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 power-reactor-relevant materials and fuel irradiations and associated post-irradiation examinations. This is an increasingly rare asset in the US 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 both a state-of-the-art nuclear reactor facility and the infrastructure 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.

For the past 58 years, the NRL 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 importantly, 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 research 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 (TREAT).

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 comprises 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. 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 laboratory'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 45 individuals. The staff consists of six groups, including the previously mentioned seven senior staff members. There are also seven research staff, seven technical staff, 11 technical support staff, four academic staff, three administrative support staff, two technicians, and four part-time student operators.

Educational Impact

The MITR reactor has been and continues to be used extensively to support MIT's research and educational missions. The principal activities that support education and training include:

- 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 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 incorporate MITR experiments, including ones on reactor design and operation and reactor dynamics. The Physics Department Junior Laboratory has also used the time-of-flight facility for neutron spectrum and Bragg diffraction experiments.
- 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 the theoretical knowledge they have 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, fission converter design and beam characterization, and the biological effects and medical applications of radiation.
- 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.

- 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 the lab hosted 150 tours for 1,600 visitors. Also, NRL staff members participated in MIT outreach events associated with Institute anniversaries and the Cambridge Science Fair.

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 permission were granted in 2010. The MITR-II is one of five high-performance research reactors in the United States that uses high-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, NRL's major experimental facility, 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 1.2×10^{14} and 6×10^{13} neutrons/cm^2, 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 3-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 the 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 irradiated experiment storage, handling, and packaging.

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 a 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 ^{3}H and ^{14}C collection and measurement instruments.

During FY2016, members of the Research and Services group collaborated with Professor Michael Short of NSE on a successful application to the US Department of Energy (DOE) Nuclear Energy University Program for a general scientific infrastructure grant. This grant will provide funding to upgrade and expand the PIE facilities within the reactor exclusion area.

Neutron Beam Experimental Facilities

The 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 conducted. Continued incremental improvements to the hardware and software are planned, together with outreach efforts to broaden the user base of the facility outside MIT.

The MIT reactor 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 reactor's in-core irradiation program. Currently, the diffractometer is undergoing upgrades to demonstrate and validate a new concept, that of a polychromatic diffractometer. The polychromatic diffractometer is being developed in collaboration with the Idaho National Laboratory. The new concept should allow 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 Idaho National Lab in support of nuclear fuel development. The demonstration and validation at MIT will be a cornerstone of that project.

Research and Services

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 the 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 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 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 of which are intended to use novel materials and advanced forms of fuel, facilities are needed to test material and fuel behavior in a variety of radiation environments. The MITR is the university reactor best suited for carrying out such basic studies because of its relatively high power density (similar to that of a light-water reactor [LWR]), its capability to control chemistry and thermal conditions to reflect prototypic conditions, its easy-access geometric configuration, its in-core space for up to three independent irradiation tests, and the proven capability of the MITR staff to design and execute proof-of-concept experiments more quickly than at other research reactors.

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, and neutronics calculations for safety evaluations of in-core 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.

Neutron Beam Applications

Dr. Boris Khaykovich leads the Neutron Beam Applications group. Neutron scattering is 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, who shared a Nobel Prize for pioneering neutron scattering techniques. Several years ago, under the direction of David Moncton and with the assistance of Dr. 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 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
- 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 5.6×10^{13} n/cm^2/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 1.2×10^{13} n/cm^2/s. The NRL's NAA laboratory is equipped with high-purity germanium gamma detectors and Canberra's Genie 2000 software for gamma spectroscopy. The two 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. The 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. These analytical methods are 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 NRL makes its facilities and expertise in these areas available to researchers from MIT, other universities, private and governmental laboratories, industry, and hospitals. The NAA and the ICP-OES have been used in research- and service-oriented collaborations with several MIT laboratories as well as with other educational and research institutions.

Research Programs

The major emphasis of the Research and Services group 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 NRL'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 the Nuclear Science User Facilities (NSUF) program, 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 the 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 and will remain an essential national capability. The 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 efforts in need of 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 the 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 NRL

The demand for the NRL's MITR experimental facilities has increased because the cost of using the MITR is lower than that of national laboratory facilities, we provide quick turnaround in experiment design and execution, and the track record of recent experiments is excellent.

