st Edition, UK: Cambridge University Press, 2014.
D. Flick. Introducing Research Methodology: A Beginner's Guide to doing a Research project, 2nd edition New York, USA: Sage Publications Ltd, 2015.

NE 4109	**NEOP–1**	**Credits: 3.0** **3.0 Hours/week**

NE 4102	**Nuclear Simulation Lab**	**Credits: 1.5** **3.0 Hours/week**

Laboratory Based on NE 3203 and NE 4103.

NE 4104	**Industrial Training**	**Credits 2.0** **2.0 Hours/week**

Students will be dispatched in the relevant industries such as different establishments of Bangladesh Atomic Energy Commission, Bangladesh Atomic Energy Regulatory Authority, Nuclear Power Company of Bangladesh Limited and thermal power stations for gathering real life experiences.

Fourth Year Second Semester

NE 4201	Advanced Nuclear Reactors Design and Features	Credits: 3.0 3.0 Hours/week

Concept of Advanced Reactor: Definition of Advanced Designs (current design, evolutionary & innovative design), nuclear reactors from early prototypes to innovative design, key differentiating factors, design goals of advanced reactor, economic aspect, safety aspect, advanced reactors by types.

Design of Advanced Reactors: Design of Fast Reactors: Basic procedure of core design, core geometry, operation and management, design of fuel element and fuel assembly, nuclear design calculation, reactivity characteristics, power distribution characteristics, thermal-hydraulic design- basic principles, coolant flow allocation, maximum temperature of coolant, cladding, fuel, transitions in core design and tendency in the future.

Next Generation Nuclear Plant (NGNP): Generation IV International Forum, areas of improvement for Gen-IV nuclear energy systems, goals of Gen-IV design, Gen-III to Gen-IV: improvements to reach the goals, Gen-IV systems (VHTR, MSR,SFR,SCWR,GFR,LFR):plant description, advantages & challenges, achievement of Gen-IV goals, basis for development, safety issues & plant safety system, R&D requirements for commercial development, Gen-IV roadmap project, licensing strategy, market & industry status and potentials, synergies with other sectors, combined cycles for efficiency of new generation nuclear power plants, nuclear renewable hybrid energy system.

Design and Analysis of Small Modular Reactors: Small modular reactors-definition, advantages, issues and challenges, SMRs by reactor types, safety features, licensing, nonproliferation resistant and security, small reactor designs in market, core design and analysis- heat pipe micro reactor, high-temperature gas-cooled reactors/advanced small modular reactor.

Recommended Readings

A. Nuclear Reactor Design, Oka.Yoshoaki, Springer, 2014, ISBN 978-4-431-54897-3
B. Nuclear Engineering Handbook, Kenneth D. Kok, ISBN 978-1-4200-5390-6
C. Bahman Zohuri, Neutronic Analysis for Nuclear System, Springer, 2019, Second Edition, ISBN 978-3-030-04905-8
D. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307.

E. Advanced Reactor Information system, International Atomic Energy Agency.

NE 4203	Risk and Safety Analysis	Credits: 3.0 3.0 Hours/week

Introduction: Definition of risk, factors affecting acceptance of risks, overview of risk. Concept of reactor safety, key safety measures, Defense-in-Depth, plant states, engineered safety features, reliability & availability, reactor safety study and safety analysis- DSA (concept, characteristics, evaluation methods & Tools), comparisons of DSA with PSA.

Probabilistic Risk Assessment (PRA): Failure modes, classification of failure events, events contribute to common cause failures, failure criteria, objectives of a human reliability analysis, failure data- hardware failures, human errors, combination of failures and consequences- inductive methods, severity classification scheme for failure modes. Concept of PRA, technical basis for PRA model, basic components of PRA, end state of PRA, objectives of Level 1, Level 2 & Level 3 PRA, principal steps in PRA, strength &principal limitations of PRA, initiating event analysis, accident sequence analysis, systems analysis--event tree analysis, fault tree analysis- fault tree symbols, tree construction & qualitative analysis, common cause failures and fault tree analysis. Human reliability analysis, data analysis, accident sequence quantification, types of uncertainty in PRAs, stochastic uncertainty analysis, sensitivity and importance analysis. Large Early Release Analysis.

