

## NUCLEAR SCIENCE AND ENGINEERING (COURSE 22)

### Undergraduate Subjects

#### 22.00 Introduction to Modeling and Simulation

Engineering School-Wide Elective Subject.

Offered under: 1.021, 3.021, 10.333, 22.00

Prereq: 3.016, 18.03, or permission of instructor

U (Spring)

4-0-8 units. REST

See description under subject 3.021.

*M. Buehler, R. Gomez-Bombarelli*

#### 22.01 Introduction to Nuclear Engineering and Ionizing Radiation

Prereq: None

U (Fall)

4-1-7 units. REST

Provides an introduction to nuclear science and its engineering applications. Describes basic nuclear models, radioactivity, nuclear reactions and kinematics. Covers the interaction of ionizing radiation with matter, with an emphasis on radiation detection, radiation shielding, and radiation effects on human health. Presents energy systems based on fission and fusion nuclear reactions, as well as industrial and medical applications of nuclear science.

*M. Short*

#### 22.011 Nuclear Engineering: Science, Systems and Society

Prereq: None

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: U (Spring)

1-0-2 units

Introduction to the basic physics of nuclear energy and radiation, with an emphasis on the unique attributes and challenges of nuclear energy as a low-carbon solution. Discusses peaceful applications of ionizing radiation, such as reactors for materials science research, nuclear medicine, and security initiatives. Explores fission energy, establishing the scientific, engineering, and economic basis for power reactors. Describes the latest advances in nuclear reactor technology. Introduces magnetic fusion energy research, with lectures covering the scientific and engineering basis of tokamaks, the state-of-the-art in world fusion experiments, and the MIT vision for a high-magnetic field fusion reactor. Uses radiation detection equipment to explore radioactivity in everyday life.

*A. White, M. Short, J. Buongiorno, J. Parsons*

#### 22.014 Ethics for Engineers

Engineering School-Wide Elective Subject.

Offered under: 1.082, 2.900, 6.904, 10.01, 16.676, 22.014

Subject meets with 6.9041, 20.005

Prereq: None

U (Fall, Spring)

2-0-4 units

See description under subject 10.01.

*D. Doneson, B. L. Trout*

#### 22.02 Introduction to Applied Nuclear Physics

Prereq: Calculus II (GIR), Physics II (GIR), and (8.03 or permission of instructor)

U (Spring)

5-0-7 units. REST

Covers basic concepts of nuclear physics with emphasis on nuclear structure and interactions of radiation with matter. Topics include elementary quantum theory; nuclear forces; shell structure of the nucleus; alpha, beta and gamma radioactive decays; interactions of nuclear radiations (charged particles, gammas, and neutrons) with matter; nuclear reactions; fission and fusion.

*M. Li*

#### 22.022 Quantum Theory of Radiation Interactions (New)

Subject meets with 22.51

Prereq: 22.02

U (Spring)

3-0-9 units

Introduces elements of applied quantum mechanics and statistical physics. Starting from the experimental foundation of quantum mechanics, develops the basic principles of interaction of electromagnetic radiation with matter. Introduces quantum theory of radiation, time-dependent perturbation theory, transition probabilities and cross sections. Applications are to controlling coherent and decoherent dynamics with examples from quantum information processing. Students taking graduate version complete additional assignments.

*P. Cappellaro*

**22.03 Introduction to Nuclear Design (New)**

Prereq: None

U (Fall)

2-3-1 units

Focuses on design thinking, rapid prototyping, overcoming fixation, and optimizing solutions within design constraints as applied to ideas relevant to nuclear science and engineering. Includes hands-on introductions to modern, rapid prototyping tools (laser cutter, 3D printer) in the context of a nuclear design problem, followed by discovery-based labs illustrating nuclear concepts. Culminates in a student-directed nuclear making experience. Enrollment limited; preference to Course 22 majors and minors.

*M. Short, Z. Hartwig*

**22.033 Nuclear Systems Design Project**

Subject meets with 22.33

Prereq: None

U (Fall)

3-0-12 units

Group design project involving integration of nuclear physics, particle transport, control, heat transfer, safety, instrumentation, materials, environmental impact, and economic optimization. Provides opportunity to synthesize knowledge acquired in nuclear and non-nuclear subjects and apply this knowledge to practical problems of current interest in nuclear applications design. Past projects have included using a fusion reactor for transmutation of nuclear waste, design and implementation of an experiment to predict and measure pebble flow in a pebble bed reactor, and development of a mission plan for a manned Mars mission including the conceptual design of a nuclear powered space propulsion system and power plant for the Mars surface, a lunar/Martian nuclear power station and the use of nuclear plants to extract oil from tar sands. Students taking graduate version complete additional assignments.

*Z. Hartwig, M. Bucci, K. Shirvan*

**22.039 Integration of Reactor Design, Operations, and Safety (New)**

Subject meets with 22.39

Prereq: 22.05 and 22.06

U (Fall)

3-2-7 units

Covers the integration of reactor physics and engineering sciences into nuclear power plant design, focusing on designs projected to be used in the first half of this century. Topics include materials issues in plant design and operations, aspects of thermal design, fuel depletion and fission-product poisoning, and temperature effects on reactivity. Addresses safety considerations in regulations and operations, such as the evolution of the regulatory process, the concept of defense in depth, general design criteria, accident analysis, probabilistic risk assessment, and risk-informed regulations. Students taking graduate version complete additional assignments.

