

Nuclear Reactor Laboratory

The MIT Nuclear Reactor Laboratory (NRL) is an interdepartmental center that operates a 6 MW research reactor in support of MIT's educational and research initiatives and goals. For 53 years, NRL has provided faculty and students from MIT and other institutions with a safe and reliable neutron source and the infrastructure to facilitate use of that source. During this time, NRL has supported educational training and cutting-edge research in the areas of nuclear fission engineering, material science, radiation effects in biology and medicine, neutron physics, geochemistry, and environmental studies. As a result, countless undergraduate and graduate students have benefited from their association with NRL. Through the years, these students have been offered an opportunity to pursue their research by utilizing a research reactor that has provided a unique hands-on environment.

Facilities and Resources

NRL's primary mission is to provide faculty and students from MIT as well as the national scientific and engineering community with both a state-of-the-art reactor facility and the infrastructure to enable and support its use for research and other societal objectives. Highest priority is placed on operating the research reactor in a highly professional manner that is safe to MIT and NRL staff and researchers, to the public as well as to the environment. A secondary, but no less important mission, is to educate the general public about the benefits of maintaining a strong nuclear science program in the US. This is accomplished by providing tours and lectures that describe and clarify different nuclear science and technology programs.

The reactor, which is designated as the MITR-II, is the second of two research reactors that have been operated by NRL. The original reactor (MITR-I) achieved criticality in 1958. In 1973, the MITR-I was shut down to allow conversion to the MITR-II, which offered a higher neutron flux level. On July 8, 1999, a formal application was submitted to the US Nuclear Regulatory Commission (NRC) to relicense the reactor for an additional 20 years and to upgrade the power level from 5 MW to 6 MW. The new license was issued on November 1, 2010, after which time, reactor staff began the process of increasing the reactor's power to its new licensed limit of 6 MW, which was achieved in May 2011. Research funded under the Department of Energy's (DOE's) Reduced Enrichment for Research and Test Reactors Program will enable the MITR-II to meet its next milestone to convert from high-enriched uranium (HEU) to low-enriched uranium (LEU) fuel.

The MITR-II, the major experimental facility of NRL, is a heavy-water reflected, light-water cooled and moderated nuclear reactor that utilizes flat, plate-type, finned, aluminum-clad fuel elements. The average core power density is about 70 kW per liter. The maximum fast and thermal neutron flux available to experimenters are 1.2×10^{14} and 6×10^{13} neutrons/cm²-s, respectively. Experimental facilities available at the MIT research reactor (MITR) include two medical irradiation rooms, beam ports, automatic transfer facilities (pneumatic tubes), and graphite-reflector irradiation facilities. In addition, several in-core sample assemblies (ICSAs) are available. It generally operates

24/7, except for planned outages for maintenance. The MITR-II encompasses a number of inherent (i.e., passive) safety features, including negative reactivity temperature coefficients of both the fuel and moderator; a negative void coefficient of reactivity; the location of the core within two concentric tanks; the use of anti-siphon valves to isolate the core from the effect of breaks in the coolant piping; a core-tank design that promotes natural circulation in the event of a loss-of-flow accident; and the presence of a full containment. These features make it an exceptionally safe facility.

Reactor Administration

NRL's organizational structure is composed of four groups that work as a team to meet the short-term operational demands and long-term strategic challenges involved in operating a nuclear research reactor in the current environment. These groups are reactor operations; research, development, and utilization; engineering; and administration. David Moncton is the director of NRL. He and Thomas Newton (director of reactor operations and associate director of reactor engineering), Lin-Wen Hu (associate director of research, development, and utilization), Edward Lau (assistant director of reactor operations), John Foster (reactor superintendent), and Mary Young (administrative officer) make up NRL's senior management team. This leadership team works to sustain NRL's long-standing record of safe operation, to continuously maintain and improve upon the MITR-II and its experimental facilities, and to provide an environment of support and excellence for researchers and students.

NRL currently employs 46 individuals. The staff consists of six groups, which include the previously mentioned six senior staff, four research staff, five technical staff, 11 technical support staff, two academic staff, three administrative support staff, two technicians, 10 part-time student operators, and four student trainees. In general, NRL support staff, student employees, and technicians have specific responsibilities to a particular group.

