# Department of Nuclear Science and Engineering

The faculty and students of the Department of Nuclear Science and Engineering (NSE) study nuclear reactions and radiation, their applications, and their consequences. We generate, control, and apply nuclear reactions and radiation for the benefit of society and the environment. The department is committed to the development of the next generation of leaders of the global nuclear energy enterprise and is a leading contributor to the innovations needed to enable an expansion in the worldwide role of nuclear energy. We are also laying the foundations for new applications of nuclear and radiation science and technology. As a leading academic department in the field, we have a responsibility to inform public debates on the wise and humane uses of nuclear science and technology.

Increasing global energy needs and rising concerns over climate change have brought new attention to the role of nuclear energy around the world, even as the safety of nuclear fission power plants is receiving renewed public scrutiny in the aftermath of the Fukushima nuclear accident in Japan. There are also many nonenergy applications of nuclear science and technology. The Department of Nuclear Science and Engineering at MIT offers what is probably the widest spectrum of research activities of any nuclear department in the country. Our faculty and students develop nuclear reactors for diverse uses, including waste management, production of fluid fuels, and space propulsion as well as electricity generation. They contribute to security by exploring ways to monitor nuclear materials and detect nuclear threats. They apply nuclear technologies to the physical and life sciences in areas ranging from neutron interferometry to radiation modeling and magnetic resonance imaging, and they work in direct support of the International Thermonuclear Experimental Reactor (ITER), a project aimed at demonstrating the scientific and technical feasibility of fusion power.

## Faculty and Administration

Professor Ronald Parker retired on September 1, 2010, and professor Jeffrey Freidberg retired on June 30, 2011.

Professor Mujid Kazimi continues as director of the Center for Advanced Nuclear Energy Systems. The center marked the 10th anniversary of its founding with a symposium on Nuclear Energy in 2050.

Professor George Apostolakis continues as a member of the US Nuclear Regulatory Commission.

Professor Richard Lester serves as faculty cochair of the MIT Industrial Performance Center.

Professor Kazimi continues his service as chair of the NSE graduate committee, and professor Dennis Whyte continues as chair of the NSE undergraduate program. Peter Brenton serves as our administrative officer, and Clare Egan is our academic administrator.

## Research Highlights

Fission energy research is mainly conducted through the department's Center for Advanced Nuclear Energy Systems. Research on advanced reactor designs, new fuel-cycle technologies, and advanced reactor technologies is carried out by professors Mujid Kazimi, Jacopo Buongiorno, Michael Driscoll, Benoit Forget, Michael Golay, and Neil Todreas and by Dr. Charles Forsberg.

NSE continues to play a leading role in the Consortium for Advanced Simulation of Light Water Reactors (CASL), the Department of Energy (DOE) Nuclear Energy Innovation Hub based at the Oak Ridge National Laboratory. Professors Ron Ballinger, Bilge Yildiz, and Sidney Yip and research scientist Aydin Karahan are developing simulation capabilities for a broad range of phenomena related to fuel behavior. Professor Buongiorno leads a program to develop and validate advanced simulation methods and diagnostics for multiphase flow and heat transfer. Professor Forget is engaged in development of advanced methods for reactor physics calculations that promise to enable much faster simulation of core behavior. Professor Kazimi and Drs. Tom McKrell, Gordon Kohse, and Edward Pilat continue their studies of ceramic materials as replacements for zirconium-based light water fuel cladding, with benefits for reactor safety. Professor Driscoll led the development of a cost-competitive uranium-fueled fast reactor core design that does not require fuel reprocessing.

A major report on the future of the nuclear fuel cycle was released this year. The report analyzed technological options for spent fuel storage and disposal and provided several recommendations for policymakers. Among the recommendations was the need to prepare for storage of spent nuclear fuel for a period of about a century and to use this time to investigate a broader range of options for reactors with high conversion ratios as well as advanced fuel separation technologies. The report also pointed out that the availability of uranium is unlikely to constrain the growth in nuclear energy generation during this century. The study was conducted by faculty from NSE as well as other parts of the Institute under the leadership of Professor Kazimi and professor Ernie Moniz. Dr. Forsberg was the executive director of the study.

Fusion and plasma physics research is conducted primarily in the Plasma Science and Fusion Center (PSFC), where NSE faculty and students predominate. The Alcator tokamak project is exploring the magnetic confinement of plasmas that are prototypical of the future burning plasma device ITER, beginning construction in France. With temperatures exceeding 50 million degrees Celsius produced by high-power radio-wave heating, the turbulent plasma transport in Alcator and other tokamaks across the confining magnetic field is a topic whose understanding constitutes a grand challenge to science as well as a crucial component in making fusion energy a reality.