Analysis of System Reliability: Basics of probability, time-independent probabilities, failure probability at a particular demand, time-independent probability distributions, reliability functions, hazard rate, mean time to failure (MTTF), repair of a device, mean time to repair (MTTR), mean time between failure (MTBF), time-dependent probability distribution, probability models for failure analyses. Reliability data- Bayes equation & its application, central limit theorem, hypothesis testing with the central limit theorem, reliability quantification by- central limit theorem, engineering approach, Chi-square distribution. Reliability of Multiple-Component Systems: Series and Active-Parallel Systems- systems with independent and redundant components, fail-to-safety and fail-to-danger systems, systems with standby components, decomposition analysis, signal flow graph analysis, cut set analysis.

Availability and Reliability of Systems with Repair: Markov governing equations, solution of Markov governing equations, rules for constructing transition rate matrices, availability transition rate matrices, time-dependent

availability, steady-state availability. Reliability transition rate matrices, time-dependent reliability, imperfect switching between system states, systems with nonconstant hazard rates.

Recommended Readings

A. John C. Lee, Norman J. McCormick, Risk and Safety Analysis of Nuclear Systems, 2011, WILEY, ISBN 978-0-470-90756-6
B. Bal Raj Sehgal, Nuclear Safety in Light Water Reactors, 2012, ISBN: 978-0-12-388446-6
C. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Springer, 2010, ISBN: 9780387981307

NE 4205	Radiation Transport and Shielding	Credits: 3.0 3.0 Hours/week

Introductory Concept: Overview of radiation interaction with matter, attenuation parameters & calculation of interaction rate.

Determination of Uncollided Fluence & Dose: Monoenergetic point source (in vacuum, in homogenous & heterogeneous attenuating medium, with shield), polyenergetic point source, point kernel, distributed source- line source in nonattenuating & attenuating medium, line source behind a shield, superposition procedure for line sources, disk source, rectangular area source, spherical surface source, infinite slab source, cylindrical volume source.

Photon Attenuation: Concept of buildup factor, buildup flux and buildup factor for multilayered shield, calculation of buildup flux for- point source with a spherical shield, line source, infinite planner disk source. Photon transport using Monte Carlo Method.

Neutron Attenuation: Difference between photon & neutron calculation, neutron removal cross section, fast neutron attenuation calculation for reactor, capture gamma attenuation, coolant activation product & calculation of equilibrium activity, attenuation of charged particles. Neutron transport using Monte Carlo Method.

Reactor Shielding: Principle of external radiation protection (TDS concept), purpose of radiation shielding in nuclear power plant (NPP), primary radiation, secondary radiation. Reactor sources of radiation- reactor core and vessel, reactor coolant system, steam and turbine system, radioactive waste system, radioactive sources in fuel cycle facilities. Thermal & biological shield, difference between FBR and LWR shielding, materials for shielding and their

nuclear, physical, and mechanical properties and technology, boron containing materials, principle of gamma & neutron shielding, shielding materials- heavy or moderately heavy elements, hydrogenous materials, ordinary & heavy concrete.

Shield Design: Effects of ducts, voids & heterogeneities in shields, streaming and backscattering of radiation, heat generation by radiation in shields, shield design aspects for power reactors, transport containers, reprocessing plants, waste storage facilities and shielded cells.

Recommended Readings

A. Chilton, A B., Shultis, J. K. and R E. Faw, Principles of Radiation Shielding, Prentice-Hall, 1984.
B. Glenn F. Knoll, Radiation Detection and Measurement, 4th edition, Illustrated, John Wiley & Sons, 2010, ISBN: 9780470131480.
C. Schaeffer, N. M. (ed), Reactor Shielding for Nuclear Engineers, Technical Information Center, USAEC, 1973.
D. Goldstein, H., Fundamental Aspects of Reactor Shielding, Pergamon, 1959.
E. Rockwell, T., Reactor Shielding Design Manual, Springfield National Technical Information Services 1956.
F. Jaeger, RG. and E.P. Blizard (eds.), Engineering Compendium on Radiation Shielding Vol. 1, 11 and, 111, Springer- Verlag, 1970

