

## 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 mission of the department is to help develop the next generation of leaders of the global nuclear enterprise while also providing technical leadership in energy and non-energy applications of nuclear science and technology. As a leading academic department in our field, NSE has 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 are bringing 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 important non-energy applications of nuclear science and technology. MIT's Department of Nuclear Science and Engineering offers what is probably the widest spectrum of research and educational activity of any nuclear department in the country. Our faculty and students develop nuclear reactors for electricity generation as well as other diverse uses, including waste management, fluid fuels production, and space propulsion. 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. They contribute to security by developing new 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, magnetic resonance imaging, and quantum information processing.

### Faculty and Administration

The department welcomed three new assistant professors, one full professor, and one professor of the practice to its faculty this year.

Assistant professor Emilio Baglietto's research interests include turbulence modeling, unsteady flow phenomena, multiphase flow and boiling, and virtual reactor modeling.

Assistant professor Felix Parra Diaz studies turbulence and magnetized plasmas and momentum in magnetic fusion devices.

Assistant professor Scott Kemp's research is primarily focused on nuclear nonproliferation and related areas including verification technologies, fuel cycle design, and nuclear energy policy.

Professor Ju Li joined the department as the Battelle Energy Alliance professor of nuclear science and engineering and holds a joint appointment in the Department of Materials Science and Engineering. Professor Li is an international leader in developing

and applying computer simulations to gain a greater understanding of fundamental nanoscale mechanical and transport properties of materials. His research has had a broad impact on understanding how materials behave under extreme conditions.

Dr. Kord Smith joined the department as Korea Electric Power Company professor of the practice of nuclear science and engineering. Professor Smith, a world leader in the development of reactor analysis methods, has developed some of the world's most widely used software for reactor physics modeling and simulation. He was recently named chief scientist of the Department of Energy (DOE) Center for Exascale Simulation of Advanced Reactors, based at Argonne National Laboratory.

Dr. Alan S. Hanson joined the department as executive director of the International Nuclear Leadership Education Program.

Professor Mujid Kazimi continues as director of the Center for Advanced Nuclear Energy Systems (CANES). He was also appointed as director of the Kuwait-MIT Center for Natural Resources and the Environment.

Professor Richard Lester continues to serve as faculty co-chair of the MIT Industrial Performance Center.

Dr. Charles Forsberg was promoted to principal research scientist.

Dr. Michael Short was hired as a research scientist.

Professor George Apostolakis, who continues his service as a member of the US Nuclear Regulatory Commission, retired on June 30, 2012.

The department was saddened by the loss of professor Elias Gyftopoulos earlier this year.

## **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 innovative reactor materials and components is carried out by the faculty and staff of the center, working with more than 70 graduate students and postdoctoral fellows.

Dr. Forsberg and Dr. Linwen Hu have begun a large new project to investigate the technology of salt-cooled reactors for high-temperature applications. This three-year project involves two other universities and will utilize the MIT reactor to study the corrosion of materials in liquid salts under prototypical irradiation conditions.

NSE continues to play a leading role in the Consortium for Advanced Simulation of Light Water Reactors, the DOE Nuclear Energy Innovation Hub based at the Oak Ridge National Laboratory. Professors Ron Ballinger and Bilge Yildiz are studying the scientific bases for hydrogen generation (from radiolysis and chemical reactions) and its effects on zircaloy cladding. Professor Li, professor Sidney Yip, and Dr. Short are developing

simulation capabilities for the behavior of corrosion-related unidentified deposits in pressurized water reactor cores. Professor Mike Demkowicz of the Department of Materials Science and Engineering and professor Ken Kamrin of the Department of Mechanical Engineering are investigating fretting and wear in grid-supported rod bundles. Professor Jacopo Buongiorno and Professor Baglietto lead a program to develop and validate advanced simulation methods and diagnostics for multiphase flow and heat transfer. Professor Benoit Forget is developing 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 the feasibility of ceramic materials—including silicon carbide—as replacements for zirconium-based light water fuel cladding. Professor Kazimi continues his investigation of thermal hydraulics and fuel performance in tight-lattice boiling water-cooled breeder reactors.