Alcator's broad research program involves collaborators from around the world. NSE faculty research specialties include plasma-materials interactions (Dennis Whyte), turbulent transport measurements and simulations (Anne White), plasma flow and magnetohydrodynamic control (Ian Hutchinson), and radio-frequency current drive (Ronald Parker, emeritus). Theoretical research in magnetohydrodynamics (Jeffrey Freidberg), plasma transport (Peter Catto, soon to be joined by Felix Parra Diaz), and

related areas contributes strongly to the local and national fusion program. Major initiatives in advanced plasma performance and fusion technology in support of the steps beyond ITER are being developed. Smaller-scale basic plasma physics studies in such fields as reconnection and plasma wakes also contribute to intellectual vitality and impact.

Highlights of the year's achievements include the discovery of a new state of the plasma in Alcator in which the energy is very well confined by a layer near the edge, but at the same time the plasma particles are able to pass rather freely through the layer. This is advantageous because it enables impurities and fusion ash (which can degrade performance) to be removed without compromising the energy confinement properties.

Professor Sidney Yip continued his research in multiphysics and multiscale materials theory, modeling, and simulation. In addition to his work with CASL, he is a principal member of the MIT Concrete Sustainability Hub and a member of the Materials and Corrosion Center recently established at MIT by BP.

Senior research scientist Richard Lanza is collaborating with Joseph Minervini and Timothy Antaya of PSFC in the development of compact superconducting cyclotrons. Potential applications include medical isotope production, materials testing, proton therapy, and fundamental neutrino physics studies. Dr. Lanza is also collaborating with Raytheon on the development of new tools for long-range detection of radioisotopes, a capability useful in nuclear safeguards and nonproliferation applications. Dr. Lanza received a three-year grant from DOE through the National Nuclear Security Administration's Global Threat Reduction Initiative to develop new curricula and courses in the area of nuclear security and threat reduction. The program is a collaboration among MIT, Texas A&M, and Penn State University.

Professor Paola Cappellaro's quantum engineering group is investigating the dynamics and control of quantum systems with the goal of building computational and measurement devices that exceed the power of their classical counterparts. In the past year, she and her students have continued their studies on quantum information transport enabled by wires of nuclear spins at thermal equilibrium. They have also formulated a new approach for high-sensitivity, high-spatial-resolution magnetometry based on the spin control of ensembles of nitrogen-vacancy centers in diamond.

## Education

A total of 120 students pursued graduate degrees in nuclear science and engineering. Fifty-nine percent of these students worked in the fission energy field, 28% in fusion and plasma physics, and 13% in other nuclear science and technology applications. The department awarded 18 SM degrees, 1 NE degree, 1 ScD degree, and 14 PhD degrees. Thirty-seven students entered the graduate program in fall 2010.

A total of 45 students were enrolled in the undergraduate program during the past year, including 15 sophomores, 17 juniors, and 13 seniors. Thirteen students completed the requirements for the bachelor's degree in nuclear science and engineering from September 2010 through June 2011.

## Faculty Awards, Honors, and Activities

Professor Jacopo Buongiorno was selected by the American Nuclear Society (ANS) to receive the Landis Young Member Engineering Achievement Award, which recognizes significant engineering contributions by an individual under the age of 40. Professor Buongiorno also received the Ruth and Joel Spira Award for Distinguished Teaching and was appointed to the ANS Special Committee on Fukushima.

Professor Benoit Forget was elected chair of the Reactor Physics Division of ANS.

Professor Richard Lester was appointed to the DOE Energy Efficiency and Renewable Energy Advisory Committee and to the Board on Science, Technology and Economic Policy of the National Research Council.

Dr. Felix Parra Diaz, who will join the NSE faculty in July 2011, received the 2011 Marshall N. Rosenbluth Outstanding Doctoral Thesis Award from the Division of Plasma Physics of the American Physical Society.

Professor Neil Todreas received the PAI Outstanding Teacher Award (presented by the MIT section of ANS).

Professor Anne White was chosen to receive a five-year Early Career Research Award by the US Department of Energy Office of Science.

Professor Dennis Whyte was appointed to the National Research Council Committee on the Prospects for Inertial Confinement Fusion Energy Systems.

Professor Bilge Yildiz was selected to receive a five-year Faculty Early Career Development (CAREER) award by the National Science Foundation.

