Nuclear Reactor Laboratory

The MIT Nuclear Reactor Laboratory (NRL) operates a research reactor (MITR) that has been operational since 1958. The 6 MW reactor has a long and proud tradition of forefront research and educational training in the areas of fission engineering, materials studies, neutron physics, radiation effects in biology and medicine, geochemistry, and environmental studies. It is the second-largest university research reactor in the United States, and it is the only research reactor located on the campus of a major research university that provides students with on-campus opportunities to participate in fuel irradiations and associated post-irradiation examinations. This is an increasingly rare asset in the United States and is highly valued by students as well as prospective employers in government and industry.

The NRL's primary mission is to provide faculty and students from MIT, as well as the national scientific and engineering community, with a state-of-the-art nuclear reactor facility and the infrastructure and technical expertise to enable and support its use for research, development, education, and training. The highest priority is placed on operating the research reactor in a highly professional manner that ensures the safety of MIT and NRL staff and researchers, the public, and 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 United States. This is accomplished by providing tours and lectures that describe and clarify different nuclear science and technology programs.

Since 1958, the Nuclear Reactor Lab has provided both a safe and reliable neutron source and the infrastructure to facilitate its use. Many generations of undergraduate and graduate students have benefited from their association with the laboratory. More important, it has proven itself to be a unique resource for assisting in the educational development of the next generation of nuclear engineers who will conceive, design, and manage the future of nuclear technology.

Current research programs at the NRL are mostly centered on irradiation tests of advanced materials and instrumentation in support of improved materials and fuels for current and next-generation power reactors. This effort is facilitated by a radiation environment in the MITR core that is similar to that in light-water power reactors. Building on the expertise of the NRL research staff, other research programs have also expanded in the areas of reactor design, analysis, and benchmarking to support the development of a fluoride salt-cooled high-temperature reactor (FHR) and the restart of the Transient Reactor Test Facility.

Other experimental facilities and instrumentation include radiochemistry laboratories, hot cells for dismantling or testing, a shielded hot box for handling and nondestructive testing of radioactive materials, nuclear detection equipment, delayed gamma activation analysis facilities, an inductively coupled plasma spectrometer, and a materials characterization laboratory.

Laboratory Administration

The NRL's organizational structure is comprised of three 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 regulatory environment) and developing a research program that supports current and future nuclear reactor research. These groups are Reactor Operations, Research and Services, and Administration. David E. Moncton is the director of the NRL. He and Lin-wen Hu, John Bernard, Al Queirolo, John Foster, Mary Young, and William McCarthy make up the NRL's senior management team. This leadership team works to sustain the NRL's long-standing record of safe operations, to continuously maintain and improve upon the reactor facility, to carry out research projects, to design and conduct irradiation experiments, and to provide an environment of support and excellence for researchers and students.

The NRL currently employs 47 individuals. The staff consists of six groups, including the previously mentioned senior staff members. There are eight research staff, seven technical staff, 11 technical support staff, four academic staff, three administrative support staff, two technicians, and six part-time student operators.

Educational Impact

The MITR is used extensively to support MIT's research and educational missions. Some of the principal activities are described below.

Use of the Reactor for Laboratory Courses

The Department of Nuclear Science and Engineering (NSE) is a long-standing user of one of the neutron beam ports equipped with a time-of-flight neutron spectroscopy facility for its course on radiation detection and measurement (this facility is described in more detail below). This course is required for all NSE juniors and is also taught to graduate students. Other NSE courses that incorporate MITR experiments include topics such as reactor design and operation and reactor dynamics. The Physics Department Junior Laboratory has also used the neutron time-of-flight facility for neutron spectrum and Bragg diffraction experiments. An initiative is under way to restart the NRL's subcritical graphite pile for teaching and research at both the undergraduate and graduate levels. NRL staff members are supporting Professor Kord Smith in this effort, with a goal of restarting the pile during AY2018.

Performance of Thesis Research at All Degree Levels

Since the 1950s, cutting-edge research utilizing the MITR has been conducted by faculty, students, and scientists from MIT as well as other institutions. Students especially enjoy doing thesis work on the reactor because they have the opportunity to combine theoretical knowledge acquired in the classroom with hands-on engineering. More than 200 SB, SM, and PhD theses have been completed by students who used the reactor for research on topics such as design and construction of in-core loops, low-enriched uranium (LEU) conversion of the MITR, design and analysis of fluoride salt-cooled high-temperature reactors, development of new methodology for reactor safety analysis, design of the fission converter and characterization of its beam, biological effects and medical applications of radiation, digital closed-loop control of the reactor, investigation of the linearity of the wave equation, design and demonstration of novel neutron focusing optics, demonstration of a polychromatic neutron diffractometer, and a variety of geochemical studies including analysis of meteorites and air pollution sources.