Professor Michael Driscoll led the development of a cost-competitive uranium-fueled fast reactor core design that does not require fuel reprocessing. With this fuel, fast reactors can be introduced into the economy without relying on separated fissile materials from reprocessed light water reactor (LWR) fuels.

Professor Ballinger's group continues with its development of advanced materials that will resist corrosion in high-temperature liquid metal environments. Professor Ballinger received a DOE research award to develop probabilistic models for the prediction of long-term behavior of spent nuclear fuel storage canisters.

In collaboration with professors Michael Rubner, Robert Cohen, and Kripa Varanasi (of the Departments of Materials Science and Engineering, Chemical Engineering, and Mechanical Engineering, respectively), Professor Buongiorno's research program on nanofluid heat transfer has focused on the effects of nanoparticles on time-dependent critical heat flux and on engineered surfaces for enhancement of nucleate boiling, critical heat flux, and quenching heat transfer. Progress has also been made in the development and validation of advanced simulation methods (computational fluid dynamics [CFD]) for multiphase flow and heat transfer.

Professor Neil Todreas and his students have completed the development of pressure drop and critical heat flux correlations for twisted tape configurations in flow channels of inverted fuel assemblies operating under pressurized water reactor conditions.

Professor Smith has expanded the high-performance computing activities within the department. Professors Smith and Forget supervise a group of graduate students engaged in the development of numerical algorithms and programming models to study co-design of software and hardware for the next generation of exascale computers.

Professor Forget and his computational reactor physics group have pursued development of open-source software for high performance computing. Of note, the OpenMC code provides a performing Monte Carlo solution for reactor analysis on leadership class computers.

Professor Baglietto and his group are working on developing advanced CFD-based simulation methods to improve the safety and reduce the operating costs of several types of nuclear power plants.

Professor Mike Golay is conducting a project that compares the methods used for risk assessment in the nuclear power programs in France and the United States.

Several events were sponsored by CANES this year. A three-day workshop on the use of advanced computational methods for multiphysics simulation was held in January, organized by professors Smith and Forget. A one-day symposium on advanced LWR fuels was held on April 1, 2012, organized by Dr. David Carpenter, Dr. McKrell, and Professor Kazimi.

In advanced materials research, Professor Li's group is developing in situ transmission electron microscopy (TEM) techniques for quantitative study of materials under thermomechanical, chemical, and electrical extremes. This work has recently appeared in *Nano Letters*, *Nature Communications*, *Science*, and *Advanced Energy Materials*. The Li group has purchased a Nanofactory scanning tunneling microscopy-TEM holder to be used on the MIT campus. The group has also developed a liquid in situ TEM cell based on microelectromechanical systems technology and demonstrated its operation.

Professor Yildiz continues her research on the response of the surface physical chemistry of ionic solids when driven by dynamic environments of chemical reactivity and mechanical stress. Her group has developed a unique capability of probing the surface chemical and electronic state with high spatial resolution in situ at elevated temperatures and with induced stresses.

Fusion and plasma physics research is conducted primarily at the Plasma Science and Fusion Center, 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. Of major concern is the financial pressure that the escalating costs of the international tokamak project are placing on the US domestic fusion program, notably including the Alcator project.

NSE faculty research specialties, many related to Alcator, include plasma-materials interactions (professor Dennis Whyte), turbulent transport measurements and simulations (professor Anne White), plasma flow and magnetohydrodynamic control (professor Ian Hutchinson), and radio-frequency current drive (emeritus professor Ronald Parker).

A highlight from Professor Anne White's research group is the successful deployment of a new correlation electron cyclotron emission radiometer system on Alcator that is used to measure turbulent fluctuations of electron temperature in the core plasma. These new measurements are essential for testing and constraining transport models used to predict the performance of ITER.