NE 4207	**NEOP–2**	**Credits 3.0** **3.0 Hours/week**

NE 4200	**Project Work**	**Credits 4.0**

NE 4202	**Reactor Operation and Experiments Lab**	**Credits 2.0** **2.0 Hours/week**

Study, Operation, and Experiments of $3MW_{th}$ TRIGA Mark-II nuclear research reactor of Bangladesh Atomic Energy Commission at Atomic Energy Research Establishment (AERE), Savar, Dhaka.

Optional Courses

NEOP	Monte Carlo Methods for Nuclear System	Credits: 3.0 3.0 Hours/week

Probability Fundamentals: Foundations of probability, random variables, univariate and multi-variate probability mass/density functions and cumulative distribution functions, conditional distribution functions, expectation, variance and covariance/correlation; transformations of random variables; law of large numbers; central limit theorem; convergence of independent, identically-distributed random sequences and confidence intervals; pseudorandom number generation.

Monte Carlo Sampling Techniques: Inversion sampling; linear decomposition methods; rejection sampling; factorization scheme; random sampling examples; sampling of multivariate random variables; transformation methods; Box-Muller transform; monoatomic free gas collision velocity sampling example (Kahn method)

Markov Chains: Markov property; properties of discrete Markov chains; classification of states; evaluation and sampling of Markov chains; continuous-time Markov chains and sampling schemes; Markov Chain Monte Carlo (MCMC) and Metropolis-Hastings sampling; Gibbs sampling; simulated annealing

Variance Reduction Techniques: General concept; antithetic variates; control variates; stratified and Latin hypercube sampling; importance sampling

Estimation: Histogram estimation; functional expansions; kernel density estimation

Perturbation Methods: Correlated sampling; differential operator sampling; applications to discrete and continuous time Markov chains.

Particle Transport I: General idea; particle state and transport equation; geometry tracking; distance to and sampling of particle interactions; neutron and photon interactions

Particle Transport II: Green's function of transport equation and sampling scheme; estimators for path-length density and current; comparison of collision and track-length estimators; considerations of parallel computing (distributed and shared memory); vectorization algorithm with GPUs

Particle Transport III: Specialized particle transport variance reduction techniques; source biasing; implicit capture; splitting and rouletting; weight windows; path-length stretching; forced collisions; forced flight; static criticality (k-eigenvalue) estimation; challenges of source convergence and bias in k-eigenvalue calculations.

Recommended Readings

A. G. Grimmett, D. Stirzaker, Probability and Random Processes (3rd Ed.), Oxford University Press, 2001.
B. M. Kalos, P. Whitlock, Monte Carlo Methods (2nd Ed.), Wiley-VCH, 2008.
C. Lux, L. Koblinger, "Monte Carlo Particle Transport Methods: Neutron and Photon Calculations,"
D. CRC press, 2000.
E. L. Carter, E. Cashwell, "Particle Transport Simulation with the Monte Carlo Method," Los Alamos National Laboratory, 1975.
F. F. Brown, "Fundamentals of Monte Carlo Particle Transport", Los Alamos National Laboratory, 2018.

NEOP	Computational Fluid Dynamics Analysis	Credits: 3.0 3.0 Hours/week

Governing Equations of Fluid Dynamics: General form of a conservation law; Equation of mass conservation; Navier Stokes Equation; Conservation equation of energy.

Fundamentals of Numerical Algorithms for Modelling Dynamics of Fluid Flow Computationally: Model development & various approaches of mesh generation on structured and unstructured grids with a variety of boundary conditions.

Fundamentals of Discretization: Finite Element Method, Finite Difference and Finite Volume Method, Consistency, Stability and Convergence.

Study of different turbulent models using ANSYS FLUENT: k-ε, k-ω, k-ω SST model, LES model, PECM model. Uses of ANSYS FLUENT to investigate more complex flows (multiphase, turbulent etc.) in simple/complex geometry with different numerical approaches.