Training of Undergraduates to Operate the Reactor

More than 300 students have participated in the NRL's Student Operator Training Program. Every year, four to six undergraduates are hired to work part time as licensed reactor operators. Individuals from all majors are welcome to apply (more details on the program are provided below).

Public Outreach

The NRL offers tours of the facility together with an introductory lecture on the reactor and nuclear technology for high school students, local area colleges, and MIT parents and alumni. This past year NRL hosted 100 tours for 1,228 visitors. Also, NRL staff members collaborated with other groups across MIT to provide educational outreach activities for local middle school students.

Facilities and Resources

The MITR-II is the second of two research reactors that have been operated by the NRL. The original reactor (MITR-I) achieved criticality in 1958. It was shut down in 1973 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 license and upgrade approval were granted in 2010. Since 2008, the MITR has been designated a partner facility of the Department of Energy's (DOE) Nuclear Science User Facilities (NSUF), and it serves a wide user base from other universities, national labs, and the nuclear industry. The MITR-II is one of five high-performance research reactors in the United States that uses highly enriched uranium (HEU) fuel. A further goal for the NRL is to convert the MITR-II's fuel from HEU to LEU.

The MITR-II—the major experimental facility of the Nuclear Reactor Laboratory—is a heavy-water-reflected, light-water-cooled, and light-water-moderated nuclear reactor that utilizes flat, plate-type, finned aluminum-clad fuel elements. The average core power density is about 80 kW per liter. The maximum fast and thermal neutron fluxes available to experimenters are 1.2 × 1014 and 6 × 1013 neutrons/cm2 , respectively. Experimental facilities available at the research reactor include two medical irradiation rooms, beam ports, automatic transfer facilities (pneumatic tubes), and graphite-reflector irradiation facilities. In addition, three in-core positions are available for controlled-temperature inert gas irradiations, pressurized water loops, and custom-designed irradiation facilities (including fuel irradiations). The reactor generally operates 24 hours a day, seven days a week, except for planned outages for maintenance. The MITR-II incorporates a number of inherent (i.e., passive) safety features, including negative reactivity temperature coefficients of both 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 building. These features make it an exceptionally safe facility.

Post-irradiation Examination Facilities

The reactor containment building is equipped with an overhead polar crane with 20-ton and three-ton hooks. These cranes are used for installations and removals of in-core and other experiments. A variety of shielded transfer casks are also available for transfers. There are two hot cells in the reactor hall. The larger cell is generally used for handling and disassembly of full-height in-core experiments. This cell is accessible for installation of custom fixturing required for certain experiments. The smaller cell has been used to handle small, high-activity components and fuel from in-core experiments. A collimated gamma scan facility can be installed in the small cell. The reactor spent fuel pool is also available for storage, handling, and packaging of irradiated experiments.

Laboratory space within the reactor exclusion area includes two standard fume hoods, a hood with a perchloric acid scrubber, and an inert-atmosphere, four-port glove box with furnace. A ventilated hot box with manipulators is available for specialized post-irradiation examination (PIE) activities requiring more shielding than can be installed in the fume hoods. Standard metallurgical sample preparation (epoxy mounting, sectioning, and polishing) can be carried out on activated samples. Macro-photography, optical microscopy, and optical profilometry of irradiated specimens are also completed in this space. Other equipment used with radioactive materials in the exclusion area includes a xenon-flash thermal diffusivity instrument, HPGe gamma spectrometers, a liquid scintillation counter, and gaseous 3H and 14C collection and measurement instruments.

Members of the Research and Services group collaborated with Professor Michael Short of NSE on a successful application to the DOE Nuclear Energy University Program for a general scientific infrastructure grant. This grant provides funding during FY2017 to upgrade and expand the post-irradiation examination facilities within the reactor exclusion area with scanning electron and optical microscopy stations as well as sample preparation equipment dedicated for use with radioactive materials.

Neutron Beam Experimental Facilities

Neutron Time-of-Flight Spectrometer

NRL's web-enabled neutron time-of-flight spectrometer can be operated locally or remotely over the Internet using MIT's iLabs server architecture. Hardware and software upgrades made during previous years improved the facility's 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 greatly enhanced the educational value of the experiments. Continued incremental upgrades to the hardware and software are planned, together with outreach efforts to broaden the user base of the facility outside MIT. The thermal neutron intensity of the beam has decreased over the past several years, and this will be investigated and addressed during upcoming reactor outages.

Neutron Diffractometer

The MITR is home to a triple-axis neutron diffractometer. This facility can be used to study the structure of materials and structural changes due to irradiation in support of the in-core irradiation program. The diffractometer has been used to demonstrate and validate a new concept, that of a polychromatic powder diffractometer (originally a senior thesis by J. Morrell '17, an NSE undergraduate student). The polychromatic diffractometer is being developed in collaboration with the Idaho National Laboratory. The new concept allows simultaneous measurements of multiple Bragg diffraction peaks, thus greatly increasing the throughput of the instrument. Such an instrument is being designed for one of the small reactors at the Idaho National Lab in support of nuclear fuel development. The demonstration and validation at MIT is a cornerstone of that project. In addition, the MIT diffractometer is undergoing upgrades to allow for measurements of irradiated materials, such as those irradiated in the core of the MITR, and other samples of interest to NSUF users.