*E. Baglietto*

**22.04[J] Social Problems of Nuclear Energy**

Same subject as STS.o84[J]

Prereq: None

U (Spring)

3-0-9 units. HASS-S

Surveys the major social challenges for nuclear energy. Topics include the ability of nuclear power to help mitigate climate change; challenges associated with ensuring nuclear safety; the effects of nuclear accidents; the management of nuclear waste; the linkages between nuclear power and nuclear weapons, the consequences of nuclear war; and political challenges to the safe and economic regulation of the nuclear industry. Weekly readings presented from both sides of the debate, followed by in-class discussions. Instruction and practice in oral and written communication provided. Limited to 18.

*R. S. Kemp*

**22.05 Neutron Science and Reactor Physics**

Prereq: 18.03, 22.01, and 22.06

U (Fall)

5-0-7 units

Introduces fundamental properties of the neutron. Covers reactions induced by neutrons, nuclear fission, slowing down of neutrons in infinite media, diffusion theory, the few-group approximation, point kinetics, and fission-product poisoning. Emphasizes the nuclear physics bases of reactor design and its relationship to reactor engineering problems.

*B. Forget*

**22.051 Systems Analysis of the Nuclear Fuel Cycle (New)**

Subject meets with 22.251

Prereq: 22.05

U (Spring)

3-2-7 units

Studies the relationship between technical and policy elements of the nuclear fuel cycle. Topics include uranium supply, enrichment, fuel fabrication, in-core reactivity and fuel management of uranium and other fuel types, used fuel reprocessing, and waste disposal. Presents principles of fuel cycle economics and the applied reactor physics of both contemporary and proposed thermal and fast reactors. Examines nonproliferation aspects, disposal of excess weapons plutonium, and transmutation of long lived radioisotopes in spent fuel. Several state-of-the-art computer programs relevant to reactor core physics and heat transfer are provided for student use in problem sets and term papers. Students taking graduate version complete additional assignments.

*C. Forsberg*

**22.054[] Materials Performance in Extreme Environments**

Same subject as 3.154[]

Prereq: 3.032 and 3.044

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: U (Spring)

3-2-7 units

See description under subject 3.154[].

*R. Ballinger*

**22.055 Radiation Biophysics**

Subject meets with 22.55[], HST.560[]

Prereq: Permission of instructor

Acad Year 2018-2019: U (Spring)

Acad Year 2019-2020: Not offered

3-0-9 units

Provides a background in sources of radiation with an emphasis on terrestrial and space environments and on industrial production. Discusses experimental approaches to evaluating biological effects resulting from irradiation regimes differing in radiation type, dose and dose-rate. Effects at the molecular, cellular, organism, and population level are examined. Literature is reviewed identifying gaps in our understanding of the health effects of radiation, and responses of regulatory bodies to these gaps is discussed. Students taking graduate version complete additional assignments.

*Staff*

**22.06 Engineering of Nuclear Systems**

Prereq: 2.005

U (Spring)

4-0-8 units

Using the basic principles of reactor physics, thermodynamics, fluid flow and heat transfer, students examine the engineering design of nuclear power plants. Emphasizes light-water reactor technology, thermal limits in nuclear fuels, thermal-hydraulic behavior of the coolant, nuclear safety and dynamic response of nuclear power plants.

*K. Shirvan*

**22.061 Fusion Energy (New)**

Prereq: 22.01 or permission of instructor

U (Spring)

4-1-7 units

Surveys the fundamental science and engineering required to generate energy from controlled nuclear fusion. Topics include nuclear physics governing fusion fuel choice and fusion reactivity, physical conditions required to achieve net fusion energy, plasma physics of magnetic confinement, overview of fusion energy concepts, material challenges in fusion systems, superconducting magnet engineering, and fusion power conversion to electricity. Includes in-depth visits at the MIT Plasma Science and Fusion Center and active learning laboratories to reinforce lecture topics.

*Z. Hartwig*

**22.071 Electronics, Signals, and Measurement**

Prereq: 18.03

U (Spring)

3-3-6 units. REST

Provides the knowledge necessary for reading schematics and designing, building, analyzing, and testing fundamental analog and digital circuits. Students construct interactive examples and explore the practical uses of electronics in engineering and experimental science, including signals and measurement fundamentals. Uses state-of-the-art hardware and software for data acquisition, analysis, and control. Suitable for students with little or no previous background in electronics. Limited to 20.

*A. White*

**22.072 Corrosion: The Environmental Degradation of Materials (New)**

Subject meets with 22.72  
 Prereq: Permission of instructor  
 Acad Year 2018-2019: Not offered  
 Acad Year 2019-2020: U (Spring)  
 3-0-9 units

Applies thermodynamics and kinetics of electrode reactions to aqueous corrosion of metals and alloys. Application of advanced computational and modeling techniques to evaluation of materials selection and susceptibility of metal/alloy systems to environmental degradation in aqueous systems. Discusses materials degradation problems in marine environments, oil and gas production, and energy conversion and generation systems, including fossil and nuclear. Students taking graduate version complete additional assignments.