Two/three projects will be assigned during the course of the semester.

Recommended Readings

A. Versteeg, H., & Malalasekera, W. (2007). An introduction to computational fluid dynamics: The finite volume method. 3rd ed. New York, NY: Pearson.
B. Blazek, J. (2004). Computational fluid dynamics: Principles and applications. New York, NY: Elsevier.
C. Anderson, J. D., Jr. (2019). Computational fluid dynamics. 7th ed. New York, NY: McGraw-Hill Education.
D. Ferziger, J. H., & Perić, M. (2002). Computational methods for fluid dynamics. 3rd ed. New York, NY: Springer.
E. Tu, J., Yeoh, G. H., & Liu, C. (2017). Computational fluid dynamics: A practical approach. 2nd ed. Hoboken, NJ: John Wiley & Sons.
F. Monin, A. S., & Yaglom, A. M. (2005). Compressible fluid dynamics and shock waves. 2nd ed. New York, NY: Dover Publications.
G. Anderson, J. D., Jr. (2001). Modern compressible flow. 3rd ed. New York, NY: McGraw-Hill Education.

NEOP	Nuclear Chemical Engineering	Credits: 3.0 3.0 Hours/week

Overall chemical engineering process technologies (Chemical engineering design, Chemical process industries, Chemical reaction engineering) and principle applicable to nuclear engineering are covered and described. Basic chemical concepts regarding chemical thermodynamics and kinetics, fundamentals of nuclear water technology and isotope separation methods, Chemical effects induced by nuclear reactions, Radiation damage induced core material property change, water or liquid metal side corrosion, corrosion in nuclear systems and design, diffusion and reaction of fission products, structural stability of metal or nonmetallic materials, radiation hardening or embrittlement and swelling are studied and analyzed in terms of lattice defect interaction with energetic neutron, the chemical analysis using radiotracers, the chemistry of transuranic elements, and environmental impacts of radionuclides and environmental friendly nuclear power assessment will be covered and carefully reviewed.

Recommended Readings

A. Monson Benedict, Thomas H. Pigford and Hans Wolfgang, Levi, Nuclear Chemical Engineering, McGraw-Hill series in Nuclear Engineering, 1981, ISBN-13: 9780070045316.

B. Richard Turton, Analysis, Synthesis and Design of Chemical Processes, Publisher: Prentice Hall, Inc. ISBN13: 978-0135129661.

NEOP	Decommissioning Procedure and Management	Credits: 3.0 3.0 Hours/week

Nuclear Plants Decommissioning Overview: Definition and Scope of Decommissioning, Introduction to Some Decommissioning Challenges, Decommissioning Strategies, Decommissioning in the World.

Decommissioning Organization and Management: Issues Affecting Decommissioning Organization and Management, Organization and Management in the Various Phases of Decommissioning, Management for Active Phases of Decommissioning, Decommissioning Planning and Licensing, Nuclear site licensing.

Plant and Site Characterization: Initial Plant Characterization: Radioactivity Sources, The Concept and Extent of Characterization, Structure Characterization. **Site Characterization**: Surface and Subsurface Soil contamination, Surface Water and Groundwater Contamination.

Decontamination Techniques: Objectives of Decontamination Techniques, Selection of Decontamination Technologies, Survey of Applied Decontamination Techniques, Chemical, Mechanical Decontamination and Other Decontamination Techniques.

Cutting and Dismantling Techniques: Overview of cutting techniques, **Techniques of material cutting:** Thermal Cutting Techniques, Hydraulic Cutting Techniques, Mechanical Dismantling Techniques, Remote Operation Technologies, Elements of robotic systems together with their integration and control, User interface design and implementation using the lab view software environment.

Decommissioning Waste Management: Overview, Clearance Levels, Radioactive species present in the decommissioning environment, Waste-Management Strategy, Treatment and Conditioning of different types of waste, Packaging, storing and Transport technologies.

Safety, Health and Environmental Protection: Instrument used to characterize radiation levels within decommissioning environment, Environmental Impact Assessment (EIA), Radiation effect on materials and electronics, Explosive in demolition.