Research and Services Division

Dr. Lin-wen Hu is the director of the Research and Services division, and Dr. Gordon Kohse is the deputy director. This division consists of four groups: Reactor Experiments, Reactor Physics Analysis, Neutron Beam Applications, and Neutron Activation and Elemental Analysis. Staff members in the division lead a wide range of research projects and perform service irradiations. They have developed a robust program that assists MIT faculty, researchers, and students, as well as those outside the NRL, in their use of the reactor and its irradiation facilities. Tasks undertaken by this division include:

- Performing research in the area of irradiation effects on advanced materials and fuel
- Conducting research projects in advanced reactor technology, reactor physics analysis, and neutron science
- Mentoring undergraduate and graduate students in thesis research
- Providing researchers with a service-based infrastructure that uses 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 MITR's experimental facilities

Reactor Experiments

Dr. David Carpenter is the leader of the Reactor Experiments group. The NRL has a strong in-core experimental program that supports research in innovative instrumentation and 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 and boiling-water reactor conditions as well as specialized facilities capable of reaching very high temperatures and containing exotic compounds. With rekindled national interest on the part of DOE and the nuclear industry in next-generation nuclear power systems using novel materials and advanced forms of fuel, there is a critical need for such facilities to test material and fuel behavior in a variety of radiation environments.

The MITR is the university reactor best suited for carrying out both basic and integrated studies because of its relatively high power density (similar to that of a light-water reactor [LWR]), its capability to control chemistry and temperature to reflect prototypic conditions, its easy-access geometric configuration, its in-core space for up to three independent irradiation tests, and the proven ability of the MITR staff to design and execute proof-of-concept experiments more quickly and cost effectively than at other research reactors. Close collaborations with national labs, universities, and domestic and international organizations have put the reactor experiments program at the forefront of worldwide research on recent advances such as radiation-resistant fiber optics, fluoride salts, and silicon carbide for commercial reactor use.

Reactor Physics Analysis

Dr. Kaichao Sun leads the Reactor Physics Analysis group. This group has two main activities: technical support for MITR operation and experiments and cutting-edge research on advanced reactor concepts and innovative test reactor designs. Technical support for the MITR consists of fuel management and code development, the LEU conversion program, criticality safety calculations, and neutronics and thermal analysis calculations for safety evaluations of reactor experiments.

The group's research activities primarily focus on a compact core design for a transportable fluoride salt-cooled high-temperature reactor that features 10 MW thermal power and a once-through fuel cycle of up to five years. Substantial efforts are being devoted to evaluating the option of constructing and operating a subcritical facility with 700°C salt circulating through multiple full-width partial-height fuel assemblies adjacent to the MITR biological shield. Such an experimental facility could operate with a power density up to 30% of a commercial FHR. It would thus allow hot systems testing as a major step toward building the test/demonstration reactor. Additional research activities are dedicated to expanding the operating envelope of the Advanced Test Reactor (which are currently limited by the existing safety basis).

Neutron Beam Applications

Dr. Boris Khaykovich leads the Neutron Beam Applications group. Neutron scattering provides a powerful suite of scientific tools for studying the structure and dynamics of matter. National neutron scattering facilities are multimillion-dollar installations serving hundreds of scientists per year. New facilities such as the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory are being built around the globe. MIT has a long tradition of leadership in neutron science, extending back to Professor Clifford Shull of the MIT Physics Department who shared a Nobel Prize for pioneering neutron scattering techniques. Several years ago, under the direction of David Moncton and with the assistance of research scientist Boris Khaykovich, a major restructuring of the NRL's neutron scattering program was initiated with the following goals:

- 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 new instruments for future installation at SNS

- Establishment of a neutron scattering facility to support development of new neutron optics components designed to allow users from outside MIT to conduct early phases of some experiments more quickly than at large facilities, and a neutron optics test station
- Use of expertise established in neutron beam applications to support development of experimental methods for exploiting compact x-ray sources