Professor Whyte's group has achieved a first demonstration of the growth of tungsten nanotendrils via tokamak plasma interactions. These are of great importance for understanding the behavior of plasma-facing materials. In parallel, work on the DIONISOS (Dynamics of IONic Implantation and Sputtering on Surfaces) test stand investigates their fundamental mechanisms. The new AGNOSTIC (Accelerator-based Gamma and Neutron Observing Surface-diagnosing Tool for In-situ Components) in situ wall surface characterization instrument, which uses a steerable high-energy ion beam, is being installed on Alcator and should obtain its first results soon.

Professor Parra Diaz is conducting research on turbulent transport of particles, energy, and momentum in fusion plasmas. He has developed a theory of turbulent transport able to predict rotation profiles and, with his group, is working on computational and experimental applications of this theory.

Dr. Peter Catto's research during the past year has focused on improving the analytic treatment of ion flow, bootstrap current, and collisional ion radial heat transport in the presence of the strong radial density and temperature gradients associated with the pedestal region at the outer edge of the core plasma during high-confinement tokamak operation. This poorly understood region is known to play a key role in tokamak performance.

Professor Paola Cappellaro's Quantum Engineering Group, based at the Research Laboratory of Electronics, 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. An important focus of research is the nitrogen-vacancy defect in diamond, and Professor Cappellaro this year obtained the first experimental demonstration of quantum information transport in a mixed spin system. Significant advances were also made in quantum metrology.

Senior research scientist Richard Lanza was awarded a grant by the National Nuclear Security Administration to develop a program for university-level nuclear security education in collaboration with Dr. Gordon Kohse and their counterparts at Penn State University and Texas A&M.

Professor Richard Lester and his research team, based at the Industrial Performance Center, completed a major project on the institutional reform of the US energy innovation system.

## Education

A total of 121 students pursued graduate degrees in nuclear science and engineering. Fifty-four percent of these students worked in the fission energy field, 34% in fusion and plasma physics, and 12% in other nuclear science and technology applications. The department awarded 25 SM degrees and 14 PhD degrees. Thirty-one students entered the graduate program in fall 2011.

A total of 36 students were enrolled in the undergraduate program during the past year, including seven sophomores, 13 juniors, and 16 seniors. Eighteen students completed the requirements for the bachelor's degree in nuclear science and engineering from September 2011 through June 2012.

## Faculty Awards, Honors, and Activities

Professor Cappellaro received a Young Investigator Award from the Air Force Office of Scientific Research for her research on the scalability of quantum information devices. She was also appointed as the leader of a major multi-university research initiative on multi-qubit-enhanced sensing and metrology.

Professor Kazimi was elected to the National Academy of Engineering. He also received the 2011 Kuwait Prize in Applied Sciences for his contributions to nuclear power technology. Professor Kazimi was appointed to the DOE Nuclear Energy Advisory Committee this year.

Professor Parra Diaz received a five-year Early Career Award from the Department of Energy for his research on the spontaneous generation of rotation in tokamak plasmas.

Professor Anne White was elected to the US Burning Plasma Organization Council and was elected chair of the Executive Committee of the International Sherwood Fusion Theory Conference.

Professor Yildiz was the winner of the Electrochemical Society's biennial Charles W. Tobias Young Investigator Award. Also, along with her colleague professor Harry Tuller of the Materials Science and Engineering Department and three international collaborators, Professor Yildiz received the Somiya Award for International Collaboration from the International Union of Materials Science Societies.

Emeritus professor Parker received the Fusion Power Associates Distinguished Career Award in 2011 for his lifetime contributions to fusion research and development.

Emeritus professor Yip received the 2012 Robert Cahn Award from the *Journal of Nuclear Materials*. He was also honored by the American Physical Society as an Outstanding Referee.

Dr. Catto was awarded an honorary doctorate by Chalmers University of Technology in Sweden.

