DEPARTMENT OF NUCLEAR SCIENCE AND ENGINEERING

The Department of Nuclear Science and Engineering (NSE) provides undergraduate and graduate education for students interested in developing and understanding nuclear technologies for the benefit of society and the environment.

This is an exciting time to study nuclear science and engineering. There is an upsurge of innovative activity in the field, including a drastic increase in nuclear start-up companies, as energy resource constraints, security concerns, and the risks of climate change are creating new demands for safe, secure, cost-competitive nuclear energy systems. At the same time, powerful new tools for exploring, measuring, modeling, and controlling complex nuclear and radiation processes are laying the foundations for major advances in the application of nuclear technologies in medicine and industry as well as in fundamental science.

In response to these developments, the department has created programs of study that prepare students for scientific and engineering leadership roles in energy and non-energy applications of nuclear science and technology. Applications include nuclear fission energy systems, fusion energy systems, quantum engineering, and systems for securing nuclear materials against the threats of nuclear proliferation and terrorism. Underlying these applications are core fields of education and research, including low-energy nuclear physics; plasma physics; thermal sciences; radiation sources, detection, and control; the study of materials in harsh chemo-mechanical, radiation, and thermal environments; and advanced computation and simulation.

Students in nuclear science and engineering study the scientific fundamentals of the field, engineering methods for integrating these fundamentals into practical systems, and the interactions of nuclear systems with society and the environment. Undergraduate and graduate students take core subjects in the field and can then select from a wide variety of application areas through more specialized subjects.

Principle areas of research and education in the department are described below.

Nuclear Fission Energy. Nuclear reactors, utilizing the fission of heavy elements such as uranium, supply approximately 13% of the world's electricity, powering grids, ships and submarines. They produce radioisotopes for medical, biological, and industrial uses, and for long-lived on-board power sources for spacecraft. They can also provide energy for chemical and industrial processing and portable fuel production (e.g., synthetic fuels or hydrogen).

Electricity generation is the most familiar application. In some countries, the fraction of electricity obtained from nuclear power exceeds 50%. In the United States, 100 nuclear power plants supply almost 20% of the nation's electricity. Thirty countries generate nuclear power today, and more than 40 others have recently expressed an interest in developing new nuclear energy programs. Nuclear power is the only low-carbon energy source that is both inherently scalable and already generating a significant share of the world's electricity supplies. Fission technology is entering a new era in which upgraded existing plants, next-generation reactors, and new fuel cycle technologies and strategies will contribute to meeting the rapidly growing global demand for safe and cost-competitive low-carbon electricity supplies.

Fission energy research in the Nuclear Science and Engineering department is focused on developing advanced nuclear reactor designs for electricity, process heat, and fluid fuels production that include passive safety features; developing innovative proliferation-resistant fuel cycles; extending the life of nuclear fuels and structures; and reducing the capital and operating costs of nuclear energy systems. These research goals are pursued via targeted technology options, based on advanced modeling and simulation techniques and state-of-the-art experimental facilities. Progress toward these goals also entails advances in the thermal, materials, nuclear, and computational sciences. The overall objective is to advance the role of nuclear energy as an economical, safe, environmentally friendly, and flexible energy source, thereby contributing to energy security, economic growth, and a sustainable global climate.

Plasma Physics and Fusion Technology. A different source of nuclear energy results from the controlled fusion of light elements, notably hydrogen isotopes. Since the basic source of fuel for fusion can be easily and inexpensively extracted from the ocean or from very abundant lithium, the supply is virtually inexhaustible. Fusion reactions can only readily occur in a fully ionized plasma heated to ultra high temperatures (150 million K). Such hot plasmas cannot be contained by material walls and are usually confined instead by strong magnetic fields. An alternative approach entails inertial confinement, usually achieved with very high-power lasers. Recent progress within the international fusion community increases the likelihood that controlled fusion will become a practical source of energy within the next half-century. Attainment of a fusion power plant involves the solution of many intellectually challenging physics and engineering problems. Included among these challenges are a mastery of the sophisticated field of plasma physics; the discovery of improved magnetic geometries to enhance plasma confinement; the development of materials capable of withstanding high stresses and exposure to intense radiation; and the need for great engineering ingenuity in integrating fusion power components into a practical, safe, and economical system. The department has strong programs in plasma fundamentals, materials for intense radiation fields, and engineering of fusion systems.

Plasma processes are key to many naturally occurring phenomena, and to many practical applications. Solar physics, space weather, and dusty plasma physics, are basic plasma research areas of departmental expertise. Treatment of toxic gases, magnetohydrodynamic energy conversion, ion propulsion, radiation generation, materials processing, and various other industrial applications use the knowledge students gain in applied plasma physics. The Department of Nuclear Science and Engineering leads MIT's interdepartmental graduate instruction in plasma physics and many of its research applications.

Nuclear Security. The field of nuclear security concerns itself with the challenges and dangers of nuclear weapons and nuclear materials. Various areas of nuclear security include nuclear nonproliferation, arms control treaty verification, cargo security, as well as nuclear safeguards. In order for nuclear power to retain its societal relevance, it is important for the nuclear community to develop a culture of security just as it has developed a culture of safety. Thus, nuclear security in its broadest sense becomes of paramount importance to the nuclear engineering community. MIT in particular is perfectly positioned to perform long-term research in the field of nuclear security, to make the use of nuclear energy less risky for global security. Part of this effort of necessity contains a component of policy, as well as a component of technological research necessary to stop proliferation, improve nuclear safeguards, and intercept any attempts at nuclear terrorism: a successful program cannot be either purely technology driven or purely policy driven but rather a careful integration of these two areas. MIT is actively pursuing an integration of both technology and policy development.

Quantum Engineering. An exciting new frontier in nuclear science and engineering is to precisely control the quantum mechanical wave function of atomic and subatomic systems. Thus far, this has been achieved only in low-energy processes, particularly nuclear magnetic resonance, a form of nuclear spectroscopy which has allowed the basic techniques needed for quantum control to be explored in unprecedented detail. The department has initiated an ambitious program in this area, which promises to be widely applicable in nanotechnology. The ultimate achievement would be the construction of a "quantum computer," which would be capable of solving problems that are far beyond the capacities of classical computers. Other significant applications are quantum-enabled sensors and actuators, secure communication, and the direct simulation of quantum physics.

Materials for Extreme Environments. An important area of research in the department which unites many of the primary applications of nuclear science and technology involves the study of materials in extreme environments. To achieve the full potential of nuclear energy from both fission and fusion reactors, it is necessary to develop special materials capable of withstanding intense radiation for long periods of time as well as high temperatures and mechanical stresses. It is also crucial to understand the phenomenon of corrosion in radiation environments. To develop a fundamental understanding of these phenomena, chemical and physical processes must be followed at multiple scales, from the atomic to the macroscopic, over timescales from less than a nanosecond to many decades, and even, in the case of nuclear waste, thousands of years. Materials research in the department draws on a wide array of new scientific tools, including advanced compact radiation sources, material probes and characterization at the nanoscale, and advanced computational simulations.

Interdisciplinary Research. Students and faculty in the department work closely with colleagues in several other departments, including Physics, Materials Science and Engineering, Mechanical Engineering, Electrical Engineering and Computer Science, and Political Science, and with the Sloan School of Management. The department is an active participant in the MIT Energy Initiative and in MIT's interdisciplinary programs of instruction and research in the management of complex technological systems and technology and public policy.