Reactor Operations

Leadership of the reactor operations group is provided by newly appointed director Thomas Newton, assistant director Edward Lau, and reactor superintendent John Foster. The reactor operations group, the largest at the NRL, is responsible for supporting all laboratory activities when necessary, with priority on the operation and maintenance of the 6 MW research reactor. The group consists of full-time employees and part-time undergraduate students. All 26 members of the group are licensed by the NRC, and most hold a senior reactor operator (SRO) license. All perform reactor shift duties to support the 24/7 operating schedule. In addition, there is one full-time project mechanic to support reactor mechanical maintenance. Reactor operations supported the following NRL research projects: the advanced cladding irradiation (ACI-2) experiment; the hydride-fueled irradiation; the heated ICSA; the 4DH4 diffractometer; and the 4DH1 student spectrometer.

The MIT reactor completed its 53rd year of operation (its 36th since the 1974–1975 upgrade and overhaul). Beginning in 1994, the reactor adopted a schedule of continuous operation to support major experiments and utilization. The reactor was nominally maintained at a full power of 4.5 MW or higher (5.5 MW or higher since

May 25, 2011). Total energy output for FY2011 was 19,800 megawatt-hours. This translates roughly to 4,000 hours of operation at full power.

Several major upgrade projects were carried out in order to improve the reliability and efficiency of the MIT research reactor:

The three main reactor heat exchangers—HE-1, HE-1A, and HE-1B—were replaced with a new, single heat exchanger HE-1, which is an all-titanium plate-and-frame design. The replacement project included major piping upgrades and piping re-configuration of the reactor's primary and secondary systems in the equipment room. Auxiliary heat exchanger HE-2 for the primary cleanup system was also replaced. Additionally, the main heat exchanger HE-D1 in the reactor's D₂O system was replaced along with its associated piping. All of this provided a major improvement in the reactor's thermal performance, allowing the reactor to operate up to 6 MW, as approved under the new NRC reactor operating license received in November 2010.

All primary system piping in the equipment room was replaced, including its cleanup system, and all with 304 stainless steel construction. Main primary piping section diameters have been increased from 6" and 8" to 8" and 10", respectively, to minimize piping pressure loss. Major primary valves were also replaced and many received motor-actuators for remote control operation. Most primary pressure and flow instruments were replaced. The 60-hp main primary pumps MM-1 and MM-1A were rebuilt using large frame ANSI rotating assemblies for increased performance and reliability. The pump foundations were upgraded to grouted polymer concrete for improved vibration control. The coupling guards on both pumps were upgraded to current Occupational Safety and Health Administration (OSHA)-compliant models. Auxiliary pump MM-2 was replaced with a new pump equipped with a variable frequency drive controller. MM-2 flow rate is now displayed locally and remotely. Several local primary flow meters have been changed from rotometers to all-metal, self-calibrated flow meters with magnetically coupled local displays that do not require electrical power for operation.

Piping for the entire secondary system in the equipment room was also replaced. The new pipes are all 316 stainless steel for improved chemical resistance to city water. The main flow path is again simplified since there is only one heat exchanger. Twin Bernoulli filters clean the secondary water before it enters the heat exchanger. The Bernoulli filters are air-operated and clean themselves with automatic backflushes that send trapped dirt and debris to an independent cleanup system in the cooling towers. The 50-hp secondary pumps also received new bases and OSHA-compliant coupling guards. A new secondary auxiliary pump HM-C was added and dedicated to supply secondary coolant to all heat exchangers other than the main HE-1 (i.e., it supplies primary cleanup heat exchanger HE-2, shield HE-3, experiment HE-4, fission converter HE-5, instrumentation air-conditioners, and D₂O reflector HE-D1 and HE-D2). Major secondary system valves were also replaced and many of the new ones are motor-actuated for remote control operation. Most secondary system pressure, temperature, and flow instruments were replaced. A new instrument cabinet installed just outside the control room contains displays of secondary coolant flow distribution to all the heat exchangers. The data there are collected by computer for maintenance analysis.

The heat exchanger replacement and piping upgrades for the primary and secondary systems alone have resulted in a significant improvement in the cooling efficiency of the reactor systems. Replacement of the D₂O heat exchanger provided additional margin on the reactor's thermal performance. The cooling tower fans are no longer required to be at high speed during normal full-power reactor operation. This reduces the amount of environmental debris entrained into the secondary system via the cooling towers, which in turn helps maintain cleaner secondary water and therefore minimizes load on the secondary cleanup system. The new primary system is much simpler in its configuration. This allows the new primary piping and components to be better positioned behind the shield walls at the ends of the equipment room, and hence reduces personnel dose exposure. The use of motor-actuators for three primary valves and 17 secondary valves, particularly the larger ones in the secondary system, reduces personnel radiation dose exposure by not requiring entry into the equipment room for shutdown and startup valve alignments.

