# NUCLEAR ENGINEERING

The Nuclear Engineering program is offered under the department of Nuclear Engineering and Radiation Science (NERS). The primary mission of the NE program is to provide an outstanding and comprehensive education to tomorrow's leaders in nuclear science and technology. Nuclear Engineering is a strong and growing engineering program administered by highly motivated and active nuclear engineering faculty.

The educational objectives for graduate degrees in Nuclear Engineering are:

1. Graduates will apply subject matter knowledge within their field of study.
2. Graduates will communicate effectively, both orally and in writing.
3. Graduates will engage in productive analysis and criticism of their own and others' research.
4. Graduates will demonstrate the ability to further develop as a professional in their field.

There are a number of research laboratories and facilities available for graduate students:

The Missouri S&T Reactor (MSTR) is located on the Missouri University of Science and Technology campus in Rolla, Missouri. MSTR provides facilities for experimental research, undergraduate training, and learning about reactor physics and other aspects of nuclear engineering. It is a 200 kW pool-type reactor, and is integral to the education of Nuclear Engineering students through hands-on laboratory activities. The reactor was initially licensed in 1961, and was converted from high-enriched uranium (HEU) to low-enriched uranium (LEU) in 1992. Recently MSTR has gone through a number of changes. A new active cooling system capable of removing up to 400 kW of heat was installed using funding from the Department of Energy in 2013. In 2014 new digital control room systems were installed, replacing the original systems from 1961 and allowing MSTR to serve as a testbed for a new digital reactor control technologies. A distance education system, also installed in 2014, allows our faculty and staff to provide online training through distance education for students around the world. Additional modifications are planned over the next several years, including the installation of new digital recording systems to replace paper records. Research facilities, experimental capabilities and services available at the reactor include:

- A neutron beam port for neutron radiography, tomography and ex-core neutron irradiations
- Thermal column for experiments involving thermal neutrons
- Pneumatic transfer tubes for in-core irradiation experiments and Neutron Activation Analysis (NAA)
- Isotope production elements and void tubes for in-core irradiations
- Internet accessible hot cell facility for high-activity sample irradiation and counting
- Subcritical assembly for teaching the fundamentals for reactor physics
- Gamma spectroscopy systems equipped with Sodium-Iodide (NaI) and High Purity Germanium (HPGe) detectors
- Liquid scintillation counter for alpha and beta spectroscopy
- State-of-the-art distance education system for broadcasting reactor labs to outside universities and organizations

Radiation imaging has been the most successful and useful method of early cancer detection as well as highly helpful nondestructive testing method for various industrial applications. In the Advanced Radiography and Tomograph Laboratory (ARTLAB), we are developing innovative radiation imaging systems for medical and industrial purposes. We develop and utilize a wide range of new tools, from x-ray sources for radiation imaging to sophisticated algorithms for image processing and computed tomography (CT) reconstruction. One such example is the ongoing project of developing a stationary CT, a new type of x-ray tubes for fast imaging is under development. Also, we develop machine learning algorithms for radiation image analysis and automatic radiosotope detection for homeland security and defense applications. The lab is equipped with a homemade benchtop 3D CT, a clean room for x-ray tube experiments and a high-performance computer server with COMSOL software for simulation studies.

The D-D generator laboratory uses Deuterium gas and a microwave to generate plasma as an ion source to induce nuclear fusion. This results in a relatively high-flux source of fast and epithermal neutrons useful for prompt gamma neutron activation analysis, neutron activation analysis, and radiography. Using Deuterium rather than radioactive Tritium, as well as an "open-vacuum" construction, allows the system to be easily reconfigured for experiments.

The Thermal Hydraulic Experiment, Modeling, and Engineering Simulation (THEMES) Laboratory is designed as a modular, multipurpose facility capable of supporting a wide variety of multiphase flow experiments, simulations, and modeling efforts. The central feature of the THEMES Laboratory is a modular test facility designed to support up to six concurrent experiments by effectively utilizing existing infrastructure. This allows for rapid deployment of experiments, lets projects to progress rapidly to the construction and testing phases, and reduces the cost to the sponsor. A 30 hp pump provides up to 1000 gpm of water flow at 90 ft of head, while a 50 hp compressor provides up to 270 acfm of compressed air at a pressure of 200 psi. Flow is measured using pressure transducers, rotameters, a laminar flow element, a vortex flow meter, a magnetic flow meter, and other state-of-the-art instruments. Robust four-sensor electrical conductivity probes for multiphase flow measurements are constructed and characterized in-house, with unique software for enhancing data processing performance.