Professor Sidney Yip serves on the advisory boards of the Energy Frontier Research Center at Idaho National Laboratory; the European Center for Atomic and Molecular Calculations at École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland; and the National Aeronautics and Space Administration (NASA) National Hypersonic Science Center, Teledyne, CA.

## Student Awards and Activities

Clarice Aiello was awarded a Faculty for the Future Fellowship by the Schlumberger Foundation.

Yue Fan won the Young Scientist Best Presentation Award at the inaugural Nuclear Materials Conference in Karlsruhe, Germany.

Eric Forrest received an ANS Graduate Scholarship Award. Forrest was also the winner of the Superior Presentation Award at the 2010 Sigma Xi annual meeting.

Nathan Gibson and Paul Romano were awarded Rickover Fellowships in Nuclear Engineering.

Lindsay Gilman was awarded the ANS James F. Schumar Memorial Scholarship for graduate studies in material science and technology for nuclear applications.

Current NSE graduate student Christian Haakonsen and incoming students Mark Chilenski and John Hanson were among 15 MIT students awarded Science Graduate Fellowships by the Department of Energy's Office of Science.

Lulu Li received an ANS Graduate Scholarship for academic excellence in nuclear science and engineering.

Mark Massie, Robert Petroski, and Jeremy Roberts were winners of the 2010 Innovations in Fuel Cycle Research Awards sponsored by DOE. Mark Massie was also awarded a Nuclear Engineering University Program Fellowship from DOE.

Ian Murray will begin a National Science Foundation Graduate Research Fellowship this fall.

Anna Nikiforova was awarded a DOE Stewardship Science Graduate Fellowship.

Paul Romano was awarded the ANS Allan F. Henry/Paul A. Greebler Scholarship. Romano is also a Rickover Fellow and was awarded the Walter Meyer Scholarship by ANS in 2010.

Vladimir Sobes, an all-American track and field athlete, was one of two MIT undergraduates to be presented with an Elite 88 Award for student-athletes by the National Collegiate Athletic Association (NCAA). He also received the Roy Axford Award for excellent academic achievement by a senior in NSE.

Joseph Yurko received the ANS Pittsburgh Local Section Graduate Scholarship Award, presented to a student entering the field of nuclear science and engineering.

Yang Zhang was awarded the 2010 Clifford G. Shull Fellowship at Oak Ridge National Laboratory.

Matthew Davidson received the Outstanding TA Award for exceptional contributions as a teaching assistant in the department.

Jacob Dobisesky, Bryan Herman, and Jacob DeWitte received Outstanding Student Service Awards for exceptional service to the department.

Matthew Reinke received the Manson Benedict Award for excellence in academic performance and professional promise by a graduate student in NSE.

Lauren Ayers and Derek Sutherland received Irving Kaplan Awards for excellent academic achievement by a junior in NSE.

Ethan Peterson received an Outstanding UROP (Undergraduate Research Opportunities Program) Award for exceptional contributions by a freshman in an NSE project or by a sophomore in NSE.

Rosemary Sugrue received an Outstanding UROP Award for exceptional contributions to a research project by a junior or senior in NSE.

Aditi Verma was selected as an MIT Burchard scholar and was also awarded the Kelly-Douglas Travelling Fellowship.

Lauren Ayers, Seung Gyon Baek, Sara Ferry, Christian Haakonsen, Geoffrey Haratyk, Heisoog Kim, Mindga Li, Robert Mumgaard, Roman Ochoukov, Vivek Sharma, Eugeny Sosnovsky, Derek Sutherland, Elizabeth Wei, and Paul Youchak were inducted into the Alpha Nu Sigma National Honor Society.

Graduate students Mark Massie and Leslie Dewan founded Transatomic Power Corporation, a nuclear reactor design company.

The Reinhold Rudenberg Memorial Prize is awarded periodically by the School of Engineering for significant contributions to the advancement of energy conversion. This year the Rudenberg Prize was awarded to a team of NSE graduate students who created a technical blog that attracted 1.5 million visitors in the days and weeks immediately following the accident at the Fukushima nuclear power plant. The recipients of the prize were Matthew Denman, Jacob DeWitte, Bo Feng, Nathan Gibson, Bryan Herman, Stephanie Kempf, Stefano Passerini, Bren Phillips, Mark Reed, Thomas Roomy, Koroush Shirvan, Eugeny Sosnovsky, Bao Truong, and Joseph P. Yurko.

**Richard K. Lester**
**Department Head**
**Japan Steel Industry Professor of Nuclear Science and Engineering**