Other important upgrades included the complete replacement of the reactor's automatic shutdown electronics and the withdraw permit circuit, which went through extensive testing by reactor staff prior to operation. The detector power supplies for the nuclear safety instrumentation were also upgraded in their entirety to provide stable, noise-free high voltage for their ion chambers. The special reinforced rubber gasket for the inner door of the basement personnel airlock was replaced after 15 years of service. Many other routine maintenance and preventive maintenance items were also scheduled and completed throughout the fiscal year for experiments and for reactor operations.

Student Reactor Operator Training Program

To fulfill one of the stated missions of NRL, the reactor operations group trains up to six MIT undergraduates each year, typically starting in their freshman year, to obtain an NRC license to operate the MIT reactor. The training program is rigorous and covers reactor dynamics, radiation detection, radiation safety, and reactor systems. The level of instruction is comparable to that offered in undergraduate courses covering the same topics. In addition, students are taught how to operate the MITR-II. Upon completion of the training program, a two-day examination is administered by NRC (one-day written, one-day oral). Successful candidates receive a reactor operator license and are employed part-time during the semester at the MITR. After the students gain experience, most are offered the opportunity to participate in a second training program that leads to a senior reactor operator (SRO) license. This training program is an excellent educational opportunity for undergraduate students because it combines theoretical study with hands-on experience, in the MIT tradition of graduating students who know how to design and build systems. In addition, students who receive the SRO license obtain management experience by serving as shift supervisors. Students who have completed this training program regularly report that it was one of the high points of their MIT experience.

During this reporting period, two sets of NRC exams were administered on-site: in September, there was one student candidate for an upgrade to an SRO license, and in January, three student candidates for reactor operator licenses. All candidates passed. Four MIT students and one ex-Navy nuclear operator are in training for this year. Two

student reactor operator exams and one upgrade to an SRO exam are scheduled for October 2011; the ex-Navy candidate exam and another MIT student operator exam are scheduled for January 2012.

Reactor Research Facilities and Services

Partnership with Idaho National Laboratory

The MITR is in a partnership with the Idaho National Laboratory's (INL's) Advanced Test Reactor National Scientific User Facility (ATR NSUF) that involves performing fuel and advanced materials irradiation experiments crucial to future-generation reactors. High-temperature and radiation-resistant materials are needed for proposed designs that would exhibit high thermal efficiency as well as for hydrogen-production reactors. A related and equally important goal is to identify advanced fuels and materials that will enable both life extension and improved economic performance of the existing light water reactor (LWR) fleet. This collaboration, the first in an expected series of national partnerships seeking to enhance NSUF infrastructure and capabilities, is designed to increase user access to national reactor irradiations and testing capabilities. NSUF test space at both reactors is made available at no cost to external users, whose projects are selected via a peer review process. The MITR will offer a portion of its test capability to NSUF experimenters. Dr. Hu and Gordon Kohse jointly manage the NRL and ATR NSUF partnership.

In-core Loops and Sample Irradiation Facilities

NRL has a strong materials and in-core loop program that supports research in the areas of advanced materials and fuels that are necessary for both existing and advanced power reactors. The MITR offers a unique technical capability that involves the design and use of in-core loops that replicate pressurized water reactor/boiling water reactor conditions to study the behavior of advanced materials and to perform scoping studies of advanced nuclear fuel. With rekindled national interest on the part of DOE and the nuclear industry in next-generation nuclear power systems, many using novel materials and advanced forms of fuels, facilities are needed to test material and fuel behavior in a variety of radiation environments. The MITR is the best-suited university reactor for carrying out such basic studies because of its relatively high-power density (similar to a LWR), its capability to control chemistry and thermal conditions to reflect prototypic conditions, its easy-access geometric configuration, and its in-core space for up to three independent irradiation tests.

Post-irradiation Examination Facility

The MITR-II is equipped with post-irradiation examination facilities that include two top-entry hot cells with manipulators (1,000-Ci capacity each), a lead-shielded hot box (20-Ci capacity) with manipulators, an overhead crane with 3- and 20-ton capacities, and several transfer casks. One of the hot cells is currently equipped with fixturing to disassemble and reassemble in-core water loop sample trains, while the hot box is set up to perform similar tasks for ICSA capsules. In addition to these reactor containment facilities, an exclusion area laboratory is equipped for irradiated sample mechanical tests (tube specimens and miniature four-point bend test bars) and for irradiated sample sectioning and polishing.

