Nuclear Reactor Laboratory

The MIT Nuclear Reactor Laboratory (NRL) operates the MIT Reactor (MITR), a research reactor that has been in service since 1958. The current version of the reactor dates from 1975, following replacement of the original core with a redesigned version providing increased neutron intensity. In 2010, the US Nuclear Regulatory Commission (NRC) extended the MITR operating license for 20 years with an increase in maximum power from 5 to 6 MW, further increasing the neutron flux levels. The NRL has a long and proud tradition of carrying out education, training, and critical research 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 US and its location on the campus of a major research university provides students with unique on-campus opportunities to participate in power reactor relevant materials, fuels irradiations, and associated post-irradiation examinations. The MITR is an increasingly rare asset in the US and is highly valued by researchers from US national labs, industry, and universities.

The NRL's primary mission is to provide MIT faculty and students, as well as the national scientific and engineering community, with a state-of-the-art nuclear reactor facility, 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 is safe for MIT, NRL staff, NRL researchers, the public, and the environment. Many generations of undergraduate and graduate students have benefited from their association with the NRL. In addition to participating in research and classwork that use the reactor, a number of undergraduate students become licensed operators at the reactor, with some progressing to the senior operator level. The MITR is 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.

The staff and students of the NRL also have an important mission to educate the general public about the benefits of maintaining a strong nuclear science program in the US. This is accomplished by providing tours and lectures that describe and clarify different nuclear science and technology programs. During the pandemic, we continued our outreach programs through the development of materials for remote presentations, reactor tours, and radiation experiments. This allowed us to continue to provide enrichment for K–12 and university students from our local community, and to expand to other parts of the country and to international audiences. As we anticipate the return to in-person tours and presentations, we also plan to maintain our remote programs for those who cannot travel to the NRL.

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 and also relevant to many advanced reactor designs. There is also active research in the areas of reactor design and analysis. A variety of programs to support fluoride-salt-cooled high-temperature reactor (FHR) development; the restart of the transient reactor test facility (TREAT); and applications of neutron scattering and imaging are also ongoing. To support the increasing demand for sophisticated, power reactor relevant irradiations, the NRL is improving and expanding its irradiation facilities. Although the reactor core irradiation space cannot be readily expanded, a wider range of experimental conditions, with instrumentation capable of operating in harsh nuclear environments, is being deployed.

This year also marked the beginning of a several year effort to transform a no longer in use medical irradiation facility to a large volume irradiation space that will provide unique testing opportunities. With significant neutron intensities over approximately a cubic meter of irradiation volume, and large amounts of shielded space for supporting systems, the "MCube" facility will be a vital part of programs to develop and test technologies such as molten salt reactors, fusion reactor breeding blankets and magnets, small modular reactors, and micro-reactors. All of these technologies have been identified as being potentially critical contributors to the efforts to reduce greenhouse gas emissions and combat climate change.

Laboratory Administration and Goals

The NRL currently employs 51 individuals. The staff consists of eight research staff, eight technical staff, 10 technical support staff, two academic staff, two administrative staff, three administrative support staff, three technicians, and 15 part-time student operators. During fiscal year 2021, progress was made toward implementing a new management structure envisioned from the appointment of new joint directors for the NRL in August 2019. The management team consists of a science and technology director, a strategic development director, and a managing director for operations. The science and technology director has ultimate oversight of the research priorities of the NRL, and coordinates the activities of a Science and Advisory Committee (to be established) and several centers that will facilitate research in particular areas. The first of these centers—Center for Reactor Instrumentation and Sensor Physics (CRISP)—has been established under the guidance of Sacit Cetiner of Idaho National Laboratory (INL) with a joint appointment at MIT and in collaboration with the leader of the NRL Irradiation Engineering Group. The strategic development director is responsible for identifying new research and services opportunities for NRL and will work closely with the program coordination and planning group to manage major reactor programs. The managing director for operations oversees the Reactor Operations Group, the Irradiation Engineering Group responsible for design and operation of all NRL experiments, and the Irradiation Materials Sciences and NRL Research Activities Group, which manages all NRL staff research activities.