The Vacuum Technology and X-Ray Generation Laboratory is located in Fulton 213 and has facilities to produce and work with vacuum technology up to $10^{-9}$ Torr. The equipment includes roughing mechanical pumps, ion pumps, turbo pumps, glass vacuum chambers, steel vacuum chambers with programmable ramp-heating capabilities, Residual Gas Analyzer-RGA200, and a variety of pressure gauges, ion guns, and radiation detectors and other measurement equipment. Total area is 561 sq ft.

The Radiochemistry and Nanotechnology Laboratory is located in Fulton 218 and houses a fume hood with wet chemistry capabilities, a two seat glove box, chemical waste disposal, safes for radioactive materials, UV-Vis Spectrophotometer, analytical balance, centrifuges, vacuum filtration and drying system, furnace, stereo microscope, ultrasonicators, with a total area of 466 sq. ft.

The Nuclear Materials Laboratory is home to two lab facilities with specialized equipment for characterizing the effects of radiation on solids at the atomic and microscopic scales. Equipment available includes a Confocal Raman Microscope, a Positron Annihilation Lifetime Spectrometer, a Modulated Photothermal Radiometer, a Three-Omega system configured for thermal diffusivity measurements and a Four-Terminal Resistivity Station. The facilities of the campus Materials Research Center are also available for nuclear materials related research. These facilities include state-of-the-art Scanning and Transmission Electron Microscopes, X-ray Diffractometers, a Nanoindenter, Atomic Force Microscope and X-Ray Photoelectron Spectrometer among other tools. Ample opportunities exist for Nuclear Engineering students to collaborate with students and researchers in the campus Materials Science and Engineering Department.

The Radiation Measurements and Spectroscopy Laboratory is a teaching lab mainly for education and training of undergraduate nuclear engineering students. Three identical workstations for alpha particle, beta particle, and gamma-ray spectroscopy can provide “hands-on” training in radiation detection and measurement for 18 students at a time. The five internet-accessible digital signal analyzers allow 50 remote users to participate in nuclear spectroscopy and measurement and collection of spectra data via an internet connection at any given time. When the RMSL is not in use for education or training, it is open for faculty and graduate students to conduct research. The lab was significantly renovated with support from DOE and is equipped with state-of-the-art radiation detectors and signal processing systems.

The Nuclear Engineering Program offers both a thesis-based and non-thesis MS degree program.  A B.S. in a related field of engineering or suitable physical science is a prerequisite for admission in to the Nuclear Engineering graduate program.  The M.S. degree program is designed to provide training and expertise in the design of nuclear energy systems, as well as the use of nuclear technology in medical and industrial applications.

Some exposure to research is considered an essential component of the MS program, so the non-thesis option is intended for students with significant industrial experience (more than 3 years) and is not encouraged for other students.  Students should plan to complete their MS program in two to four semesters. A MS program requires a minimum of 30 credit-hours of research and coursework.  A minimum of six credits of 6000-level courses must be included (nine credits for a non-thesis option), and at most three credits of 3000-level courses.  Students are encouraged to take at least six credits of courses outside of their program. For a thesis option, at least 6 credits of graduate research and at least 18 credits of lecture courses are required as part of the 30 credit-hours.

The ‘core’ Nuclear Engineering courses are NUC ENG 5203 (Reactor Physics I), 5241 (Nuclear Materials I), 5257 (Introduction to Nuclear Thermal Hydraulics), and 5312 (Nuclear Radiation Measurements and Spectroscopy).  These courses address key competencies that all Nuclear Engineers should possess.  Students who completed these courses or their equivalent during an undergraduate Nuclear Engineering degree need not take the courses again, however students with undergraduate degrees from other disciplines should take NUC ENG 3205 (Fundamentals of Nuclear Engineering) in addition to these core courses.  Students are also encouraged to take at least 3 credits of graduate level mathematics or computer science. A maximum of nine credit-hours of graduate level courses taken elsewhere as a graduate student can be transferred to the MS plan of study, provided that the courses correspond to at least a 5000-level course at Missouri S&T.