*M. Li*

**22.074 Radiation Damage and Effects in Nuclear Materials (New)**

Subject meets with 3.31[], 22.74[]  
 Prereq: Permission of instructor  
 Acad Year 2018-2019: Not offered  
 Acad Year 2019-2020: U (Fall)  
 3-0-9 units

Studies the origins and effects of radiation damage in structural materials for nuclear applications. Radiation damage topics include formation of point defects, defect diffusion, defect reaction kinetics and accumulation, and differences in defect microstructures due to the type of radiation (ion, proton, neutron). Radiation effects topics include detrimental changes to mechanical properties, phase stability, corrosion properties, and differences in fission and fusion systems. Term project required. Students taking graduate version complete additional assignments.

*M. Short, B. Yildiz*

**22.078 Principles of Nuclear Chemical Engineering and Waste Management (New)**

Subject meets with 22.78  
 Prereq: Permission of instructor  
 Acad Year 2018-2019: Not offered  
 Acad Year 2019-2020: U (Spring)  
 3-0-9 units

Introduces scientific and engineering aspects of chemical engineering and waste management applied to reactors and the fuel cycle. Includes chemical behavior in reactors (normal and accident), spent nuclear fuel aging, separation processes in reprocessing (aqueous, pyro, and molten salt), and waste treatment processes. Addresses management of radioactive wastes, including waste forms, classification, fundamental principles, governing equations for radionuclide transport in the environment, performance assessment of geological waste disposal systems, and implications of advanced fuel cycles. Students taking graduate version complete additional assignments.

*C. Forsberg*

**22.081[] Introduction to Sustainable Energy**

Same subject as 2.650[], 10.291[]  
 Subject meets with 1.818[], 2.65[], 10.391[], 11.371[], 22.811[]  
 Prereq: Permission of instructor  
 U (Fall)  
 3-1-8 units

Assessment of current and potential future energy systems. Covers resources, extraction, conversion, and end-use technologies, with emphasis on meeting 21st-century regional and global energy needs in a sustainable manner. Examines various renewable and conventional energy production technologies, energy end-use practices and alternatives, and consumption practices in different countries. Investigates their attributes within a quantitative analytical framework for evaluation of energy technology system proposals. Emphasizes analysis of energy propositions within an engineering, economic and social context. Students taking graduate version complete additional assignments. Limited to juniors and seniors.

*M. W. Golay*

**22.09 Principles of Nuclear Radiation Measurement and Protection**

Subject meets with 22.90

Prereq: 22.01

U (Fall)

2-6-4 units. Institute LAB

Combines lectures, demonstrations, and experiments. Review of radiation protection procedures and regulations; theory and use of alpha, beta, gamma, and neutron detectors; applications in imaging and dosimetry; gamma-ray spectroscopy; design and operation of automated data acquisition experiments using virtual instruments. Meets with graduate subject 22.90, but homework assignments and examinations differ. Instruction and practice in written communication provided.

*A. Danagoulian, G. Kohse*

**22.091, 22.093 Independent Project in Nuclear Science and Engineering**

Prereq: Permission of instructor

U (Fall, IAP, Spring, Summer)

Units arranged

Can be repeated for credit.

For undergraduates who wish to conduct a one-term project of theoretical or experimental nature in the field of nuclear engineering, in close cooperation with individual staff members. Topics and hours arranged to fit students' requirements. Projects require prior approval by the Course 22 Undergraduate Office.

22.093 is graded P/D/F.

*M. Short*

**22.099 Topics in Nuclear Science and Engineering (New)**

Prereq: None

U (Fall, Spring)

Units arranged

Can be repeated for credit.

Provides credit for work on material in nuclear science and engineering outside of regularly scheduled subjects. Intended for study abroad with a student exchange program or an approved one-term or one-year study abroad program. Credit may be used to satisfy specific SB degree requirements. Requires prior approval. Consult department.

*Consult Undergraduate Officer*

**22.S092-22.S094 Special Subject in Nuclear Science and Engineering**

Prereq: None

U (Fall, IAP, Spring, Summer)

Not offered regularly; consult department

Units arranged

Can be repeated for credit.

Seminar or lecture on a topic in nuclear science and engineering that is not covered in the regular curriculum.

*M. Short*

**22.EPE UPOP Engineering Practice Experience**

Engineering School-Wide Elective Subject.

Offered under: 1.EPE, 2.EPE, 3.EPE, 6.EPE, 8.EPE, 10.EPE, 15.EPE, 16.EPE, 20.EPE, 22.EPE

Prereq: 2.EPW or permission of instructor

U (Fall, Spring)

0-0-1 units

See description under subject 2.EPE.

*Staff*

**22.EPW UPOP Engineering Practice Workshop**

Engineering School-Wide Elective Subject.

Offered under: 1.EPW, 2.EPW, 3.EPW, 6.EPW, 10.EPW, 16.EPW, 20.EPW, 22.EPW

Prereq: None

U (Fall, IAP)

1-0-0 units

See description under subject 2.EPW. Enrollment limited.