Professor Buongiorno was a member of the American Nuclear Society (ANS) Special Committee on Fukushima, and Professor Golay was appointed to a National Research Council committee to identify the long-term lessons of the Fukushima accident.

Professor Driscoll received the PAI Outstanding Teacher Award presented by the MIT student chapter of the American Nuclear Society.

## Student Awards and Activities

Clarice Aiello was selected to receive a Schlumberger Foundation Faculty for the Future Fellowship.

Josh Richard was awarded a first-place prize in the Department of Energy's 2012 Innovations in Fuel Cycle Research Awards Competition. Ethan Bates and Sam Brinton received second-place awards in the 2011 competition.

Bradley Black, Will Boyd, and Sam Shaner were awarded Department of Energy Nuclear Energy Graduate Fellowships.

Mareena Robinson was awarded a Department of Energy Stewardship Science Graduate Fellowship.

Lindsey Gilman received the Robert A. Dannels Memorial Scholarship for graduate studies in nuclear science and engineering from the ANS.

Franco Julio Mangiarotti was awarded the Institute of Electrical and Electronics Engineers Council on Superconductivity Graduate Study Fellowship in Applied Superconductivity.

NSE junior Cameron McCord was awarded a Harry S. Truman Scholarship. These national scholarships for graduate study are presented to students committed to careers in government or the nonprofit sector.

Ekaterina Paramonova received an American Society of Mechanical Engineers Nuclear Engineering Division Scholarship and an ANS William R. & Mila Kimel Nuclear Engineering Scholarship. She also received the Outstanding UROP (Undergraduate Research Opportunities Program) Award for exceptional contributions to a research project by a junior or senior in NSE.

Victoria Winters received the Outstanding UROP Award for exceptional contributions by a freshman in an NSE project or by a sophomore in NSE.

Mark Reed won two Best Presentation Awards at the 2012 ANS Student Conference. He also received the Outstanding TA Award for exceptional contributions as a teaching assistant in the department.

Elliott Fray won a Best Presentation Award at the 2012 ANS Student Conference.

Ethan Bates won a 2011 DOE Innovations in Fuel Cycle Research award. He was also inducted as an associate member of the Sigma Xi Scientific Research Society.

Paul Romano received the Manson Benedict Award for excellence in academic performance and professional promise by a graduate student in nuclear science and engineering.

Uuganbayar Otonbaatar received the Roy Axford Award for academic achievement by a senior in nuclear science and engineering.

Bryan Herman received the Outstanding Grader Award presented by the student chapter of the American Nuclear Society.

Ruaridh Macdonald was part of a team that was awarded the Carl G. Sontheimer Prize for creativity and innovation in design by the Mechanical Engineering Department.

Curran Oi and Ethan Peterson each received the Irving Kaplan Award for academic achievement by a junior in nuclear science and engineering.

NSE graduate students Justin Ball, Dan Brunner, Mark Chilenski, Ian Faust, Mike Garrett, Zach Hartwig, Nathan Howard, Bob Mumgaard, Goeff Olynyk, Brandon Sorbom, and John Walk and Department of Physics graduate student Jennifer Sierchio received an NSE Outstanding Service Award for their contributions to the public debate on the future of the Alcator C-Mod experiment and the US fusion research and development program.

Koroush Shirvan received an NSE Outstanding Service Award for managing the suite of computer codes in the fission area.

A team of NSE students including Mark Reed and ANS student chapter co-presidents Brittany Guyer and Koroush Shirvan prepared a successful bid to host the 2013 American Nuclear Society Student Conference at MIT next spring. The conference will be co-chaired by graduate student Nathan Gibson, graduate student Samuel Brinton, and undergraduate student Ekaterina Paramonova.

Graduate students Samuel Brinton, Christopher Copeland, and Mark Reed represented MIT as members of the 2011 Nuclear Engineering Student Delegation in Washington, DC.

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