Nanofluids Laboratory

The Nanofluids Laboratory experimental facilities and associated instrumentation are part of the Thermal Hydraulics Laboratory, supported jointly by the Department of Nuclear Science and Engineering (NSE) and NRL. These facilities can be used for research projects in general, heat transfer and two-phase flow research, as well as teaching at both the undergraduate and graduate levels. Experimental facilities and advanced instrumentation were constructed or acquired with funding support from industry sponsors AREVA, Electric Power Research Institute, and ABB; the INL; the DOE Nuclear Education and Engineering Research Program; the DOE Innovations in Nuclear Infrastructure and Education Program (INIE); and the King Abdulaziz City of Science and Technology. These experimental facilities can be described briefly as follows:

- Single-phase heat transfer loops: These are forced convection loops designed and constructed by MIT students and staff to investigate nanofluid heat transfer and pressure drop characteristics in laminar and turbulent flow regimes.
- Critical heat flux (CHF) loop: The CHF facility obtains flow CHF data for different types of nanofluids that do not exist in the literature.
- Pool boiling facility: This apparatus is designed to understand the fundamental CHF mechanism. The facility is equipped with a thin indium-tin-oxide heater deposited over a sapphire substrate to provide a direct bottom-up view of the boiling phenomena on the heater surface and an optical probe for measuring bubble size distribution.

Neutron Capture Therapy User Center

The Neutron Capture Therapy User Center comprises the following facilities and capabilities:

- High-intensity, high-purity beams of thermal and epithermal neutrons that approach the theoretical optimum for boron neutron capture therapy (BNCT)
- Physical and computational dosimetry associated with experimental (and clinical) studies
- Bulk analysis of boron distributions in tissue specimens using prompt gamma neutron activation analysis (PGNAA) or inductively coupled plasma atomic emission spectroscopy (ICP-AES)
- Assistance with designing and performing animal or cell culture experiments to test new boron tumor-targeting agents or translational research to initiate new clinical trials in BNCT

The thermal and epithermal neutron medical irradiation facilities are the only beams licensed by NRC for clinical trials. The fission converter-based epithermal neutron beam line has been augmented to include an optional lithium filter that improves beam penetration and increases the therapeutic ratio for deep-seated tumors by as much as 15 percent.

The center maintains and operates the reactor's fission converter, PGNAA, and the thermal neutron beam facilities used primarily for boron drug testing and characterization.

Neutron Spectrometer Experimental Facility

The web-enabled time-of-flight experimental facility was fully deployed during FY2010 in support of NSE's nuclear measurements laboratory subject (22.09/22.90) and the Department of Physics junior laboratory. This facility can be operated locally or remotely over the internet using MIT's iLabs server architecture. Hardware and software upgrades made during previous years improved reliability and supported a heavy schedule of student experiments in both the fall and spring terms. The longer data collection times that are feasible with remote operation have markedly improved the data quality available to students and have greatly enhanced the educational value of the experiments conducted. Continued incremental improvements to the hardware and software are planned, together with outreach to broaden the user base of the facility outside MIT.

Neutron-scattering Facility

The revitalization of NRL's neutron-scattering capability is essentially complete. This program was initiated five years ago under the direction of Professor Moncton with the assistance of research scientist, Boris Khaykovich. As a result of their efforts, the neutron-scattering capability, funded by the National Science Foundation, includes new neutron-scattering instruments, a neutron diffractometer with polarizing capabilities, and a neutron optics test station. Both instruments are operational. Professor Moncton and Dr. Khaykovich use this instrument to support a new DOE-funded neutron optics research program whose goal is to develop specialized neutron-focusing optics for scattering and imaging applications. In addition, professor Peter Fisher and several outside groups have utilized the test station to develop novel neutron detectors.

Neutron scattering and spectroscopy are among the preeminent tools for studying the structure and dynamics of matter at the atomic and molecular scales. A powerful new neutron facility, the Oak Ridge National Laboratory's (ORNL's) Spallation Neutron Source (SNS), is widely anticipated to revolutionize this field and enable the United States to regain leadership lost to Europe decades ago. SNS catalyzes a new generation of instrument development, a new generation of neutron scientists, and, as a result, new scientific research with neutrons.