*Staff*

**22.THT Undergraduate Thesis Tutorial**

Prereq: None

U (Fall)

1-0-2 units

A series of lectures on prospectus and thesis writing. Students select a thesis topic and a thesis advisor who reviews and approves the prospectus for thesis work in the spring term.

*N. Louriero*

**22.THU Undergraduate Thesis**

Prereq: 22.THT

U (Fall, IAP, Spring, Summer)

Units arranged

Can be repeated for credit.

Program of research, leading to the writing of an SB thesis, to be arranged by the student and appropriate MIT faculty member. See department undergraduate headquarters.

*M. Short*

### 22.UR Undergraduate Research Opportunities Program

Prereq: None  
 U (Fall, IAP, Spring, Summer)  
 Units arranged [P/D/F]  
 Can be repeated for credit.

The Undergraduate Research Opportunities Program is an excellent way for undergraduate students to become familiar with the Department of Nuclear Engineering. Student research as a UROP project has been conducted in areas of fission reactor studies, utilization of fusion devices, applied radiation research, and biomedical applications. Projects include the study of engineering aspects for both fusion and fission energy sources.

*M. Short*

### 22.URG Undergraduate Research Opportunities Program

Prereq: None  
 U (Fall, IAP, Spring, Summer)  
 Units arranged  
 Can be repeated for credit.

The Undergraduate Research Opportunities Program is an excellent way for undergraduate students to become familiar with the department of Nuclear Science and Engineering. Student research as a UROP project has been conducted in areas of fission reactor studies, utilization of fusion devices, applied radiation physics research, and biomedical applications. Projects include the study of engineering aspects for fusion and fission energy sources, and utilization of radiations.

*M. Short*

## Graduate Subjects

### 22.11 Applied Nuclear Physics

Prereq: 22.02 or permission of instructor  
 G (Fall; first half of term)  
 2-0-4 units  
 Can be repeated for credit.

Introduction to nuclear structure, reactions, and radioactivity. Review of quantization, the wave function, angular momentum and tunneling. Simplified application to qualitative understanding of nuclear structure. Stable and unstable isotopes, radioactive decay, decay products and chains. Nuclear reactions, cross-sections, and fundamental forces, and the resulting phenomena.

*B. Yildiz*

### 22.12 Radiation Interactions, Control, and Measurement

Prereq: 8.02 or permission of instructor  
 G (Fall; second half of term)  
 2-0-4 units  
 Can be repeated for credit.

The interaction, attenuation, and biological effects of penetrating radiation, especially neutrons and photons. Physical processes of radiation scattering and absorption, and their cross-sections. Outline of health physics. Biological effects of radiation, and its quantification. Principles of radiation shielding, detection, dosimetry and radiation protection.

*A. Danagoulian*

### 22.13 Nuclear Energy Systems

Prereq: 2.005, 22.01, or permission of instructor  
 G (Spring; second half of term)  
 2-0-4 units  
 Can be repeated for credit.

Introduction to generation of energy from nuclear reactions. Characteristics of nuclear energy. Fission cross-sections, criticality, and reaction control. Basic considerations of fission reactor engineering, thermal hydraulics, and safety. Nuclear fuel and waste characteristics. Fusion reactions and the character and conditions of energy generation. Plasma physics and approaches to achieving terrestrial thermonuclear fusion energy.

*M. Bucci*

### 22.14 Materials in Nuclear Engineering

Prereq: Chemistry (GIR) or permission of instructor  
 G (Spring; first half of term)  
 2-0-4 units  
 Can be repeated for credit.

Introduces the fundamental phenomena of materials science with special attention to radiation and harsh environments. Materials lattices and defects and the consequent understanding of strength of materials, fatigue, cracking, and corrosion. Coulomb collisions of charged particles; their effects on structured materials; damage and defect production, knock-ons, transmutation, cascades and swelling. Materials in fission and fusion applications: cladding, waste, plasma-facing components, blankets.

*J. Li*

**22.15 Essential Numerical Methods**

Prereq: 12.010 or permission of instructor

G (Fall; first half of term)

2-0-4 units

Can be repeated for credit.

Introduces computational methods for solving physical problems in nuclear applications. Ordinary and partial differential equations for particle orbit, and fluid, field, and particle conservation problems; their representation and solution by finite difference numerical approximations. Iterative matrix inversion methods. Stability, convergence, accuracy and statistics. Particle representations of Boltzmann's equation and methods of solution such as Monte-Carlo and particle-in-cell techniques.

*N. Louriéro***22.16 Nuclear Technology and Society**

Prereq: 22.01 or permission of instructor

G (Spring)

2-0-4 units

Can be repeated for credit.

Introduces the societal context and challenges for nuclear technology. Major themes include economics and valuation of nuclear power, interactions with government and regulatory frameworks; safety, quantification of radiation hazards, and public attitudes to risk. Covers policies and methods for limiting nuclear-weapons proliferation, including nuclear detection, materials security and fuel-cycle policy.