Decommissioning Cost Evaluation: Regulatory and site infrastructure cost, Standard Criteria for Cost Evaluation, Cost Evaluation Methodologies, Cost Calculation Model Example, Cost-Breakdown Structure.

Recommended Readings

A. Handbook of Nuclear Engineering, Dan Gabriel Cacuci, Volume-5, Springer publication.
B. Cutting techniques for facilities dismantling in decommissioning projects, Paulo E. O. Lainetti, International Nuclear Atlantic Conference - INAC 2011, Belo Horizonte, MG, Brazil, October 24-28, 2011, ISBN: 978-85-99141-04-5.
C. A Guide to Nuclear Power Technology, Frank J. Rahn, A.G Adamantiades, J.E Kenton and Chaim Braun, John Wiley & Sons 1984
D. Introduction to Nuclear Engineering, John R. Lamers& Anthony J. Barata, 3rd edition, Prentice Hall, 1982
E. Decommissioning of Nuclear Power Plants and Research Reactors, IAEA safety standards series, No. WS-G-2.1.

NEOP	Plasma Physics	Credits 3.0 3.0 Hours/week

Overview of magnetic fusion. Plasma properties necessary for a fusion reactor.

Basic definition of plasma and its characteristics. Shielding DC electric fields in a plasma the Debye length. Derivation of Debye length. The concept of quasi neutrality of plasma. Shielding of AC electric fields in plasma. Derivation of electron plasma frequency. Collective behavior in plasma.

Single Particle Motion in Electric and Magnetic Fields. (a) Motion in uniform fields. (b) Motion in oscillating fields. (c) Curvature and grad-B drifts. (d) Ponderomotive force. (e) General treatments: method of averaging, guiding center motion and drifts, invariance of the magnetic moment, Poincare invariants, adiabatic invariants. (f) Examples: magnetic mirrors,

Van Allen Radiation Belts, Fermi acceleration, etc.

Collision processes. Coulomb collision between charged particles in plasma. Applications of collision analysis: energetic ('runaway') electrons, collision time, energy equilibrium. Fluid Description of Plasma. Relation of plasma physics to ordinary electromagnetics. The fluid equation of motion, fluid drift perpendicular to B, fluid drifts parallel to B.

Magnetohydrodynamics (MHD). MHD model, Alfven theorem, Diffusion of a B-field, MHD waves.

Diffusion and Resistivity. Diffusion and mobility in weakly ionized gases, decay of a plasma by diffusion, steady state solutions, recombination, diffusion across a magnetic field, diffusion in fully ionized plasmas, solution of the diffusion equation.

Theory of Plasma. Kinetic theory of plasmas, Boltzmann Vlasov equation, Drift Kinetic equation, Linearization of the Vlasov model, Linear electrostatic response, Landau damping, Stability methods.

Present status and challenges of fusion research for energy production

Recommended Readings

A. Francis F. Chen, Introduction to Plasma Physics and Controlled Fusion. Springer; 2nd Ed., 1984
B. Jeffrey P. Freidberg, Plasma Physics and Fusion Energy, 2007
C. Francis F. Chen, An Indispensable Truth. How Fusion Power Can Save the Planet. Springer, 2011
D. Lyman Spitzer Jr., Physics of Fully Ionized Gases, 2nd Revised Edition, Dover Publications, 1962
E. John Wesson, Tokamaks, Oxford Univ. Press, USA, 4th edition, 2011
F. Mitsuru Kikuchi, Karl Lackner, and Minh Quang Tran, Fusion Physics, IAEA, Vienna 2012
G. Leslie C. Woods, Theory of Tokamak Transport, Wiley-VCH Verlag GmbH & Co.
H. KGaA, 2006
I. Jeffrey P. Freidberg, Ideal MHD, Cambridge University Press, 2014 (updated version f 1987 Ed.)
J. Richard Fitzpatrick, Plasma Physics An Introduction, CRC Press, 2015
K. Peter C. Stangeby, The Plasma Boundary of Magnetic Fusion Devices, Taylor & Francis, 2000
L. Dwight Nicholson, Introduction to Plasma Theory, John Wiley & Sons, 1983
M. K. Nishikawa, M. Wakatani, Plasma Physics, 3rd Edition, Springer
N. Richard D. Hazeltine, Francois L. Waelbroeck, The framework of plasma physics, Perseus Book

NEOP	Radiation Imaging	Credits: 3.0 3.0 Hours/week

A Brief Introduction to Tomographic Imaging: Introduction to general imaging principles, imaging terms and definitions linear optics (ray tracing).