Neutron Activation and Elemental Analysis

Dr. Michael Ames is the leader of the Neutron Activation and Elemental Analysis group. The NRL has several facilities that are used for trace elemental analysis and for the production and analysis of radioisotopes. The primary analytical method employed is neutron activation analysis (NAA), which first uses neutrons from the reactor to create radioactive isotopes in sample materials. Then gamma spectroscopy is performed on the activated samples to quantify the material's original elemental composition. The MITR is equipped with two pneumatic systems that transport samples to locations near the reactor core, where the thermal neutron fluxes are up to 5.6 × 1013 n/cm2/s. A third, manual facility is also available in which a large number of samples can be irradiated simultaneously in a thermal neutron flux up to 1.2 × 1013 n/cm2/s. The NRL's NAA laboratory is equipped with high-purity germanium gamma detectors and Canberra's Genie 2000 software for gamma spectroscopy. The NAA components can be applied separately to (1) produce radionuclides in a variety of forms for use as tracers in physical, chemical, and biological fate and transport studies; (2) induce neutron damage in sample materials; and (3) detect, identify, and measure the presence of radioactivity in natural or manmade materials. This analytical method is often used to detect and quantify trace elements that are difficult to measure by other means but which are of particular interest in nuclear systems. NAA is performed on materials that are part of planned in-core experiments so that the materials' in-core behavior and post-irradiation dose levels can be predicted. The Neutron Activation and Elemental Analysis group also operates an inductively coupled plasma–optical emission spectrometer (ICP-OES). The ICP-OES complements NAA as it can be used for elements that are not suitable for such analyses.

The neutron activation analysis and inductively coupled plasma facilities have been used in research- and service-oriented collaborations with several MIT laboratories as well as with other educational and research institutions. The NRL makes these facilities and technical expertise in these areas available to researchers from MIT, other universities, private and governmental laboratories, industry, and hospitals.

Research Programs

The major emphasis of the Research and Services division is on in-core experiments that support current and next-generation nuclear power reactor technology development. Several of these programs have related elements taking advantage of the expertise of the Reactor Physics Analysis, Neutron Beam Applications, and Neutron Activation and Elemental Analysis groups. In addition, there are research programs, such as the LEU conversion project, that do not involve any reactor experiment activity. Following a general overview of the in-core experimental program, this section offers brief descriptions of all of the lab's ongoing research programs.

The NRL's in-core experimental program has been seamlessly integrated into various US industry- and government-funded programs, such as NSUF, the Accident Tolerant Fuel Program, the Advanced Reactor Program, and other DOE Office of Nuclear Energy initiatives. The MITR was designated as NSUF's first partner facility and has played a key role in performing various NSUF-funded irradiation experiments since 2008. The proven capability of NRL staff to design and successfully execute complex proof-of-concept experiments and to deploy in-core loops for studying both LWR and non-LWR coolants and materials at high temperatures is an essential national capability. NRL's unique expertise and capabilities have established its reputation to rapidly demonstrate the survivability of new sensors and instrumentation components and to develop rigs for irradiation testing. In addition, it is anticipated that several recently launched, privately funded advanced reactor development initiatives will seek support from the NRL to study their chosen materials and fuels. There are also international groups interested in the MITR's capabilities. For example, the fluoride salt-cooled high-temperature reactor program has attracted substantial support from a large Chinese development program.

Factors that have made NRL's in-core program successful include:

- The high neutron flux, the flexible core design, and the MITR's 24-hour-a-day, seven-day-a-week operating schedule
- The expertise of NRL staff research scientists and engineers with the assistance of MIT undergraduate and graduate students
- Recent upgrades to the infrastructure of the MITR as a result of the DOE Nuclear Energy University Program and other programs
- The continuing collaboration with the NSUF program, which is to the benefit of both the Idaho National Laboratory and the Nuclear Reactor Laboratory

Westinghouse Accident-Tolerant Fuel Project

The Fukushima Daiichi Nuclear Power Plant accident has created very strong interest in finding alternatives to the currently used Zircaloy™ fuel cladding. This interest is driven by the problematic behavior of Zircaloy in high-temperature steam, where rapid reactions can occur with the generation of hydrogen and heat, compromising the ability of the cladding to maintain a "coolable geometry" for the fuel pins.

Westinghouse is leading a multi-institutional effort to design and demonstrate an advanced fuel concept with improved post-accident behavior that can be rapidly commercialized. This research is funded by the DOE Nuclear Engineering Enabling Technology program. The effort involves changes to both the fuel meat and the cladding. MIT's NRL is conducting irradiation tests of candidate cladding materials and associated end-plug sealing methods. A leading replacement candidate is a multi-layer SiC/SiC composite tubing with or without engineered coatings to enhance corrosion resistance. Large-scale manufacture and bonding of this tubing may be an obstacle to near-term commercial deployment, so alternate clad concepts based on Zircaloy tubes coated with MAX phases or glassy iron-based materials are also being considered, together with "hybrid" concepts involving composite layers in conjunction with metal alloy tubing.

The final five-year phase of the Accident-Tolerant Fuel project is currently under way with the goal of producing a "lead test assembly" for testing in an operating pressurized water reactor. Under this program, irradiations of optimized fuel cladding will begin in August 2017. In a related effort, accident-tolerant fuel cladding samples from Oak Ridge National Laboratory were exposed at LWR temperatures in an inert gas environment in-core from October to December 2016. The same samples were then exposed in the water loop from January through June 2017. The water loop irradiation was shared with additional accident-tolerant cladding samples from Ceramic Tubular Products under first-round funding from a new DOE initiative, the Gateway for Accelerated Innovation in Nuclear (GAIN) program.