*R. S. Kemp****Nuclear Reactor Physics*****22.211 Nuclear Reactor Physics I**

Prereq: 22.05

G (Spring)

3-0-9 units

Provides an overview of reactor physics methods for core design and analysis. Topics include nuclear data, neutron slowing down, homogeneous and heterogeneous resonance absorption, calculation of neutron spectra, determination of group constants, nodal diffusion methods, Monte Carlo simulations of reactor core reload design methods.

*B. Forget***22.212 Nuclear Reactor Analysis II**

Prereq: 22.211

G (Fall)

3-2-7 units

Addresses advanced topics in nuclear reactor physics with an additional focus towards computational methods and algorithms for neutron transport. Covers current methods employed in lattice physics calculations, such as resonance models, critical spectrum adjustments, advanced homogenization techniques, fine mesh transport theory models, and depletion solvers. Also presents deterministic transport approximation techniques, such as the method of characteristics, discrete ordinates methods, and response matrix methods.

*K. Smith***22.213 Nuclear Reactor Physics III**

Prereq: 22.211

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Spring)

3-0-9 units

Covers numerous high-level topics in nuclear reactor analysis methods and builds on the student's background in reactor physics to develop a deep understanding of concepts needed for time-dependent nuclear reactor core physics, including coupled non-linear feedback effects. Introduces numerical algorithms needed to solve real-world time-dependent reactor physics problems in both diffusion and transport. Additional topics include iterative numerical solution methods (e.g., CG, GMRES, JFNK, MG), nonlinear accelerator methods, and numerous modern time-integration techniques.

*K. Smith***22.251 Systems Analysis of the Nuclear Fuel Cycle**

Subject meets with 22.051

Prereq: 22.05

Acad Year 2018-2019: G (Spring)

Acad Year 2019-2020: Not offered

3-2-7 units

Study of the relationship between the technical and policy elements of the nuclear fuel cycle. Topics include uranium supply, enrichment, fuel fabrication, in-core reactivity and fuel management of uranium and other fuel types, used fuel reprocessing and waste disposal. Principles of fuel cycle economics and the applied reactor physics of both contemporary and proposed thermal and fast reactors are presented. Nonproliferation aspects, disposal of excess weapons plutonium, and transmutation of long lived radioisotopes in spent fuel are examined. Several state-of-the-art computer programs relevant to reactor core physics and heat transfer are provided for student use in problem sets and term papers. Students taking graduate version complete additional assignments.

*C. Forsberg*

## ***Nuclear Reactor Engineering***

### **22.312 Engineering of Nuclear Reactors**

Prereq: (2.001 and 2.005) or permission of instructor

G (Fall)

3-0-9 units

Engineering principles of nuclear reactors, emphasizing power reactors. Power plant thermodynamics, reactor heat generation and removal (single-phase as well as two-phase coolant flow and heat transfer), and structural mechanics. Engineering considerations in reactor design.

*J. Buongiorno*

### **22.313]] Thermal Hydraulics in Power Technology**

Same subject as 2.59]]], 10.536]]]

Prereq: 2.006, 10.302, 22.312, or permission of instructor

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Fall)

3-2-7 units

Emphasis on thermo-fluid dynamic phenomena and analysis methods for conventional and nuclear power stations. Kinematics and dynamics of two-phase flows. Steam separation. Boiling, instabilities, and critical conditions. Single-channel transient analysis. Multiple channels connected at plena. Loop analysis including single and two-phase natural circulation. Subchannel analysis.

*E. Baglietto, M. Bucci*

### **22.315 Applied Computational Fluid Dynamics and Heat Transfer**

Prereq: Permission of instructor

G (Spring)

3-0-9 units

Focuses on the application of computational fluid dynamics to the analysis of power generation and propulsion systems, and on industrial and chemical processes in general. Discusses simulation methods for single and multiphase applications and their advantages and limitations in industrial situations. Students practice breaking down an industrial problem into its modeling challenges, designing and implementing a plan to optimize and validate the modeling approach, performing the analysis, and quantifying the uncertainty margin.

*E. Baglietto*

### **22.33 Nuclear Engineering Design**

Subject meets with 22.033

Prereq: 22.312

G (Fall)

3-0-15 units

Group design project involving integration of nuclear physics, particle transport, control, heat transfer, safety, instrumentation, materials, environmental impact, and economic optimization. Provides opportunity to synthesize knowledge acquired in nuclear and non-nuclear subjects and apply this knowledge to practical problems of current interest in nuclear applications design. Past projects have included using a fusion reactor for transmutation of nuclear waste, design and implementation of an experiment to predict and measure pebble flow in a pebble bed reactor, and development of a mission plan for a manned Mars mission including the conceptual design of a nuclear powered space propulsion system and power plant for the Mars surface. Students taking graduate version complete additional assignments.

*M. Short, A. White*

### **22.38 Probability and Its Applications To Reliability, Quality Control, and Risk Assessment**

Prereq: Permission of instructor

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Fall)

3-0-9 units

Interpretations of the concept of probability. Basic probability rules; random variables and distribution functions; functions of random variables. Applications to quality control and the reliability assessment of mechanical/electrical components, as well as simple structures and redundant systems. Elements of statistics. Bayesian methods in engineering. Methods for reliability and risk assessment of complex systems, (event-tree and fault-tree analysis, common-cause failures, human reliability models). Uncertainty propagation in complex systems (Monte Carlo methods, Latin hypercube sampling). Introduction to Markov models. Examples and applications from nuclear and other industries, waste repositories, and mechanical systems. Open to qualified undergraduates.