The Doctor of Philosophy (PhD) program is open to students who have successfully completed their MS program or have enrolled in a direct PhD program.  It is designed to provide additional training and expertise in the design of nuclear energy systems and the use of nuclear technology in medical and industrial applications, with a strong focus on engineering research.

Typically a minimum of 5 semesters (not including summer sessions) is required to complete the program for students arriving with a MS degree, and a minimum of 7 semesters for students starting a direct PhD program.  The doctoral program will include at least 72 credit hours of total coursework.  Students who already hold a Master’s degree will receive a block of 30 credit hours that will apply toward that requirement.  They must complete an additional 42 hours of graduate credit.  A minimum of 12 credit hours must be lecture courses, and a minimum of 24 credit hours must be graduate research.  It is recommended that nine of the 12 credit hours of lecture courses come from 6000-level lecture courses.  A student who does not hold a Master’s degree must complete a minimum of 30 credit hours of lecture courses and at least 24 credit hours of graduate research.  At least 15 credit hours should be in 6000-level lecture courses.  Students are also encouraged to enroll in at least six credits of advanced mathematics or computer science courses.

PhD candidates must also complete a qualifying examination within their first four semesters of study, comprehensive examination when at least 50% of their coursework is completed, and final examination where they will present and defend the research included in their dissertation.

There is a residency requirement for the PhD in Nuclear Engineering.  Residency at Missouri S&T is defined as sustained intellectual interactions among the student and the academic community.  The candidate for a Ph.D. degree will normally complete three years of residency, which is the equivalent of completing six academic semesters while enrolled as an on-campus student at Missouri S&T.  Students holding a master’s degree are automatically credited with two semesters of residency. Students unable to meet the residency requirement given above, such as distance students, can meet this requirement through an alternative route in consultation with their advisor.

# Nuclear Nonproliferation

The nuclear engineering program offers a graduate certificate program to professionals and students who desire to undergo formal instruction in nuclear nonproliferation.  The topics in comprising the certificate program are selected from courses available to graduate students in the nuclear engineering program at Missouri University of Science and Technology.  All courses are available both in traditional on-campus delivery and online format.  The certificate program deployment strategy allows all enrollees to pace their study in manner consistent with the individual’s plans.

The Graduate Certificate in Nuclear Nonproliferation is open to all persons holding a B.S., M.S., or Ph.D. degree in Engineering, Science, and/or Mathematics as well as related B.A. or M.A. degrees, or are currently accepted into a graduate degree program at Missouri S&T.

### Curriculum

The certificate program requires 4 courses equivalent to 12 credit hours.  There are 8 course available to the certificate program, 1 of which is required for the completion of the graduate certificate in nuclear nonproliferation.  Program enrollees may select any 3 of the remaining 7 courses towards the completion of the graduate certificate.  Enrollees may take 1 or 2 classes each semester so that the certificate program may be completed within 1 to 2 years.

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| **Required Course:** | | |
| NUC ENG 5509 | Nuclear Nonproliferation | 3 |
| **Elective Courses:** | | |
| NUC ENG 5207 | Nuclear Fuel Cycle | 3 |
| NUC ENG 5281 | Introduction to Probabilistic Risk Assessment | 3 |
| NUC ENG 5312 | Nuclear Radiation Measurements and Spectroscopy | 3 |
| NUC ENG 5347 | Radiological Engineering | 3 |
| NUC ENG 5577 | Advanced Nuclear Forensics and Radiochemistry | 3 |
| NUC ENG 5507 | Nuclear Policy | 3 |
| NUC ENG 6331 | Radiation Shielding | 3 |

**Muthanna Hikmat Al Dahhan**, Curators' Distinguished Professor
DSc Washington University
Multiphase reaction and reactor engineering flow systems; transport-kinetic integration; advanced measurement and computational techniques; application to green technology and sustainable development in energy, products, and environment.

**Ayodeji Babatunde Alajo**, Associtate Professor
PHD Texas A&M University
High fidelity nuclear systems design and modeling, criticality safety advanced fuel cycles, radioactive waste management, and nuclear systems safety.

**Syed Bahauddin Alam**, Assistant Professor
PHD University of Cambridge
Multiscale and Multiple modeling, digital twin, explainable and trustworthy AI, uncertainty quantification, robust optimization.