In-Core Sensor Irradiation Test

Current-generation light water reactors and advanced nuclear reactors have harsh environments in and near the reactor core that can severely challenge materials performance and limit their operational life. As a result, several DOE Office of Nuclear Energy research programs require that the long-duration radiation performance of fuel and materials be demonstrated. Such demonstrations require enhanced instrumentation to detect microstructural changes under irradiation conditions with unprecedented accuracy and resolution. Recent work supported by several Office of Nuclear Energy research programs has been investigating ultrasonic transducers for both under sodium viewing and in-service inspection measurements near the core. A long-term irradiation based on ultrasonic transducers was completed in FY2015, followed by post-irradiation examination and planning of the next irradiation test in FY2016.

A second in-core instrumentation test—designated ULTRA2—was installed in the reactor in April 2017. In addition to a second generation of ultrasonic transducers, this test included fiber optic temperature sensors provided by the University of Pittsburgh and the French Centre d'Energie Atomique. All of these instruments are being read in real time, allowing for inter-comparisons among the advanced sensors and benchmarking against well-characterized thermocouples. The ultrasonic and fiber optic sensors have the potential to provide temperature data over a range of locations from a single sensor. They can also be used to investigate other parameters such as mechanical strain, pressure, and gas composition. The testing is scheduled to continue until March 2018.

Materials and Fluoride Salt Irradiation

MIT, the University of Wisconsin, and the University of California, Berkeley, initiated a cooperative integrated research project to develop the path forward to a test reactor and ultimately a commercial fluoride salt-cooled high-temperature reactor. The second of two three-year projects funded by the DOE Nuclear Energy University Program is currently under way with MIT in the leadership role. The FHR is a new reactor concept that combines high-temperature graphite-matrix coated particle fuel developed for high-temperature gas-cooled reactors (fuel failure temperature above 1,650°C), liquid salts developed for molten salt reactors (boiling point above 1,400°C), safety systems originating from sodium fast reactors, and Brayton power cycle technology. This combination of existing technologies may enable the development of a large power reactor wherein catastrophic accidents, such as the Fukushima accident, would not be credible because the FHR fuel and coolant combination may allow decay heat to conduct to the environment without massive fuel failure even with large-scale structural and system failures. One of the major technical challenges is the corrosion behavior of fluoride salt (LiF-BeF2 known as FLiBe) and reactor fuel/materials in a radiation environment. Testing in the MITR addresses this concern and is also intended to help verify models for tritium generation and transport.

The third in a series of FLiBe salt irradiation tests was conducted in the reactor core for 950 hours in November and December 2016. This test included graphite and carbon/carbon-composite samples from US and Chinese sources, the latter under funding from the Chinese Academy of Sciences. This irradiation incorporated improvements based on two earlier irradiations, including an electrical heater to maintain minimum temperatures as a means of preventing gamma-irradiation-driven release of free fluorine from the FLiBe during unplanned reactor shutdowns. As with the earlier FLiBe irradiations, tritium and short-half-life irradiation products were monitored during the run. The rig is currently in the process of disassembly for sample extraction in the reactor floor hot cell. PIE and analyses of samples from the first two salt irradiation tests continued during FY2017.

NRL staff also initiated two research projects to accelerate the FHR technology demonstration: design of a transportable FHR and design of a sub-critical facility at the MITR to support testing of a variety of FLiBe salt fuel and materials technologies. In the facility, 700°C salt would circulate through multiple full-width, partial-height fuel assemblies operating with a power density up to 30% of a reference FHR. Recent research activities focus on the detailed thermal-hydraulics design of the sub-critical facility for both nominal (forced convection) and loss-of-primary-flow (natural convection and/or fully drained) conditions. In particular, heat pipes placed at the periphery of the active zone have been shown to be satisfactory as a back-up heat removal system—ensuring a sufficient thermal-hydraulic safety margin without affecting the routine MITR operation. Further optimization of the heat pipe arrangement is being studied.

Transient Reactor Test Facility Restart Support

The Transient Reactor Test Facility (TREAT), located at the Idaho National Laboratory (INL), has been used to study light water reactor and sodium-cooled fast reactor fuel under a variety of transient conditions. It was last operated in 1994, but is currently being prepared for a restart, with the goal of renewed operation by 2018. Members of the NRL Research and Services division are part of an integrated research project funded by DOE. This effort includes developing an instrumentation plan for TREAT and designing and operating a test instrumentation facility for use in the MITR and the Oregon State TRIGA Reactor. Work completed in FY2017 includes planning for MITR irradiation tests at low power, selection of possible sensors for use in TREAT core instrumentation deployment and testing, and coordination with TREAT staff to conduct testing of new neutron and gamma detectors in the MITR to complement instrumentation plans and a benchmarking study.