*Staff*



**22.39 Integration of Reactor Design, Operations, and Safety**

Subject meets with 22.039

Prereq: 22.211 and 22.312

G (Fall)

3-2-7 units

Integration of reactor physics and engineering sciences into nuclear power plant design focusing on designs that are projected to be used in the first half of this century. Topics include materials issues in plant design and operations, aspects of thermal design, fuel depletion and fission-product poisoning, and temperature effects on reactivity. Safety considerations in regulations and operations such as the evolution of the regulatory process, the concept of defense in depth, general design criteria, accident analysis, probabilistic risk assessment, and risk-informed regulations. Students taking graduate version complete additional assignments.

*E. Baglietto, K. Shirvan***22.40[J] Fundamentals of Advanced Energy Conversion**

Same subject as 2.62[J], 10.392[J]

Subject meets with 2.60[J], 10.390[J]

Prereq: 2.006, (2.051 and 2.06), or permission of instructor

G (Spring)

4-0-8 units

See description under subject 2.62[J].

*A. F. Ghoniem, W. Green****Radiation Interactions and Applications*****22.51 Quantum Theory of Radiation Interactions**

Subject meets with 22.022

Prereq: 22.11

G (Spring)

3-0-9 units

Introduces elements of applied quantum mechanics and statistical physics. Starting from the experimental foundation of quantum mechanics, develops the basic principles of interaction of electromagnetic radiation with matter. Introduces quantum theory of radiation, time-dependent perturbation theory, transition probabilities and cross sections. Applications are to controlling coherent and decoherent dynamics with examples from quantum information processing. Students taking graduate version complete additional assignments.

*P. Cappellaro***22.55[J] Radiation Biophysics**

Same subject as HST.560[J]

Subject meets with 22.055

Prereq: Permission of instructor

Acad Year 2018-2019: G (Spring)

Acad Year 2019-2020: Not offered

3-0-9 units

Provides a background in sources of radiation with an emphasis on terrestrial and space environments and on industrial production. Discusses experimental approaches to evaluating biological effects resulting from irradiation regimes differing in radiation type, dose and dose-rate. Effects at the molecular, cellular, organism, and population level are examined. Literature is reviewed identifying gaps in our understanding of the health effects of radiation, and responses of regulatory bodies to these gaps is discussed. Students taking graduate version complete additional assignments.

*Staff***22.561[J] Magnetic Resonance Analytic, Biochemical, and Imaging Techniques**

Same subject as HST.584[J]

Prereq: Permission of instructor

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Spring)

3-0-12 units

See description under subject HST.584[J].

*L. Wald, K. Setsompop****Plasmas and Controlled Fusion*****22.611[J] Introduction to Plasma Physics I**

Same subject as 8.613[J]

Prereq: (6.013 or 8.07) and (18.04 or Coreq: 18.075)

G (Fall)

3-0-9 units

Introduces plasma phenomena relevant to energy generation by controlled thermonuclear fusion and to astrophysics. Elementary plasma concepts, plasma characterization. Motion of charged particles in magnetic fields. Coulomb collisions, relaxation times, transport processes. Two-fluid hydrodynamic and MHD descriptions. Plasma confinement by magnetic fields, simple equilibrium and stability analysis. Wave propagation in a magnetic field; application to RF plasma heating. Introduction to kinetic theory; Vlasov, Boltzmann and Fokker-Planck equations; relation of fluid and kinetic descriptions. Electron and ion acoustic plasma waves, Landau damping.

*I. Hutchinson*

**22.612[J] Introduction to Plasma Physics II**

Same subject as 8.614[J]  
 Prereq: 22.611[J]  
 Acad Year 2018-2019: Not offered  
 Acad Year 2019-2020: G (Spring)  
 3-0-9 units

See description under subject 8.614[J].  
*Staff*

**22.615 MHD Theory of Fusion Systems**

Prereq: 22.611[J]  
 Acad Year 2018-2019: G (Spring)  
 Acad Year 2019-2020: Not offered  
 3-0-9 units

Discussion of MHD equilibria in cylindrical, toroidal, and noncircular configurations. MHD stability theory including the Energy Principle, interchange instability, ballooning modes, second region of stability, and external kink modes. Description of current configurations of fusion interest.

*N. Louriéro*

**22.617 Plasma Turbulence and Transport**

Prereq: Permission of instructor  
 G (Spring)  
 Not offered regularly; consult department  
 3-0-9 units

Introduces plasma turbulence and turbulent transport, with a focus on fusion plasmas. Covers theory of mechanisms for turbulence in confined plasmas, fluid and kinetic equations, and linear and nonlinear gyrokinetic equations; transport due to stochastic magnetic fields, magnetohydrodynamic (MHD) turbulence, and drift wave turbulence; and suppression of turbulence, structure formation, intermittency, and stability thresholds. Emphasis on comparing experiment and theory. Discusses experimental techniques, simulations of plasma turbulence, and predictive turbulence-transport models.