**Carlos Henry Castano Giraldo**, Associate Professor
PHD University of Illinois Urbana-Champaign
Energy, nuclear materials, plasma material interactions, hydrogen in materials, radio electromechanical effects and nanotechnology.

**Joseph Graham**, Associate Professor
PHD University of Texas at Austin
Radiation effects in ceramics, radiation solid interactions, nuclear fuel properties and nuclear waste forms.

**Joseph W Newkirk**, Professor and Department Chair of Nuclear Engineering and Radiation Science
PHD University of Virginia
Additive manufacturing, powder metallurgy, wear and corrosion resistant alloys, high temperature materials, aerospace materials, nuclear materials, and heat treating.

**Joshua P Schlegel**, Associate Professor
PHD Purdue University
Two-phase flow experiments and modeling, nuclear reactor thermal hydraulics, heat transfer and fluid mechanics.

**Joseph D Smith**, Professor and Laufer Endowed Chair in Energy
PHD Brigham Young University
Hybrid energy systems, fuels combustion and gasification, industrial gas flare design, operation and regulation, process modeling, monitoring control and operation.

**Shoaib Usman**, Associate Professor
PHD University of Cincinnati
Radiation transport, radiation protection, radioactive waste management.

**Haiming Wen**, Assistant Professor
PHD University of California-Davis

***NUC ENG 5000 Special Problems*** (IND 0.0-6.0)
Problems or readings on specific subjects or projects in he department. Consent of instructor required.

***NUC ENG 5001 Special Topics*** (IND 0.0-6.0)
This course is designed to give the department an opportunity to test a new course. Variable title.

***NUC ENG 5010 Seminar*** (RSD 0.0-6.0)
Discussion of current topics.

***NUC ENG 5203 Reactor Physics I*** (LEC 3.0)
Study of neutron interactions, fission, chain reactions, neutron diffusion and neutron slowing down; criticality of a bare thermal homogeneous reactor. Prerequisite: Nuc Eng 3205.

***NUC ENG 5207 Nuclear Fuel Cycle*** (LEC 3.0)
Nuclear fuel reserves and resources; milling, conversion, and enrichment; fuel fabrication; in-and-out-of core fuel management; transportation, storage, and disposal of nuclear fuel; low level and high level waste management; economics of the nuclear fuel cycle. Prerequisite: Nuc Eng 3205.

***NUC ENG 5241 Nuclear Materials I*** (LEC 3.0)
Fundamentals of materials selection for components in nuclear applications; design and fabrication of UO2 fuel; reactor fuel element performance; mechanical properties of UO2; radiation damage and effects, including computer modeling; corrosion of materials in nuclear reactor systems. Prerequisites: Civ Eng 2210; Nuc Eng 3205: Nuc Eng 3223; Met Eng 2110. (Co-listed with Met Eng 5170).

***NUC ENG 5251 Reactor Kinetics*** (LEC 3.0)
Derivation and solutions to elementary kinetics models. Application of the point kinetics model in fast and thermal reactor dynamics, internal and external feedback mechanisms, rigorous derivation and solutions of the space dependent kinetics model fission product and fuel isotope changes during reactor operation. Prerequisite: Nuc Eng 3205.

***NUC ENG 5257 Introduction to Nuclear Thermal Hydraulics*** (LEC 3.0)
An introductory course in the application of thermal-hydraulic principles to energy systems, with emphasis on nuclear energy issues. Will include the development of constitutive models and applications to power systems, fluid mechanics, and heat transfer problems (including multiphase flows). Prerequisite: Graduate standing.

***NUC ENG 5281 Introduction to Probabilistic Risk Assessment*** (LEC 3.0)
An introduction to advanced techniques for assessing reliability, safety and risk in complex systems. Classification of initiating events, fault tree analysis, consequences, figures of merit, and use of probabilistic risk analysis in regulation are discussed using examples and applied through a simple case study. (Co-listed with Sys Eng 5281).

***NUC ENG 5312 Nuclear Radiation Measurements and Spectroscopy*** (LAB 1.0 and LEC 2.0)
Contemporary radiation detection theory and experiments with high resolution gamma-ray spectroscopy, solid state detectors, neutron detection and conventional gas filled detectors. Neutron activation analysis of unknown material, statistical aspects of nuclear measurements. Prerequisite: Nuc Eng 3205.