Low Enrichment Uranium Conversion Program

The goal of this research program is to convert the MITR from HEU to LEU fuel. NRL staff aims to carry out the first conversion among the remaining five high-performance reactors in the United States, adopting a special high-density LEU fuel currently undergoing qualification tests. While the fuel development program sponsored by the

National Nuclear Security Administration has experienced delays, the MITR remains a valuable reactor to provide the first demonstration of this important new fuel, which is critical to the mission of eliminating weapons-grade HEU from civilian use worldwide. A major objective of the MITR's LEU conversion is to maintain the HEU core performance. A previous feasibility study showed that a power upgrade to 7 MW is necessary.

After a new MITR LEU U-10Mo monolithic fuel design with graded fuel meat thickness was developed, LEU conversion impacts on in-core experiments and accident analyses were completed. During FY2017, the nuclear and thermal-hydraulic design was evaluated and confirmed to meet operational safety requirements. A preliminary safety analysis report on LEU fuel conversion was completed and is scheduled to be submitted to the US Nuclear Regulatory Commission in FY2018. Transition cycles to reach an equilibrium core using the new LEU fuel design are ongoing as part of the startup plan. Work on detailed MITR LEU fuel specifications and fabrication tolerances will commence in collaboration with the reactor conversion and fuel fabrication pillars of the Reduced Enrichment Research and Test Reactors Program. In addition to the U-10Mo plate-type fuel study, another feasibility study was completed for converting the MITR using UZrH rod-type fuel. It was concluded that such an option is not feasible due to the limited safety margin.

Neutron Optics Research Program

The Neutron Beam Applications group conducts neutron optics research aimed at developing specialized neutron-focusing optics for scattering and imaging applications, demonstrating improved magnetic imaging with polarized neutrons, and developing novel technology for manufacturing neutron guides. These studies are funded by DOE, the Department of Commerce (DOC), and INL. A DOE-funded collaboration with a small company (Dawn Research Inc.) resulted in the demonstration of sections of neutron guides that could be used in future neutron scattering facilities. Another DOE-funded project with a small company (ENI) resulted in the demonstration of axisymmetric optics. In addition, a DOC-funded collaborative project with the National Institute of Standards and Technology resulted in the demonstration of novel modes of neutron imaging, such as a polarized neutron microscope and a focusing neutron interferometer for spatially resolved small angle scattering. The polarized neutron microscope was used to study modern quantum magnets, including under cryogenic temperatures and pressure. The collaborative project with the Idaho National Laboratory could revolutionize the way in which the lab conducts neutron imaging of spent nuclear fuel in order to significantly improve its post-irradiation examination capabilities.

Services

Irradiations and experiments conducted over the past year include the following:

- Activation of gold-198 seeds for brachytherapy
- Activation of uranium foils for detector calibration at the Los Alamos National Laboratory and the Ciambrone Laboratory at Patrick Air Force Base
- Activation of platinum targets for activation yield studies at the Los Alamos National Laboratory

- Activation of ocean sediments for the University of British Columbia
- Activation of fusion laminate samples to study radiation damage effects for Composite Technology Development
- Activation of cesium iodide crystal to study radiation damage effects for Radiation Monitoring Devices
- Activation of cement samples to develop crack detection devices for Radiation Monitoring Devices
- Activation of silicon, sapphire, and Teflon samples and NAA standards for the University of Alabama
- Support of superconducting REMCO ribbon samples for MIT Plasma Science and Fusion Center to investigate changes of properties with neutron damage
- Activation of metallic single-crystal samples for the MIT Department of Nuclear Science and Engineering
- Neutron activation of silicon wafers to study radiation-induced photonic defects for the MIT Materials Processing Center
- Activation and NAA of FLiBe salt samples, carbon composites, and silicon carbide materials for the Shanghai Institute of Applied Physics in support of the fluoride-salt-cooled high-temperature reactors research project
- Activation and NAA of various sample materials and structural components for the Westinghouse Accident Tolerant Fuel Experiment
- Activation of uranium and plutonium targets for detailed fission product yield measurements in the thermal neutron beam facility at the Los Alamos National Laboratory
- Experiments in reactor building in the MIT Department of Physics to determine the background neutron flux for future reactor neutrino detection
- 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, 22.011 Seminar in Nuclear Science and Engineering, 22.921 Nuclear Power Plant Dynamics and Control, and the reactor technology course for nuclear power executives).

Reactor Operations Division

Leadership of the Reactor Operations division is provided by Al Queirolo, director of reactor operations; John Foster, deputy director of reactor operations; Edward Lau, assistant director of reactor operations; and Sarah Don, reactor superintendent. The Reactor Operations group is responsible for supporting all laboratory activities, with priority given to operation and maintenance of the 6 MW research reactor. The group consists of full-time employees and part-time undergraduate students. Almost all of the members of the group are licensed by the NRC, and most hold a senior reactor operator (SRO) license. These licensed individuals perform reactor shift duties to support the reactor's operating schedule. In addition, there is one full-time project mechanic to support reactor mechanical maintenance. In FY2017, Reactor Operations supported NRL research projects in the following areas: pressurized water loop facilities, molten fluoride salt irradiations, high-temperature in-core sample assembly capsule irradiations, 4DH4 diffractometers, and 4DH1 student spectrometers.