*Staff*

**22.62 Fusion Energy**

Prereq: 22.611[J]  
 G (Spring)  
 3-0-9 units

Basic nuclear physics and plasma physics for controlled fusion. Fusion cross sections and consequent conditions required for ignition and energy production. Principles of magnetic and inertial confinement. Description of magnetic confinement devices: tokamaks, stellarators and RFPs, their design and operation. Elementary plasma stability considerations and the limits imposed. Plasma heating by neutral beams and RF. Outline design of the ITER "burning plasma" experiment and a magnetic confinement reactor.

*I. Hutchinson*

**22.63 Engineering Principles for Fusion Reactors**

Prereq: Permission of instructor  
 Acad Year 2018-2019: G (Fall)  
 Acad Year 2019-2020: Not offered  
 3-0-9 units

Fusion reactor design considerations: ignition devices, engineering test facilities, and safety/environmental concerns. Magnet principles: resistive and superconducting magnets; cryogenic features. Blanket and first wall design: liquid and solid breeders, heat removal, and structural considerations. Heating devices: radio frequency and neutral beam.

*D. Whyte, Z. Hartwig*

**22.67[J] Principles of Plasma Diagnostics**

Same subject as 8.670[J]  
 Prereq: 22.611[J]  
 Acad Year 2018-2019: Not offered  
 Acad Year 2019-2020: G (Fall)  
 3-0-9 units

Introduction to the physical processes used to measure the properties of plasmas, especially fusion plasmas. Measurements of magnetic and electric fields, particle flux, refractive index, emission and scattering of electromagnetic waves and heavy particles; their use to deduce plasma parameters such as particle density, pressure, temperature, and velocity, and hence the plasma confinement properties. Discussion of practical examples and assessments of the accuracy and reliability of different techniques.

*A. White*

**Nuclear Materials****22.71[] Modern Physical Metallurgy**

Same subject as 3.40[]

Subject meets with 3.14

Prereq: 3.022 and 3.032

G (Fall)

3-0-9 units

See description under subject 3.40[].

*C. Tasan*

**22.72 Corrosion: The Environmental Degradation of Materials (New)**

Subject meets with 22.072

Prereq: None

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Spring)

3-0-9 units

See description under subject 22.072.

*M. Li*

**22.73[] Defects in Materials**

Same subject as 3.33[]

Prereq: 3.21 and 3.22

G (Fall)

3-0-9 units

See description under subject 3.33[].

*J. Li*

**22.74[] Radiation Damage and Effects in Nuclear Materials**

Same subject as 3.31[]

Subject meets with 22.074

Prereq: 3.21, 22.14, or permission of instructor

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Fall)

3-0-9 units

Studies the origins and effects of radiation damage in structural materials for nuclear applications. Radiation damage topics include formation of point defects, defect diffusion, defect reaction kinetics and accumulation, and differences in defect microstructures due to the type of radiation (ion, proton, neutron). Radiation effects topics include detrimental changes to mechanical properties, phase stability, corrosion properties, and differences in fission and fusion systems. Term project required. Students taking graduate version complete additional assignments.

*M. Short, B. Yildiz*

**22.75[] Properties of Solid Surfaces**

Same subject as 3.30[]

Prereq: 3.20, 3.21, or permission of instructor

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Spring)

3-0-9 units

Covers fundamental principles needed to understand and measure the microscopic properties of the surfaces of solids, with connections to structure, electronic, chemical, magnetic and mechanical properties. Reviews the theoretical aspects of surface behavior, including stability of surfaces, restructuring, and reconstruction. Examines the interaction of the surfaces with the environment, including absorption of atoms and molecules, chemical reactions and material growth, and interaction of surfaces with other point defects within the solids (space charges in semiconductors). Discusses principles of important tools for the characterization of surfaces, such as surface electron and x-ray diffraction, electron spectroscopies (Auger and x-ray photoelectron spectroscopy), scanning tunneling, and force microscopy.

*B. Yildiz*

**22.78 Principles of Nuclear Chemical Engineering and Waste Management**

Subject meets with 22.078

Prereq: Permission of instructor

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Spring)

3-0-9 units

Introduces scientific and engineering aspects of chemical engineering and waste management applied to reactors and the fuel cycle. Includes chemical behavior in reactors (normal and accident), spent nuclear fuel aging, separation processes in reprocessing (aqueous, pyro, and molten salt), and waste treatment processes. Addresses management of radioactive wastes, including waste forms, classification, fundamental principles, governing equations for radionuclide transport in the environment, performance assessment of geological waste disposal systems, and implications of advanced fuel cycles. Students taking graduate version complete additional assignments.

*C. Forsberg*

**Systems, Policy, and Economics**

**22.811[] Sustainable Energy**

Same subject as 1.818[], 2.65[], 10.391[], 11.371[]

Subject meets with 2.650[], 10.291[], 22.081[]

Prereq: Permission of instructor

G (Fall)

3-1-8 units

Assessment of current and potential future energy systems. Covers resources, extraction, conversion, and end-use technologies, with emphasis on meeting 21st-century regional and global energy needs in a sustainable manner. Examines various energy technologies in each fuel cycle stage for fossil (oil, gas, synthetic), nuclear (fission and fusion) and renewable (solar, biomass, wind, hydro, and geothermal) energy types, along with storage, transmission, and conservation issues. Emphasizes analysis of energy propositions within an engineering, economic and social context. Students taking graduate version complete additional assignments.