Westinghouse Accident Tolerant Fuel Project

The Fukushima 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 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; the NRL is conducting irradiation tests of candidate cladding materials and associated end plug sealing methods. A leading replacement candidate is 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.

An irradiation containing examples of many of these clad material candidates took place from December 2015 through June 2016 in the MITR in-core water loop under pressurized water reactor (PWR) conditions. In addition to new samples, several tubes that were previously irradiated in the MITR water loop and showed promising behavior were returned to the reactor. For this irradiation, the loop capability was enhanced by increasing the maximum hydrogen concentration achievable to match the current practice in PWRs. Loop operation was stable throughout the irradiation period, and the sample capsules were successfully transferred to the reactor floor hot cell for disassembly and sample extraction. Post-irradiation examination of these samples will be carried out from July to September 2016.

Westinghouse is negotiating the final five-year phase of the Accident Tolerant Fuel Program with the goal of producing a "lead test assembly" for testing in an operating PWR. Under this program, continuing irradiations are planned in the MITR water loop beginning in April 2017. In the interim, accident-tolerant fuel cladding samples from Ceramic Tubular Products Inc. and from Oak Ridge National Laboratory will be exposed in the water loop between October 2016 and March 2017.

Ultrasonic Transducer 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.

No in-core irradiations were performed under this program during FY2016. Experimental activities were limited to follow-up PIE of samples of ultrasonic transducer materials. In addition, planning of a second instrumented, in-core sensor irradiation was completed with funding from NSUF. The test will again include ultrasonic transducers with thermocouples and other sensors providing supplementary and comparison data. Fiber-optic temperature sensors will also be included, with real-time data readout. This irradiation is projected to be in the reactor from January to December 2017.

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 ($LiF-BeF_2$ 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.

Based on the results of two earlier FLiBe salt irradiations under inert gas in the MITR, planning for two new irradiations was undertaken in FY2016. DOE funding will be used for irradiations primarily aimed at understanding tritium evolution and transport and the behavior of short-lived, gaseous, radioactive species generated in salt under neutron irradiation. With additional funding from the Chinese Academy of Sciences, investigation of gaseous radioactive species transport and low fluence corrosion behavior of a variety of materials will continue. The mechanical design of the necessary irradiation facility and agreement on a test matrix are complete, and sample materials have been received from China. The irradiation is planned for November and December 2016.

NRL staff also initiated two research projects to accelerate the FHR technology demonstration: design of a transportable FHR and design of a subcritical 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. In FY2016, a preliminary neutronic design was completed and several advantages of this approach were elaborated. Capital cost is significantly reduced relative to a stand-alone test reactor through sharing of infrastructure, operating personnel, and administrative management expenses with the existing MITR. Furthermore, licensing a subcritical assembly as an experimental facility at the MITR will be much easier than licensing an advanced reactor concept while still allowing research into the integrated effect of an advanced reactor core design that includes neutronics, thermal hydraulics, materials, and systems designs.

Transient Reactor Test Facility Support

The Transient Reactor Test Facility (TREAT), located at the Idaho National Laboratory, has been used to study LWR 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 group 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. Examples of work completed in FY2016 are as follows:

- Planning for irradiation tests at the MIT research reactor, including scoping of reactor low-power open-tank capabilities, block-out scheduling for experiment time, and surveys of available in- and near-core positions
- Identifying parameter monitoring needs and how these needs have been affected by the TREAT restart program (e.g., upgrades to the reactor data acquisition systems and planned experiment data acquisition systems)
- Initial selection and differentiation of possible sensors for use in the TREAT core based on open literature, TREAT operator experience, and expert collaborator advice on the latest available technologies
- Instrumentation deployment and testing from the MITR to various TREAT core positions and near-core instrumentation ports
- Coordination with TREAT staff to conduct testing of a new neutron detector 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 seeks 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, and a previous feasibility study showed that a power upgrade to 7 MW was 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 were identified and accident analyses were completed. During FY2016, the nuclear and thermal-hydraulic design has been evaluated and confirmed to meet operational safety requirements. In parallel to the U-10Mo plate-type fuel study, another feasibility study was completed in FY2016 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 technologies for manufacturing neutron guides. These studies are funded by DOE, the Department of Commerce (DOC), and the Idaho National Laboratory. 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. 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 polarized neutron microscopes and focusing neutron interferometers for spatially resolved small angle scattering. 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.