NRL envisions the following programs resulting from this initiative: education and training for students in basic concepts of neutron scattering; enhanced production of new materials at MIT and elsewhere by allowing rapid evaluation via neutron scattering; development of novel neutron optics components; conceptual development of a new imaging instrument—a neutron microscope in absorption and phase contrast—for future installation at SNS; and establishment of a user facility designed to allow users from outside MIT to conduct early phases of some experiments more quickly than at large facilities, and to test and develop new neutron optics components.

Environmental Research and Radiochemistry

NRL's environmental research and radiochemistry laboratories are equipped for both prompt and delayed gamma neutron activation analysis (NAA). Relative to the former, a prompt gamma spectrometer was built as part of the BNCT program to measure the boron content in the blood and tissue of patients and experimental animals and is now available to other users. Relative to the latter, the MITR is equipped with two pneumatic tubes that are commonly used for NAA, primarily for analysis of trace metals. One offers a thermal flux of 6×10^{13} , and the other offers a thermal flux of 9.6×10^{12} . Several of the tubes are automated so that samples can either be ejected to a hot cell within the reactor containment or be transferred via a pneumatic tube to a laboratory in an adjacent building. In addition to the pneumatic tubes, there are four water-cooled facilities in which large numbers of samples can be simultaneously irradiated in a uniform flux. Samples in these facilities can be rotated. ICP-AES is also available at NRL. NRL's NAA laboratory is equipped with three HPGe detector systems with Genie 2000 software.

NRL makes its NAA facilities and expertise available to industry, other universities, private and governmental laboratories, and hospitals. Research- and service-oriented collaborations were continued with several MIT research laboratories as well as with other educational and research institutions.

Reactor Engineering

Dr. Newton is associate director for engineering at NRL. This group's activities include support and development for experiments such as the ICSA, the high-temperature irradiation facility, and ACI-2s. This group also performs neutronic modeling of proposed experiments for evaluation of neutron fluxes, reactivity, and heat generation. Work with ex-core experiments, including upgrade and operation of a neutron diffractometer, has continued as well. Other activities of this group include engineering support of upgrades to reactor mechanical and instrumentation systems, supervising the management of fuel in the reactor and fission converter, overseeing shipments of spent fuel, and other engineering services as needed.

In addition, Dr. Newton is the principal investigator for the program to convert the reactor to LEU fuel. The Global Threat Reduction Initiative (GTRI) Program under DOE has committed to converting all research reactors using HEU to LEU. Although a number of lower power reactors have been converted under this program, the remaining five US reactors with higher power densities (the MITR, the University of Missouri Research Reactor Center, the National Institute of Standards and Technology Reactor, the High Flux Isotope Reactor at ORNL, and the Advanced Test Reactor at INL) require the development of fuels with significantly higher densities. Such a fuel, a monolithic U-Mo fuel with a uranium density of about 16 g/cm^3 , is under development and is expected to be qualified and approved for use in 2014. The MITR is expected to be the first reactor worldwide to use this fuel.

With ongoing support from the GTRI program, neutronic and thermal-hydraulic modeling tools for the MITR conversion study have been developed and benchmarked for both steady-state and transient conditions. These models are being used to compare the current HEU fuel with proposed LEU fuels. Burn-up modeling tools using both

Monte Carlo and diffusion theory methods are also being developed so that fuel life, reactivity, neutron fluxes, and power peaking can be evaluated over time. Such models are being used to determine core performance and to develop a fuel management strategy that will reduce power peaking in the LEU core while meeting experimental as well as fuel supply needs.

Feasibility studies have shown that this LEU fuel can be used in the MIT reactor, although without an increase in reactor power it could come at a significant penalty in neutron flux to in-core and ex-core experimental facilities. These studies have also shown that the reactor could operate using LEU fuel at or near 7 MW without significant changes to the reactor infrastructure, which would allow all experiments to operate with the same or greater neutron fluxes present in the current HEU core at 6 MW.

Studies on mixed HEU-LEU cores show that it also appears feasible to introduce LEU into the current core to allow testing under nominal operating conditions during the transition. Introduction of LEU fuel into the MITR is expected to begin in 2016.