This year was significantly impacted by the Covid-19 pandemic, with loss of reactor operating time due to campus closures, restricted hours, restricted occupancy, and delays from outside sponsors, contractors, and suppliers. Despite this, progress was made toward the NRL goals of wider engagement with MIT faculty and students, increased scientific impact of the NRL and MITR research program, and eventual elimination of MIT subsidies for reactor operating costs. This is evidenced in the discussions below of educational and research uses of the MITR. A pillar of the approach to achieving these goals is to enhance collaborations with INL. Progress continued in this area, with a number of joint research initiatives and increasing cooperation at a variety of levels.

Educational Impact

The MITR is used extensively to support MIT's educational missions. There was, unavoidably, an impact of the pandemic restrictions on educational activities at the NRL. However, we were able to implement virtual tours, lectures, and demonstrations alongside of some in-person activities for MIT students during the spring term of 2021.

The principal activities that support education and training include:

Use of the Reactor for 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 (TOF) neutron spectroscopy facility for their course on Radiation Detection and Measurement. This course is required for all NSE juniors and is also taught to graduate students. The TOF lab was completed by all the students during spring 2021. In the fall 2020 term, with most undergraduate education occurring remotely, a TOF experiment to measure the energy distribution of the neutrons in the beam was carried out remotely for a graduate class on ionized gases that is offered jointly by the Department of Aeronautics and Astronautics (AeroAstro) and NSE. The Maxwell-Boltzmann distribution of neutrons in thermal equilibrium with the neutron moderator was used as an analogue for the distribution of thermal energies in gases.

Other NSE courses incorporate activities using the MITR, including ones on Reactor Design and Operation, and Reactor Dynamics. Again, pandemic restrictions meant that one of the usual activities, in which students are able to perform power manipulations on the reactor, was not possible. However, a recently developed simulator for the reactor was used for remote demonstrations of similar concepts. The flexibility of the simulator, and access to data not available for the reactor itself, allowed for a wider range of activities and learning. In addition, NRL staff irradiated toenail samples provided by the students in an NSE class, and provided gamma spectroscopy data for neutron activation analysis. A related activity provided data for the students on the radioactivity present in some commonly available foods. These activities were adapted for remote teaching in fall 2020.

Student Research

Since the 1950s, cutting edge research utilizing the MITR has been conducted by faculty, students, and researchers from MIT as well as other institutions. Students benefit from doing thesis work on the reactor because they have the opportunity to combine the theoretical knowledge that they have acquired in the classroom with hands-on engineering. As a result, more than 200 BS, MS, and PhD theses have been completed by students who utilized the reactor for their research. Some of the research topics include the design and construction of the in-core loops, performance of experiments using those loops, low-enriched uranium conversion of the MITR, design and analysis of FHRs, 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, 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.

In the past year, a PhD thesis was completed using samples from MITR irradiations to study the transport of tritium in components of FHRs. Another PhD student analyzed irradiated samples to further the development of cladding for accident tolerant fuel. The goal is to produce nuclear fuel capable of withstanding conditions like those encountered in the Fukushima accident without releasing large amounts of radioactive material or producing hydrogen. An additional seven MS and PhD students conducted research in NRL-led projects related to molten salt reactors, instrumentation for the next-generation US research reactor the Versatile Test Reactor, space nuclear propulsion, and low-enrichment fuel for research reactors, and reactor operation, control, and simulation.

NRL staff also mentor Undergraduate Research Opportunities Program (UROP) students using the MITR and associated facilities. Despite the pandemic restrictions, seven UROP students participated in projects at the NRL over the past year. Three were working on characterization of salts for molten salt reactors, two were working on neutron optics for MITR beamlines, and there were also projects on neutron computed tomography and improvements to the neutron TOF spectroscopy system and laboratory guides.

Training of Undergraduates to Operate the Reactor

More than 300 students have participated in the NRL's Reactor Operator Training Program. Every year, 4–6 MIT undergraduates are hired to work part-time as licensed reactor operators. Individuals from all majors are welcome to apply. The MITR training program is an invaluable educational opportunity for undergraduate students because it combines theoretical nuclear science and engineering studies with hands-on operational experience. In addition, students who receive senior reactor operator licenses obtain managerial experience by serving as shift supervisors. Students who have completed this training program have regularly reported that it was one of the highlights of their MIT experience.

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. Due to COVID-19 pandemic restrictions, no on-site tours were given to members of the public this past year. In order to continue educational outreach efforts, NRL staff members developed a remarkable virtual tour, consisting of a video walkthrough of the facility with footage shot in the fall of 2020, graphics and pictures of experiments, and lab activities. Approximately 13 virtual tours and other virtual educational outreach activities were given to approximately 156 participants. The NRL plans to continue using this virtual tour format in the future, facilitating meaningful outreach to groups unable to attend in-person tours. "Skype-a-Scientist" Q&A sessions between K–12 school groups and the NRL's engineers and researchers, introduced shortly before the COVID-19 pandemic, remain in place as an additional virtual educational outreach option.