Compact X-ray Light Source

The Compact X-ray Light Source (CXLS) combines a small linear accelerator with a powerful laser to produce an x-ray beam with synchrotron-like properties. The CXLS concept was created at MIT and is now being further developed at Arizona State University, which is constructing new laboratories to house the instrument that will be ready in early 2018. In the interim, the CXLS is being assembled at MIT Bates Laboratory and operated to demonstrate particular x-ray science experiments. Five demonstration experiments are planned during the 12- to 18-month running period at MIT Bates. These experiments include x-ray phase contrast medical imaging supported by the Mayo Clinic and research and development toward a compact x-ray free-electron laser supported by the National Science Foundation. The NRL is developing x-ray optics for these and other experiments.

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 ocean sediments for the Woods Hole Oceanographic Institute and the University of British Columbia
- Activation of silicon, sapphire, and Teflon samples and NAA standards for the University of Alabama
- Activation of damage studies and NAA of superconducting REMCO ribbon samples for the 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
- Activation and NAA of salt samples for the MIT Department of Nuclear Science and Engineering
- Activation and NAA of carbon composite and silicon carbide samples for the Shanghai Institute of Applied Physics in support of a research project focused on FHRs
- Activation and NAA of various sample materials and structural components for the Westinghouse Accident Tolerant Fuel Program
- 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, 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), and for the Physics Department’s 8.13 Junior Lab

Reactor Operations

Leadership of the Reactor Operations division is provided by Al Queirolo, director of reactor operations designate; John Foster, interim director of reactor operations; Edward Lau, assistant director of reactor operations; and Sarah Don, interim 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 group's members 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 FY2016, 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 58th year of operation (its 41st 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 2015 to June 2016 was 24,565 megawatt-hours. This translates to 4,163 hours of operation at full power.

Major NRL maintenance and upgrade projects accomplished in FY2016 included the following:

- Scheduled maintenance and cleaning of the 13.8 kilovolt feeder lines and the main electrical distribution system were performed in coordination with MIT Facilities.
- The auxiliary intake damper controls were upgraded, including the addition of remote operation from the control room.
- New power supply controls for the main airlock's hydraulic system were installed.
- An isolation device for the auto controller pre-amplifier was installed.
- The air handler unit for NW12 (AHU-1) was replaced in coordination with MIT Facilities.
- The magnets for shim blades #4 and #6 were replaced, and refurbished blade drive mechanisms were installed.
- A new containment building penetration for future use by the secondary water monitors was installed and tested.
- A digital logbook was implemented.
- A shed for eventual housing of newly acquired stack effluent monitoring equipment was installed.
- A reactor building ventilation steam control valve was replaced in coordination with MIT Facilities.
- A new 15-volt power supply for safety channel #3 was designed and installed.
- New sampling probes at an elevation of 20 feet in the effluent stack were installed.
- Bernoulli filter B was rebuilt.
- The D2O recombiner blower was replaced.
- Survey measurements for all underground services in the backyard area were performed in coordination with MIT Facilities.

- Neutron transmission testing of six newly acquired shim blades was performed.

Many other routine maintenance 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 2015 through June 2016, two sets of NRC examinations were administered at MIT. There were two candidates for an SRO license in both October 2015 and March 2016. Three MIT undergraduate students are applying for reactor operator licenses and are in training for the next NRC examinations, scheduled for October 2016.

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 FY2016, the MIT Security and Emergency Management Office (SEMO) continued to have responsibility for repair and maintenance of NRL's security system. The NRL initiates all work requests, and each of these requests involves a written corrective action; thus, the performance of the system is tracked. In December 2015, an annual system-wide test was completed satisfactorily in coordination with the MIT Police, SEMO, and Siemens Building Technologies. Reports were completed by Edward Lau for documentation purposes and for NRC inspections. The reactor's security hardware has been properly maintained and continues to meet all NRC regulatory requirements.

Throughout the year, the most common types of work requests involved surveillance cameras. The camera system, including recording hardware, operates continuously and is more than eight years old. It has experienced the expected aging seen in similar systems. In 2015, the MIT Reactor Safeguards Committee approved the first phase of an upgrade of the system after reviewing input from MIT Information Systems and Technology, SEMO, and Reactor Operations. The upgrade improves the technology of the cameras and communication with the MIT Police. The first phase is now near completion, with most of the installation taking place during FY2016.