Reactor Research, Development, and Utilization

Dr. Hu is the associate director of the research, development, and utilization group. She and her staff have developed a robust program that assists MIT faculty, researchers, and students, as well as those outside NRL, in their use of the reactor and its irradiation facilities. Tasks undertaken by this group include:

- Supporting research in the area of advanced materials and fuel research
- Providing researchers with a service-based infrastructure that utilizes the MITR-II for trace element analysis, isotope production, and irradiation services
- Supporting an outreach program to the educational community to encourage understanding of nuclear energy and its applications
- Supporting MIT's educational missions by providing Independent Activities Period lectures; hosting Undergraduate Research Opportunities Program students; and offering laboratory courses for professionals, undergraduates, and advanced secondary school students
- Expanding the user base for underutilized experimental facilities. Irradiations and experiments conducted during this reporting period include the following: activation of gold-198 seeds and ytterbium pellets for brachytherapy, xenated silicon chips for trace element analyses, and fusion material laminates and Ge wafers for material science studies
- Irradiation of SiC in a 2PH1 pneumatic facility for non-destructive irradiation damage studies (funded by ATR NSUF) conducted at the Colorado School of Mines
- Activation of uranium foils for detector calibration at the Los Alamos National Laboratories
- Activation of ocean sediments for the Woods Hole Oceanographic Institute
- Activation of Teflon and Si wafers for the University of Alabama

- Activation of crystal samples for neutron damage studies conducted by the Department of Earth, Atmospheric, and Planetary Sciences
- Activation and NAA of ultra-high-purity B-11 for a trace element analysis conducted by Ceradyne Boron Inc.
- Activation and NAA of shielding materials for NSE for a new accelerator design
- Experiments at the 4DH1 radial beam port facility by MIT undergraduate and graduate students, including measurements of leakage in the neutron energy spectrum to determine reactor temperature, measurements of neutron wavelength and time of flight, and measurements of attenuation coefficients for eight shielding materials
- Use of the reactor for training MIT student reactor operators and for NSE classes (22.06 Engineering of Nuclear Systems; 22.09 Principles of Nuclear Radiation Measurement and Protection; 22.921 Nuclear Power Plant Dynamics and Control; and the reactor technology course for nuclear power executives)
- Use of the facility and source handling services for handheld gamma spectrometer development and testing for Symetrica Inc.
- Neutron transmutation doping of Si wafers for the Lawrence Berkeley National Laboratory and subsequent use of the wafers for further neutrino detector research

Research Programs

In-core Loops

After the advanced cladding irradiation (ACI) was successfully completed in October 2007, a new set of internals—including bend test bars, thermal conductivity specimens, and a set of tube specimens—were designed, manufactured, and installed to accommodate a second advanced cladding irradiation campaign (ACI-2). This second round of in-core irradiations of SiC cladding with a planned in-reactor exposure of two years started in February 2009, with funding from Toshiba/Westinghouse. The same experiment, with different SiC composite samples, was also selected for funding by INL's ATR NSUF. This project began in mid-June 2009 and continued throughout FY2010, with an intermediate sample examination and change-out from December 2009 to February 2010. In addition to tube samples of composite cladding, specimens to evaluate the performance of candidate end-sealing methods were irradiated. Professor Mujid Kazimi is the principal investigator for this project.

A new ICSA was fabricated and test-fitted in February 2009. The goals of the redesign were to provide positive sweep gas flow and allow for a wider range of feedthroughs to accommodate temperature and other in-core measurements or active control of irradiation parameters. The redesigned ICSA was demonstrated as a test bed for high-temperature irradiations during December 2009, with funding from ATR NSUF. Capsules equipped with gamma susceptors were used in conjunction with a neon/helium gas mixture control system to maintain constant irradiation temperatures in the range of 500–850°C. Irradiation programs have been funded to utilize this facility

for testing advanced high-temperature materials (MAX phases) and advanced in-core thermocouples and fiber optic sensors. The ICSEA was also used to irradiate molybdenum targets to investigate the feasibility of generating $n\text{-}\gamma^{99}\text{Mo}$ for use in producing the medically important isotope Tc-99m. This project was undertaken in cooperation with General Electric, with funding from DOE's National Nuclear Security Administration (NNSA).

Planning for hydride metallic fuel irradiation was ongoing since last year. This fuel matrix is being studied by the University of California, Berkeley (UCB) researchers for use in advanced LWRs. This fuel irradiation project was selected by the ATR user facility (ATR-UF) to be performed at the MITR. Working closely with UCB and INL staff, the fuel capsules were designed and fabricated, and the irradiation started in March 2011.

In March 2011, the NRL reached a utilization milestone of operating three in-core experiments simultaneously, for the first time since the MITR was built in 1950's. This accomplishment reflects the successful planning and execution of reactor experiments by the utilization and research development group with the support of reactor operations and reactor radiation protection staff. The following in-core experiment projects are ongoing as a result of the partnership with ATR NSUF and other DOE initiatives: ACI loop for LWR SiC composite cladding irradiation; hydride fuel capsule irradiation; high-temperature material titanium compounds (MaxPhases); and high-temperature irradiation resistant thermocouples irradiation in ICSEA.