The MITR-II completed its 59th year of operation (its 42nd since the 1974–1975 upgrade and overhaul). The reactor was maintained at a full power of 5.5 MW or higher. Total energy output from July 2016 to June 2017 was 31,034 megawatt-hours. This translates to 5,260 hours of operation at full power.

Major NRL maintenance and upgrade projects accomplished in FY2017 included the following:

- A splash guard was installed on the core purge suction in the core tank.
- ASCO solenoid valves for various control and safety functions in the reactor's mechanical system were replaced.
- The remaining power supplies for the nuclear safety amplifiers on channels 1, 2, 4, 5, and 6 were replaced.
- Wiring was installed to upgrade the electric power supply in Room NW12-007 in coordination with MIT Information Systems and Technology (IS&T).
- All stack base exhaust air roughing filters and HEPA (high-efficiency particulate air) filters were replaced in coordination with MIT Facilities.
- The steam check valves for automatic transfer of the Building NW12 steam supply to the Central Utilities Plant if necessary (i.e., if steam pressure from the on-site NW12 boiler drops below a check valve's setting) were replaced in coordination with MIT Facilities.
- Installation of 19 cameras for the first phase of the NRL security camera upgrade was completed in coordination with IS&T.
- Floor tiles in the NW12 reception area containing asbestos were removed in coordination with MIT Facilities. New floor tiles were then installed.
- The HV-50 city water makeup solenoid valve was replaced.
- The magnet for shim blade #1 was replaced.

- The primary ion column and its inlet and outlet filters were replaced.
- The regulating rod was replaced and its drive was refurbished.
- The fan in core purge blower #1 was replaced after it had seized.
- Shim blade #5 and its associated magnet and drive were replaced.
- Intake ventilation system equipment, including the intake fan's motor, bearings, pulley wheels (sheaves), and belts, was replaced by MIT Facilities.
- Mass flow stack base instrumentation and return lines leading back into the stack were installed.
- Unshielded RG55 connecting cables between the channel #2 Keithley 26000 unit and the scram amplifier were replaced with shielded RG400 cable. In addition, and the connectors were replaced.
- Installation of the upgraded cathodic protection system was completed in coordination with MIT Facilities and contractors.
- All iris identification units were replaced with upgraded models in coordination with IS&T.

Many other routine and preventive maintenance activities were also scheduled and completed throughout the fiscal year for experiments and for reactor operations.

Student Operator Training Program

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. On completion of the training program, students take a two-day examination administered by the NRC (one day written, one day oral). Successful candidates receive a reactor operator license and are employed part time. After the students gain experience, most are offered the opportunity to participate in a second training program that leads to a senior reactor operator license. This training program is an excellent educational opportunity for undergraduate students because it combines theoretical study with hands-on experience—squarely 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 have regularly reported that it was one of the high points of their MIT experience.

From July 2016 through June 2017, two sets of NRC examinations were administered at MIT; there were two candidates for reactor operator licenses, one in October 2016 and the other in February 2017. Three undergraduate students are currently applying for reactor operator licenses and are in training for the next NRC examinations, scheduled for September 2017.

Operational Safety

The NRC's Office of Nuclear Reactor Regulation has oversight responsibility for program management, inspections, and operator licensing for all test and research reactors, including the MITR-II. Many years ago, MIT established its own means of ensuring safe operation of the nuclear reactor by appointing independent experts to a reactor safeguards committee. The committee—whose members are from both MIT and industry—is ultimately responsible for overseeing all nuclear safety issues related to the reactor and ensuring that reactor operation is consistent with MIT policies as well as with NRC rules, operating procedures, and licensing requirements. 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 the NRL's management team. An environment of cooperation and attention to detail among reactor employees and experimenters regarding all reactor safety matters is essential. Because of this approach to safety, each and every individual employed at the reactor can be proud of the NRL's outstanding safety and operating record, which is seen in the results of NRC inspections.

Security

In FY2017, NRL revised and updated the reactor's physical security plan and provided written responses to NRC questions about the plan. During the year, 19 new cameras were installed and tested satisfactorily, replacing most of the original cameras in the respective locations. These cameras, considered the first phase of an overall camera upgrade, are currently in operation in combination with the original system from 2009. A petition for an exception to the MIT camera image policy has been reviewed by the Special Subcommittee for Security of the MIT Reactor Safeguards Committee and submitted to MIT's Information Technology Policy Committee, whose decision is still pending.

Additionally, the NRL iris reader system was completely replaced, upgraded with newer hardware and software. A "guard tour reader" system was also installed, allowing self-checking, more efficient logging of MIT Police patrols, and early notifications as needed. Both systems are in service, enhancing compliance with the physical security plan.