Linear Imaging Systems: The delta function and the impulse function superposition, instrument response function, point spread function, space invariance, pin-hole camera.

Fourier transform: Fourier transformations, modulation transfer functions, convolution, deconvolution, Fourier convolution. Sampling: Sampling, Nyquist, counting statistics, additive noise, Sound imaging: Coherent imaging & ultrasound, ultrasound imaging, ultrasound contrast, microscopy and Doppler.

Radiation Imaging: Radiation types, interactions, radiation detection, dose, planar $x-$ ray imaging, system response, s/n, projective imaging, back projection, shadow imaging, bp and 2-d resolution, x-ray ct, spect, pet, basics of NMR, pulses and relaxation times, echoes & kspace, echoes and contrast, 2-d gradient and spin echoes, selective pulses, 3-d methods of MRI volume localized spectroscopy, flow / diffusion MRI.

Recommended Readings

A. Cho, Z. H., J. Jones, M. Singh, Foundations of Medical Imaging, Illustrated Edition, Wiley, 1993. ISBN: 9780471545736.
B. Webb, S., The Physics of Medical Imaging, Illustrated Edition, CRC Press, 1988. ISBN: 9781439822081.
C. MacOvski, A. Medical Imaging, Illustrated Edition, Pearson Education Limited, 1983. ISBN: 9780135726853.
D. Callaghan, P., Principles of NMR Microscopy, Illustrated Edition, Oxford University Press, 1993. ISBN: 9780198539971.
E. Blackledge, J. M., Quantitative Coherent Imaging: Theory, Methods and Some Applications, Elsevier Science, 2012. ISBN: 9780323153591.
F. Bushberg, J., J. Siebert, E. Leidholdt, J. Boone, The Essential Physics of Medical Imaging, 3^{rd} Edition, Lippincott W., Wilkins, 2011. ISBN: 978145115394.
G. Carlton R. R., A. M. Adler, Principles of Radiographic Imaging: An Art and A Science, 5^{th} Edition, Cengage Learning, 2012. ISBN: 9781439058725.
H. Barratt, H. B., Swindell W., Radiological Imaging, Illustrated Edition, Academic Press, 1996. ISBN: 9780120796038.

NEOP	Beams and their Applications	Credits: 3.0 3.0 Hours/week

Beams: Types of beams, types of particle beams, proton and photon beam, creation of particle beams, spallation neutron beam, acceleration of particle beams, applications of particle beams.

Accelerators: Introduction to accelerators, Methods of particle acceleration, Common beamline elements and the transfer matrix method, Introduction to simulations and simulation codes, existing and future accelerators, Uses of accelerators.

Classes of Accelerators: electrostatic and oscillating field accelerators, cathode ray tube, Cockcroft-Walton generator, Van de Graaff generator, Tandem accelerator, Electrostatic particle/nuclear accelerators, Oscillating field particle accelerators, linear particle accelerator, circular or cyclic accelerators, cyclotrons, synchrocyclotrons and isochronous cyclotrons, betatrons, synchrotron, electron synchrotrons, storage ring, synchrotron radiation sources, FFAG accelerator. Targets and detectors. Tandem accelerator: System description, available ions, available experimental techniques, future incorporation, typical PIXE analysis, scope of research, industrial applications,

Qualitative and Quantitative Elemental Analysis: Irradiation of materials with neutrons in a nuclear reactor and neutron generator, Nuclear Analysis using Ion Beam Analytical Techniques (IBA), Proton Induced X-ray Emission (PIXE), Proton Induced Gamma Emission (PIGE), Rutherford Backscattering Spectroscopy (RBS), X-ray Diffraction, Semiconductor Gamma-ray spectrometers.