NRL staff members have also collaborated with other groups at MIT and a variety of educational enrichment programs to discuss nuclear power, the role of research reactors and the research done at the NRL with middle and high school student groups.

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 1974 to allow extensive upgrade and conversion to the MITR-II, which offered a neutron energy spectrum and flux similar to a commercial light water reactor. On July 8, 1999, a formal application was submitted to the NRC to relicense the reactor for an additional 20 years and to upgrade the power level from 5 MW to 6 MW; the new license and power upgrade approval was granted in 2010. The MITR has been designated as a partner facility of Department of Energy's Nuclear Science User Facilities (NSUF) since 2008 and serves a wide user base from other universities, national labs, and nuclear industry. The MITR-II is one of five US high performance research reactors utilizing highly enriched uranium (HEU) fuel. The NRL is projected to the first of these reactors to convert to, and demonstrate the performance of, a high-density low-enriched uranium (LEU) fuel after it is qualified.

The MITR, the major experimental facility of the NRL, is a heavy-water-reflected, light-water-cooled and moderated nuclear reactor that utilizes flat, plate-type, finned, aluminum-clad fuel elements. The average core power density is about 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 s respectively. Experimental facilities available at the research reactor include beam ports, pneumatic tubes to transfer samples to irradiation positions in the reflectors, and graphite-reflector irradiation facilities. The centerpiece of the irradiation capability is three in-core positions available for controlled temperature inert gas irradiations, pressurized water loops, and custom-designed irradiation facilities (including fuel irradiations). Except for planned outages for maintenance, the reactor generally operates 24 hours a day, seven days a week. The MITR incorporates a number of inherent, passive, safety features. These include negative reactivity temperature coefficients of both fuel and moderator and a negative void coefficient of reactivity, meaning that the reactor power naturally decreases if temperature increases or if boiling begins to occur. In addition, 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, operation at low temperature and atmospheric pressure, and the presence of a full containment building all contribute to the exceptional safety of the reactor design.

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 installation and removal 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 particular experiments. The smaller cell is used to handle small, high activity components and fuel from in-core experiments. Various post-irradiation-examination (PIE) instruments such as a remote balance, an optical micrometer, and a laser profilometer are installed as necessary for use in the small hot cell. The hot cells and the reactor spent fuel pool are also used to support packaging and shipping of irradiated samples to other facilities for PIE.

Laboratory space within the restricted area includes two standard fume hoods and an inert-atmosphere, 4-port glove box with furnace dedicated to work with irradiated fluoride salts and associated materials. A ventilated enclosure has also been completed to house standard metallurgical sample preparation equipment. Epoxy mounting, low- and high-speed sectioning, wet polishing, and sputter coating can be carried out in this enclosure on activated and contaminated samples. Macro-photography, optical microscopy, optical profilometry, and weighing of irradiated specimens are also completed in this space. Other equipment used with radioactive materials in the exclusion area include a xenon-flash thermal diffusivity instrument, HPGe gamma spectrometers, a liquid scintillation counter, and gaseous ^{3}H and ^{14}C collection and measurement instruments. Radioactive samples can be sectioned and polished in this area and examined in an optical microscope or scanning electron microscope. During the past year, installation of a water-cooled Instron mechanical testing machine with environmental chamber and filtered ventilation for irradiated material tests was finalized. This includes a stereo optical camera system for 3D real-time strain measurements. Much of this equipment was obtained with funding from the Nuclear Energy University Program scientific infrastructure program in collaboration with Michael Short, Class of '42 Associate Professor of Nuclear Science and Engineering, and Koroush Shirvan, John C. Hardwick Assistant Professor of Nuclear Science and Engineering.