In FY2017, MIT IS&T assumed responsibility for repair and maintenance of the NRL's security system, replacing the former MIT Security and Emergency Management Office. The Nuclear Reactor Laboratory continues to initiate all work requests, each of which receives a written corrective action, thereby tracking the performance of the system. In January 2017, an annual system-wide test was completed satisfactorily in coordination with the MIT Police, IS&T, and Siemens Building Technologies. Reports were completed for documentation purposes and NRC inspections. The reactor's security hardware has been properly maintained and continues to meet all NRC regulatory requirements.

Annual training of the MIT Police took on a new format starting in January 2016 and continuing into 2017. The training session, which included blood-borne pathogen training, was conducted weekly, with MIT Police officers being rotated through half a dozen at a time until all of the officers had completed training (by April 2017). One emergency exercise (combining radiological and medical scenarios) was conducted in December 2016 involving the MIT Police, the MIT Office of Emergency Management and Business Continuity, and other off-site support agencies, including the Cambridge Fire Department and Mount Auburn Hospital.

Environment, Health, and Safety Activities

The NRL coordinated with MIT Facilities and the MIT Capital Renewal Program on weekly planning for engineering design and development of the replacement and upgrade of the NW12 fire alarm and fire protection system. This effort included a review of fire barrier walls as well as a review of the aging ceiling tiles within the one-story section of NW12.

In FY2017, all EHS level II inspections were completed on time and performed in coordination with NRL's EHS lead contact William McCarthy and EHS safety officer Joseph MacLeod. Many labs were provided with information on findings related to eye wash stations that are not plumbed but continue to be equipped with eye wash squeeze bottles. EHS has taken note of these findings and remains supportive of the transition to plumbed stations.

In coordination with EHS, detailed planning and implementation was conducted for the successful upgrade of the NW12 containment building cathodic protection system. This project involved preparation and drilling of 19 holes that were 15 feet or deeper for installation of the system's electrodes. This work was successfully completed in April 2017 ahead of schedule and with no challenges to the numerous underground utilities.

Reactor Radiation Protection

Radiation protection coverage is provided by the Reactor Radiation Protection Program of the Environment, Health, and Safety Office (EHS). Although this is a separate organization within MIT, it is very responsive to the NRL management team. Personnel include a deputy director who serves as the reactor radiation protection officer (William McCarthy), two EHS officers, one full-time and three part-time technicians, 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 the lab are as low as reasonably achievable in accordance with applicable regulations and Institute committees. An EHS officer (Joe MacLeod from the safety program) serves as the NRL-EHS team member under the EHS management system organizational structure and provides expertise on industrial safety matters. The NRL has a robust ALARA (as low as reasonably achievable) program. ALARA-related policies, procedures, and metrics have resulted in improvements to the facility's day-to-day safety and efficiency.

New stack radiation monitors purchased with funds from a DOE Nuclear Energy University Program grant were installed in a new outbuilding. These monitors replaced the older equipment, which had outdated technology. Over the next year, the system will be calibrated, characterized, and, when fully functioning, integrated with the NRL's existing control monitoring system.

Appointments, Awards, and Events

Dr. Lin-wen Hu was promoted to senior research scientist.

Guiqui (Tony) Zheng was promoted from postdoctoral associate to research scientist.

Al Queirolo completed his qualifications and assumed the full duties of director of reactor operations.

John Foster filled the newly created position of deputy director of reactor operations.

Sarah Don, former NSE graduate student and reactor operator, was promoted to reactor superintendent.

Kathleen O'Connell, senior administrative assistant to Dr. Moncton, retired from MIT.

Kathleen Fitzgerald joined the NRL staff as senior administrative assistant to Dr. Moncton and Dr. Hu.

The NRL added two new academic staff members: postdoctoral associates Akshay Dave and Durgesh Rai. In addition, the lab hosted three visiting students: Yu-Jou Wang, Wenwen Zhang, and Chenzhen Yang.

William McCarthy, EHS deputy director and reactor radiation protection officer, was presented the Excellence Award for Innovative Solutions for the ALARA program at NRL.

Edward Lau, assistant director of reactor operations, was the recipient of an Outstanding Partnership Award from the Reactor Technology Course for Utility Executives in gratitude for his 25 years of service.

In November 2016, Dr. Lin-wen Hu and Dr. David Carpenter hosted a workshop at MIT on TREAT reactor modeling, simulation, benchmarking, and instrumentation. Research progress on this DOE-sponsored integrated research project was presented and reviewed. More than 30 attendees participated in the workshop, including representatives from MIT, the University of Michigan, Oregon State University, Idaho National Laboratory, the Oak Ridge National Laboratory, the Argonne National Laboratory, AREVA, TerraPower LLC, and the Department of Energy.

David E. Moncton
Director