***NUC ENG 5347 Radiological Engineering*** (LEC 3.0)
Radiation exposure pathways analysis. Modeling of radionuclides transport through atmosphere, surface and ground water. Human health impact. Transportation of nuclear waste. Nuclear Waste characterization. Regulatory structure and requirements. Scenario case studies and computer simulation of transport. Prerequisite: Nuc Eng 3205.

***NUC ENG 5350 Advanced Nuclear Medical Science*** (LEC 3.0)
Advanced level of technologies involved in medical modalities, such as digital radiography, digital mammography, modern computed tomography, gamma camera, SPECT and PET will be covered. Prerequisites: Nuc Eng 4312 or equivalent.

***NUC ENG 5363 Applied Health Physics*** (LEC 3.0)
Radiation sources; external and internal dosimetry; biological effects of radiation; radiation protection principles; regulatory guides; radioactive and nuclear materials management. Prerequisite: Nuc Eng 3103 or Physics 2305.

***NUC ENG 5365 Radiation Protection Engineering*** (LEC 3.0)
Radiation fields and sources including nuclear reactors, radioactive wastes, x-ray machines, and accelerators. Stopping of radiation (Charges particles, photons, and neutrons) by matter. Radiation transport methods. Radiation shielding design. Dose rate calculations. Biological effects of radiation. Regulatory guides (10CFR20). Prerequisite: Nuc Eng 3205.

***NUC ENG 5367 Radioactive Waste Management And Remediation*** (LEC 3.0)
Sources and classes of radioactive waste, long-term decay, spent fuel storage, transport, disposal options, regulatory control, materials issues, site selection and geologic characterization, containment, design and monitoring requirements, domestic and foreign waste disposal programs, economic and environmental issues, history of disposal actions, and conduct of remedial actions and clean up. Prerequisite: Math 3304. (Co-listed with Geology 4421).

***NUC ENG 5370 Plasma Physics I*** (LEC 3.0)
Single particle orbits in electric and magnetic fields, moments of Boltzmann equation and introduction to fluid theory. Diffusion of plasma in electric and magnetic fields. Analysis of laboratory plasmas and magnetic confinement devices. Introduction to plasma kinetic theory. Prerequisite: Aero Eng 3131 or Mech Eng 3131 or Physics 3211 or Nuc Eng 3221 or Elec Eng 3600. (Co-listed with Aero Eng 5570, Mech Eng 5570, Physics 4543).

***NUC ENG 5428 Advanced Reactor Laboratory I*** (LAB 1.0 and LEC 2.0)
Acquaints the student with neutron flux measurement, reactor operation, control rod calibration, reactor power measurement and neutron activation experiments. Experiments with the thermal column and neutron beam port are also demonstrated. Prerequisites: Nuc Eng 4312, Nuc Eng 3205.

***NUC ENG 5438 Advanced Reactor Laboratory II*** (LAB 1.0 and LEC 1.0)
A continuation of Nuclear Engineering 4428 with experiments of a more advanced nature. Prerequisite: Nuc Eng 4428 or Nuc Eng 5428.

***NUC ENG 5456 Reactor Operation II*** (LAB 1.0)
The operation of the training reactor. The program is similar to that required for the NRC Reactor Operator's license. Students from other disciplines will also benefit from the course. Prerequisite: Nuc Eng 2105, 2406.

***NUC ENG 5507 Nuclear Policy*** (LEC 3.0)
This course introduces nuclear security and safeguards policy. It explores the following topics: history of domestic and international nuclear policy, evolution of U.S. nuclear weapons policy, factors influencing policy, the IAEA, nuclear deterrence policy, nuclear safeguards policy, policy in non-proliferation issues, and various international agreements. Prerequisites: Graduate Standing or enrolled in the Nuclear Nonproliferation certificate program.

***NUC ENG 5509 Nuclear Nonproliferation*** (LEC 3.0)
This course will introduce IAEA mission specific to nonproliferation. The class will provide discussion of essential elements of a nuclear weapon, followed by a brief historical over of nonproliferation treaties in place to deter proliferation. Methods of fissile material production will be discussed followed by a survey of tool and techniques available an Prerequisites: Graduate Standing or enrolled in the Nuclear Nonproliferation certificate program.