Another common type of work request involved the iris reader system. This system is also approaching eight years old and has begun to experience aging effects as well. The NRL is now working with SEMO to plan an upgrade.

Annual training of the MIT Police took on a new format starting in January 2016. 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 2016). Three emergency exercises (radiological, medical, and fire evacuation) were conducted between December 2015 and January 2016 involving the MIT Police and other off-site support agencies. Written reports summarizing lessons learned were reviewed during the biennial meeting between the MIT Police and NRL's senior management in April 2016.

Environment, Health, and Safety Activities

In FY2016, Edward Lau, who is the Environment, Health, and Safety Office (EHS) coordinator, oversaw the completion of safety upgrades for all NRL machine lathes. These lathes are now equipped with debris shields and emergency stop buttons. Additionally, the access ladder for the reactor containment building's polar crane was replaced and equipped with fall protection, and an "up-and-over" structure was installed on the crane bridge to provide a safe means of access with fall protection for performing maintenance on the containment dome.

John Foster coordinated with EHS and an outside contractor to complete an arc-flash analysis of all circuit breakers and electrical panels in NW12, including those in the containment building.

All EHS level II inspections were completed on time and performed in coordination with the 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.

Reactor Radiation Protection

Radiation protection coverage is provided by the EHS Reactor Radiation Protection Program. 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) 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 the NRL are as low as reasonably achievable in accordance with applicable regulations and Institute committee guidelines. 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 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.

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

Appointments, Awards, Events, and Highlights

During the past year, Lin-wen Hu, principal research scientist, was a member of a review committee appointed by the National Academy of Sciences to study the state of molybdenum-99 production and utilization and progress toward eliminating use of highly enriched uranium.

The NRL is also pleased to report that mechanical engineer Adam Grein was the recipient of an Infinite Mile Award in 2016.

In December 2015, the NRL received the MIT Environmental Health and Safety 2015 Excellence Award. This recognition is awarded annually to an MIT lab, center, or department with the highest achievement in the implementation and completion of EHS safety initiatives and training, including laboratory self-inspections and follow-through.

Two employees left MIT to explore new opportunities: Thomas Newton, director of reactor operations, accepted the position of deputy director at the National Institute of Standards and Technology, and principal research scientist William Graves accepted a faculty position at Arizona State University.

Al Queirolo, previously at Brookhaven National Laboratory, joined the NRL as director of reactor operations, and Sarah Don, former NSE graduate student and reactor operator, was hired as assistant superintendent. Lance Snead, previously at Oak Ridge National Laboratory, joined the NRL as a research scientist. Thomas Bork was promoted to reactor utilization manager.

The NRL added a technical support staff member, Keith Honeycutt, and a new academic staff member, visiting scholar Long Yan. The NRL hosted two visiting students: Huarui Wu and Yuyun Zeng.

The 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. Edward Lau and Thomas Newton co-chaired the TRTR from August 2014 through October 2015. They raised awareness in the TRTR and regulatory communities about emerging NRC rule making and met with the NRC chairman and commissioners on behalf of TRTR to highlight topics of mutual interest.

In October 2015, the NRL hosted and coordinated the annual TRTR conference (in collaboration with the International Atomic Energy Agency), which was held at the Ocean Edge Resort in Brewster, MA. The conference included an increased number of technical presentations, on topics such as research reactor aging management and digital instrumentation and control upgrades, as well as presentations on new experiments. There was also an increase in the number of participants to about 150, including staff members from NRC and DOE and students from many US universities. The conference was well organized, with sponsorships provided by major industrial vendors.

Tritium management is an important area of research that the NRL contributes to as part of the fluoride salt-cooled high-temperature reactor research project. While preventing release of tritium into the environment has been identified as a technological challenge for the FHR system, it is also critical for other fields such as fusion and defense. In October 2015, the NRL organized a workshop in Salt Lake City, UT, that brought together experts from all areas of research concerning tritium at high temperatures, including four national laboratories. The goals of this workshop were to exchange information, initiate an effort for benchmarking of experiments and models, and encourage cooperation between different groups working on the same challenges.

David E. Moncton
Director