New Initiatives

NRL, in collaboration with UCB, is pursuing research in the area of high-temperature salt-cooled reactors. A proposal entitled High-temperature Salt-cooled Reactor for Power and Process was submitted to DOE under its Integrated Research Project; the proposal aims to develop a path forward to a commercially viable salt-cooled, solid-fuel, high-temperature reactor with superior economic, safety, waste, nonproliferation, and physical security characteristics compared to LWRs for base-load electricity production and process heat applications. This is a new reactor concept that is about a decade old. The work thus far shows great potential but there are significant uncertainties. While the end product is a pre-conceptual reactor design and a development roadmap, the experimental and analytical work will: (1) conduct material tests in laboratory loops and the MIT reactor to test key materials required in-core and out-of-core, (2) develop the appropriate tools for the thermal hydraulic/neutronic/safety analysis, validated with experiments using salt stimulants to provide key data, (3) develop pre-conceptual point designs for a test reactor and commercial prototype reactor, and (4) conduct a series of workshops and collaborative research and development (R&D) to support the development of the roadmap to commercialization that includes defining what is known and unknown, R&D needs, and a prioritized development strategy (technology, licensing, etc.).

Department of Energy Programs

In 2008, DOE's Office of Nuclear Energy (NE) initiated the Nuclear Energy University Program, consolidating its university support programs and thereby replacing INIE, which had been a significant benefit to the university nuclear engineering and research

reactor community. Under the new program, 20 percent of NE funds appropriated for its R&D programs are now designated for universities and research institutes through a competitive solicitation process. One of the NE university programs of particular importance to NRL is the Research Reactor Infrastructure (RRI) Program, which supports infrastructure and equipment upgrades for university-based research reactors and laboratories. As a result of a proposal submitted in response to an FY2011 RRI solicitation, principal research engineer John Bernard was awarded RRI funding that allowed purchase and installation of major equipment to support ongoing NRL and NSE research projects. This equipment included:

- On-line tritium monitor: This monitor will be used by the secondary cooling system to continuously detect any tritium leakage, including when the reactor is operating as well as when it is shut down.
- Continuous air monitors: These monitors will be used to upgrade and expand upon dated existing air monitors located in the control room, experiment floor, and reactor top in order to support research such as in-core irradiations and hot cell work being conducted at NRL.
- Hand and foot monitor: These monitors will efficiently and reliably detect loose contamination from work with radioactive materials as well as efficiently process large tours out of the restricted area. This particular monitor includes a large area probe to scan for contamination on the rest of the body.
- Area radiation monitor system: The existing MITR area radiation monitor system accommodates 12 units, allowing instantaneous display and alarm functions for 12 different locations. In the last several years, units from a different manufacturer were added to the system but could not be fully integrated. The new system will include networking, data-sharing, and remote indication capabilities.
- Handheld portable gamma spectrometer: Identifying the source of radiation is the first step in reducing radiation exposure. Short-lived isotopes can decay away before work would begin, whereas longer-lived isotopes would need to be shielded or removed (if possible); this instrument will be used to evaluate the source term in areas where the source term has not yet been determined through direct measurements. In addition, this tool will prove useful in the event of an emergency where isotopic identification at the site boundary or beyond may aid in more quickly bringing the emergency under control.
- Nuclear safety system: A digital/analog wide-range neutron flux monitoring system to replace the existing analog system that requires manual transition from source-range to power-range operation. The existing system was built in the mid-1970s. The new system features continuous functional self-checks, and can be tested while the reactor is at power.
- Recorders for reactor operating parameters and radiation monitors: The control room has a dozen paper-chart recorders, all of which have been in operation 10+ years. Some have suffered partial failures that are beyond repair. The new recorders will provide up to 18 channels of recording each,

allowing comprehensive documentation of more than 100 reactor and radiation parameters.

Safety and Security

Operational Safety

Many years ago, MIT established a means of ensuring safe operation of the nuclear reactor by appointing independent experts to the Reactor Safeguard Committee. The committee, whose members are from MIT as well as from industry, is ultimately responsible for overseeing all nuclear safety issues related to the reactor and ensuring that reactor operation is consistent with MIT policy, rules, operating procedures, and licensing requirements. However, *all* members of the NRL organization are keenly aware that safe operation of the nuclear reactor at MIT is their top priority. This level of awareness is achieved through the commitment and continuous training provided by NRL's management team. An environment of cooperation and attention to detail among reactor employees and experimenters regarding all reactor safety matters is essential. As a result of this approach to safety, each and every individual employed at the reactor can be proud of NRL's outstanding safety and operating record, which is evidenced by the results of NRC inspections.