*M. W. Golay*

**22.813[] Energy Technology and Policy: From Principles to Practice**

Same subject as 5.00[], 6.929[], 10.579[]

Prereq: None

G (Spring)

Not offered regularly; consult department

3-0-6 units

See description under subject 5.00[]. Limited to 100.

*J. Deutch*

**22.814[] Nuclear Weapons and International Security**

Same subject as 17.474[]

Prereq: None

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (Fall)

4-0-8 units

Examines the historical, political, and technical contexts for nuclear policy making, including the development of nuclear weapons by states, the evolution of nuclear strategy, the role nuclear weapons play in international politics, the risks posed by nuclear arsenals, and the policies and strategies in place to mitigate those risks. Equal emphasis is given to political and technical considerations affecting national choices. Considers the issues surrounding new non-proliferation strategies, nuclear security, and next steps for arms control.

*R. S. Kemp, V. Narang*

**General**

**22.90 Nuclear Science and Engineering Laboratory**

Subject meets with 22.09

Prereq: Permission of instructor

G (Fall)

2-6-4 units

See description under subject 22.09.

*A. Danagoulian, G. Kohse*

**22.901 Independent Project in Nuclear Science and Engineering**

Prereq: Permission of instructor

G (Fall, Spring, Summer)

Units arranged

Can be repeated for credit.

For graduate students who wish to conduct a one-term project of theoretical or experimental nature in the field of nuclear engineering, in close cooperation with individual staff members. Topics and hours arranged to fit students' requirements. Projects require prior approval.

*J. Li*

**22.911 Seminar in Nuclear Science and Engineering**

Prereq: None

G (Fall, Spring)

2-0-1 units

Can be repeated for credit.

Restricted to graduate students engaged in doctoral thesis research.

*C. Forsberg, P. Cappellaro, M. Li, N. Gomes Loureiro*

**22.912 Seminar in Nuclear Science and Engineering**

Prereq: None

G (Spring)

Not offered regularly; consult department

2-0-1 units

Can be repeated for credit.

Restricted to graduate students engaged in doctoral thesis research.

*C. Forsberg, I. Hutchinson, P. Cappellaro*

**22.921 Nuclear Power Plant Dynamics and Control**

Prereq: None

Acad Year 2018-2019: Not offered

Acad Year 2019-2020: G (IAP)

1-0-2 units

Introduction to reactor dynamics, including subcritical multiplication, critical operation in absence of thermal feedback effects and effects of xenon, fuel and moderator temperature, etc. Derivation of point kinetics and dynamic period equations. Techniques for reactor control including signal validation, supervisory algorithms, model-based trajectory tracking, and rule-based control. Overview of light-water reactor start-up. Lectures and demonstrations with use of the MIT Research Reactor. Open to undergraduates with permission of instructor.

*J. A. Bernard***22.93 Teaching Experience in Nuclear Science & Engineering**

Prereq: Permission of department

G (Fall, Spring, Summer)

Units arranged

For qualified graduate students interested in teaching as a career. Classroom, laboratory, or tutorial teaching under the supervision of a faculty member. Students selected by interview. Credits for this subject may not be used toward master's or engineer's degrees. Enrollment limited by availability of suitable teaching assignments.

*D. Whyte***22.94 Research in Nuclear Science and Engineering**

Prereq: Permission of research supervisor

G (Fall, Spring, Summer)

Units arranged [P/D/F]

Can be repeated for credit.

For research assistants in Nuclear Science and Engineering who have not completed the NSE doctoral qualifying exam. Hours arranged with and approved by the research supervisor. Units may not be used towards advanced degree requirements.

*J. Li***22.95 Internship in Nuclear Science and Engineering**

Prereq: None

G (IAP, Summer)

Units arranged [P/D/F]

Can be repeated for credit.

For Nuclear Science and Engineering students participating in research or curriculum-related off-campus experiences. Before enrolling, students must have an offer from a company or organization. Upon completion, the student must submit a final report or presentation to the approved MIT supervisor, usually the student's thesis supervisor or a member of the thesis committee. Subject to departmental approval. Consult the NSE Academic Office for details on procedures and restrictions. Limited to students participating in internships consistent with NSE policies relating to research-related employment.

*Consult J. Li***22.S902-22.S905 Special Subject in Nuclear Science and Engineering**

Prereq: Permission of instructor

G (Spring)

Not offered regularly; consult department

Units arranged

Can be repeated for credit.

Seminar or lecture on a topic in nuclear science and engineering that is not covered in the regular curriculum. 22.S905 is graded P/D/F.

*J. Li***22.THG Graduate Thesis**

Prereq: Permission of instructor

G (Fall, IAP, Spring, Summer)

Units arranged

Can be repeated for credit.

Program of research, leading to the writing of an SM, NE, PhD, or ScD thesis; to be arranged by the student and an appropriate MIT faculty member. Consult department graduate office.

*J. Li*