***NUC ENG 5577 Advanced Nuclear Forensics and Radiochemistry*** (LEC 3.0)
Fundamentals of radiochemistry, including nuclear science, cosmochemistry, spent fuel reprocessing, with details on solvent extraction. We will review case studies in Nuclear Forensics. This advanced section also includes experiments on radiochemistry and demonstrate experimental nuclear forensics techniques. Dual listed with Nuc Eng 4577.

***NUC ENG 6000 Special Problems*** (IND 0.0-6.0)
Problems or readings on specific subjects or projects in the department. Consent of instructor required.

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***NUC ENG 6001 Special Topics*** (LEC 0.0-6.0)
This course is designed to give the department an opportunity to test a new course. Variable title.

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***NUC ENG 6010 Seminar*** (RSD 0.0-6.0)
Discussion of current topics.

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***NUC ENG 6040 Oral Examination*** (IND 0.0)
After completion of all other program requirements, oral examinations for on-campus M.S./Ph.D. students may be processed during intersession. Off-campus M.S. students must be enrolled in oral examination and must have paid an oral examination fee at the time of the defense/ comprehensive examination (oral/ written). All other students must enroll for credit commensurate with uses made of facilities and/or faculties. In no case shall this be for less than three (3) semester hours for resident students.

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***NUC ENG 6050 Continuous Registration*** (IND 1.0)
Doctoral candidates who have completed all requirements for the degree except the dissertation, and are away from the campus must continue to enroll for at least one hour of credit each registration period until the degree is completed. Failure to do so may invalidate the candidacy. Billing will be automatic as will registration upon payment.

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***NUC ENG 6085 Internship*** (IND 0.0-15)
Students working toward a doctor of engineering degree will select with the advice of their committees, appropriate problems for preparation of a dissertation. The problem selected and internship plan must conform to the purpose of providing a high level engineering experience consistent with the intent of the doctor of engineering degree.

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***NUC ENG 6099 Research*** (IND 0.0-15)
Investigations of an advanced nature leading to the preparation of a thesis or dissertation. Consent of instructor required.

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***NUC ENG 6203 Advanced Reactor Physics*** (LEC 3.0)
Transport and diffusion theory; multigroup approximation; criticality calculations; cross-section processing; buildup and depletion calculations; delayed neutrons and reactor kinetics; lattice physics calculations; full core calculations; analysis and measurement of reactivity coefficients. Prerequisite: Math 5325.

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***NUC ENG 6205 Linear Transport Theory*** (LEC 3.0)
Monoenergetic Boltzmann equation for neutral particles by the method of singular eigen-functions and polynomial expansions. Prerequisites: Nuc Eng 4203, Math 5358.

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***NUC ENG 6223 Nuclear Reactor Safety*** (LEC 3.0)
Study of safety criteria; reactor characteristics pertinent to safety; reactor transient behavior; loss of coolant accident analysis; emergency core cooling; fuel behavior during accident conditions; reactor risk analysis; current reactor safety issues. Prerequisites: Nuc Eng 4203 and 3229.

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***NUC ENG 6241 Effects Of Radiation On Solids*** (LEC 3.0)
The theories of the interaction of nuclear radiation with matter. Experimental approaches to radiation studies, including the sources and dosimetry. Nature and properties of crystal imperfections. The influence of radiation on physical, mechanical and surface properties of metals and alloys. Radiation effects on materials other than those incorporated in nuclear reactors. The annealing of defects. Prerequisite: Met Eng 5170.

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***NUC ENG 6257 Advanced Nuclear Thermal Hydraulics*** (LEC 3.0)
Treatment of advanced topics in nuclear reactor thermal-hydraulics including analysis of fuel elements and fuel melting, multiphase flow dynamics and two-fluid models, interfacial transfer of mass, momentum, and energy, multiphase flow scaling, and numerical applications. Prerequisite: Math 5325.

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***NUC ENG 6331 Radiation Shielding*** (LEC 3.0)
Radiation sources; interactions of radiation with matter; dosimetry and radiation protection guidelines. The particle transport equation and methods of solving it; the Monte Carlo Method; special computational methods for neutron and gamma attentuation. Computer codes used in shielding. Shielding materials, shield design. Prerequisite: Nuc Eng 4203.

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