Reactor Radiation Protection

Radiation protection coverage is provided by the Reactor Radiation Protection Program of the Environment, Health, and Safety Office (EHS). While this is a separate organization within MIT, it is very responsive to the NRL management team. Personnel include a deputy director for EHS serving as the reactor radiation protection officer (William McCarthy) and two EHS officers, one technician, and a part-time administrative support staff member. Routine activities include but are not limited to radiation and contamination surveillance, experimental review and approval, training, effluent and environmental monitoring, internal and external dosimetry programs, radioactive waste management, emergency preparedness, and ensuring that all exposures at NRL are maintained as low as reasonably achievable (ALARA) in accordance with applicable regulations and Institute committees. An EHS officer (James Rowlings, from the safety program) serves as EHS lead contact to NRL under EHS management system organizational structure.

ALARA Program

During the past year, MITR staff members worked closely with the Reactor Radiation Protection Program staff in support of NRL's as-low-as-reasonably-achievable (ALARA) program. ALARA-related policies, procedures, and metrics have resulted in improvements to the facility's day-to-day safety and efficiency. Plans and lessons learned were captured throughout the year, laying the framework for continued enhancements. The major accomplishments of this program include:

- An increased level of awareness pertaining to dose reduction, which is now at the forefront of conducting day-to-day operations of the MITR

- Enhanced communication of work activities coupled with the ALARA process, resulting in practical application of a number of specific dose reduction techniques
- A 30 percent reduction in annual collective dose from the previous year, implementation of methods to measure programmatic effectiveness, and a system to ensure that future resources are applied to sustain dose reduction activities

Security

Assistant director Lau led a renewed effort to coordinate with NNSA on a second round of upgrades for reactor security infrastructure. This year's effort resulted in the creation of one new contract, for \$120,000. The project focused on improving presentation of signals and camera images in the operations office, control room, utility room, and MIT Police dispatch center. Additional cameras, communication relays, and other hardware were installed in strategic locations. Installation was implemented by NRL's reactor operations group, Information Services and Technology, and the Security and Emergency Management Office (SEMO), and the major subcontractor was Siemens Building Technologies. Installation for the contract began in September 2010 and was completed on schedule in December 2010. It received a satisfactory review as part of DOE's annual assessment visit in June 2011.

A second contract on security was also approved by DOE, for approximately \$50,000, to conduct a tabletop radiological/security emergency exercise on the MIT campus. The "Tech Thunder" exercise was conducted on August 19, 2010, with about 160 participants, including MIT, local, state, and federal law enforcement and civil authorities. All 24 players at the main table participated actively and demonstrated their expertise, giving useful lessons-learned summaries at the conclusion. Comments from DOE and other participants were constructive and positive. Several key emergency support organizations followed up the exercise with further discussions, meetings, and training. These included NRC, MIT Police, EHS, SEMO, Cambridge Police Department, Cambridge Fire Department, Boston Police Department, Boston Federal Bureau of Investigation, Children's Hospital Boston, and Mount Auburn Hospital. Some of these organizations went on to conduct smaller-scale exercises on their own for improvement of their response procedures.

Professional Activities in Support of NRL's Mission

NRL maintains a very close working relationship with the National Organization of Test, Research, and Training Reactors (TRTR). TRTR's primary mission is education, fundamental and applied research, application of technology in areas of national concern, and improving US technological competitiveness around the world.

Appointments, Awards, and Events

NRL is pleased to report that reactor project mechanic John DiCiaccio received a 2011 Infinite Mile Award for his 30 years of outstanding and innovative service to the MIT research reactor. David Carpenter was promoted from postdoctoral associate to research

scientist. Shawn Hanvy, just out of active duty with the US Navy nuclear program, was hired as an SRO trainee for reactor instrumentation. Research scientist Sung Joong Kim left NRL to take a faculty position in the Department of Nuclear Engineering at Hanyang University, in Seoul, South Korea. However, in order to participate in future collaborations with NRL, he will continue to act as a research affiliate. Bao Truong graduated with a PhD in nuclear science and engineering in 2011, having worked for eight years since his freshman year as a licensed reactor operator/SRO.

David E. Moncton
Director