Higher Energies: Black hole production and public safety concerns. Large Hadron Collider (LHC): Brief detail on LHC, four particle detectors of LHC ATLAS, CMS, ALICE and LHCb.

Recommended Readings

A. Klaus Wille, The Physics of Particle Accelerators: An Introduction, Illustrated, reprint edition, Oxford University Press, 2000, ISBN: 9780198505495.

B. Edmund Wilson, Edward J. N. Wilson, An Introduction to Particle Accelerators, Illustrated, reprint edition, Oxford University Press, 2001, ISBN: 9780198508298.

NEOP	Nanotechnology and its Applications	Credits: 3.0 3.0 Hours/week

Importance of nanotechnology, history of nano technology, properties of nanomaterials, difference between bulk and nanomaterial. Influence of Nano structure on mechanical, optical, electronic, magnetic and chemical properties. Overview of different nanomaterials available.

Nanomaterials Synthesis, "Top-Down" and "Bottom-Up" approaches of nanomaterial (nanoparticles, nanoclusters and quantum dots) synthesis. Self-assembly, self-assembled monolayers, directed assembly, layer-by-layer assembly. Pattern replication techniques: soft lithography, nanoimprint lithography. Quantum dots, gold, silver, different types of nano-oxides, $Al2O3, TiO2, ZnO$ etc. Carbon nanotubes, preparation properties and applications like field emission displays. Characterization Techniques Related to Nanoscience and Nanotechnology. Application of Nanomaterials, molecular motors, energy storage, electronic-nano particles for molecular diagnostics, nano biosensors, nanopharmaceuticals, nanoparticle-based drug delivery, nanostructures for tissue engineering/regenerative medicine etc. Handling, Safety and Hazard of Nanomaterials Processing.

Recommended Readings

A. Nanocomposite science and technology, Pulikel M. Ajayan, Wiley-VCH 2005
B. Nanolithography and patterning techniques in microelectronics, David G. Bucknall, Wood head publishing 2005
C. Transport in Nanostructures, D.K. Ferry and S.M. Goodmick, Cambridge university press 1997.
D. Micro and Nanofabrication, Zheng Cui, Springer 2005
E. Nanotechnology and nanoelectronics, W.R, Fahrner, Springer 2005
F. Hand book of Nano science, Engineering, and Technology, William A. Goddard, CRC press 2003
G. Nanomaterials: Risks and Benefits, Edited by Igor Linkov and Jeffery Steevens, Nato Science for Peace and Security Series-C,: Environmental Security, Springer 2009.

NEOP	Theory of Machines	Credits: 3.0 3.0 Hours/week

Kinematics and kinetics of motion; Kinematic link; Structure; Kinematic pair and chain; Mechanism; Velocity and acceleration of Mechanisms;

Kinetic and inertia energy of reciprocating and rotating parts; Balancing of machines; Static and dynamic balancing;

Longitudinal, transverse, and torsional vibrations; Undamped free vibration; Damped free and forced vibrations; Whirling of rotors and shafts; Vibration absorption, isolation, and desolation; Vibration measurement;

Cams and cam followers; Brakes and clutches; Gears and gear trains; Governors; Flywheels; Gyroscopes;

Introduction to stress analyses for design; Deflection and stiffness limits; Impact and shock analyses; Design for static and fatigue strength; Fracture mechanics;

Design of shafts; Design of rope, belt, and chain drives; Design of gears; Design of bearings; Design of screws and welded joints;

Recommended Readings

A. Khurmi, R. S., and J. K. Gupta. Theory of machines. S. Chand Publishing, 2005.
B. Uicker, John Joseph, et al. Theory of machines and mechanisms. Vol. 768. New York: Oxford University Press, 2003.
C. Khurmi, R. S., and J. K. Gupta. A textbook of machine design. S. Chand publishing, 2005.
D. Budynas, Richard Gordon, and J. Keith Nisbett. Shigley's mechanical engineering design. Vol. 9. New York: McGraw-Hill, 2011.

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