Neutron Beam Experimental Facilities

Neutron Time of Flight Spectrometer

This web-enabled TOF experimental facility can be operated locally or remotely over the Internet through a LabView™ interface. Hardware and software upgrades made during previous years improved reliability and supported a heavy schedule of student experiments in both the fall and spring terms. The beam repairs described in the fiscal year 2018 (FY2018) report have greatly enhanced the student experience in course 22.09 Principles of Nuclear Radiation Measurement and Protection (meets with 22.90 Nuclear Science and Engineering Laboratory). Graduate students in the course now complete a neutron diffraction experiment in addition to a TOF neutron spectrometry experiment. Undergraduate students benefit from shorter run times and improved statistics resulting from the higher intensity of the restored beam. Use of the facility over the web has been offered to groups outside MIT as well, including students in a master's program in nuclear instrumentation at Aix-Marseille University in France who ran the experiment remotely in September 2020.

Other Neutron Beam Facilities

One of the MITR neutron beams is equipped with a triple-axis diffractometer and a neutron-imaging facility. 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 at the MIT Reactor, MIT faculty work, and outside users requiring access to neutron diffraction or imaging. The diffractometer is a standard triple-axis diffractometer equipped with graphite monochromator and analyzer, and He3 detectors. The neutron imaging facility at the same beam port is equipped with the necessary beam-forming apertures and a scintillator-based imaging detector. NRL staff in collaboration with Bradley Olsen, professor of Chemical Engineering, began performing a feasibility study for installation and use of a Small Angle Neutron Scattering (SANS) facility on an MITR neutron beam port. Such a facility would provide a very useful complement to the Department of Energy (DOE) user facilities that offer SANS. There is an active SANS research community at MIT and other Boston-area universities, and among local companies. A design effort is continuing to better understand the possible approaches and costs for establishing SANS capability at the MITR.

Research Highlights

Fluroide Salt High-Temperature Reactor Materials and Fluoride Salt Irradiation

The NRL has established itself as a leader in the irradiation of fluoride salts in support of Fluoride Salt High-Temperature Reactor (FHR) development. With two successful DOE Integrated Research Projects (IRP) grants in collaboration with multiple universities, collaboration with the Chinese Academy of Sciences, and multiple successful DOE rapid turn-around grants, the NRL has successfully conducted the first in-reactor irradiations of fluoride salts in the last 60 years. This is an effort to rediscover the techniques for handling this challenging substance and test it against modern materials and instrumentation, especially in regards to corrosion and tritium transport. Kairos Power, a engineering company developing its own FHR and is the recipient of substantial public and private support, was born from this previous FHR work and is now sponsoring doctoral research using the MITR beamlines. They are irradiating a novel liquid fluoride salt target to observe the generation and transport of tritium as well as the performance salt-wetted tritium permeation barriers. The control of radioactive tritium, which is produced from any lithium- or beryllium-bearing salt, and preventing exposure to workers or the environment is a critical challenge to FHR viability.

The NRL is also the principal organization in a 2021 DOE IRP award for the development of a high-temperature forced-flow salt loop coupled to an MITR beamline. Along with the University of California at Berkeley, the North Carolina State University, and Oak Ridge National Laboratory (ORNL), MIT is responsible for design and implementation of this new facility, which will be the first in the US for testing of materials and instrumentation in a forced-flow loop with in-situ neutron and gamma irradiation. This project will utilize the M^3 Facility being constructed to replace the medical radiation MITR Boron Neutron Capture Therapy (BNCT) facility that is attached to the MITR Fission Converter. The Fission Converter is a reactor-driven sub-critical pile that offers the only location in the US for large-scale, long-term dry irradiations with a fission neutron spectrum that is safely isolated from the reactor. Work has begun on the design of the new irradiation facility, which includes testing facilities and fluoride salt loops in other NRL lab spaces as well, and the substantial task of decommissioning, clean-out, and repurposing of the existing BNCT equipment and structures within the MITR containment building.

Thermo-Electric Generator Irradiations

The University of Notre Dame was awarded a DOE NSUF project to conduct a series of thermo-electric generator (TEG) irradiations at the MITR. These devices can be used to generate useful power from the strong temperature gradients that arise in and near the core of a reactor, so long as they can survive the extreme radiation environment. Starting in late 2020, the first of two cycles of irradiation included two TEG modules located in a new in-core dry irradiation facility. This facility allowed for a several hundred-degree thermal gradient to be created across each TEG using only nuclear heating, while the electrical resistance and current produced from each module was monitored in real-time at a series of different temperatures. After irradiation the facility was disassembled and examined in the NRL hot cells. Lessons learned from these first radiation-tolerant TEG modules is being used in the design for the next cycle of irradiation to be conducted in the second half of 2021.

Westinghouse eVinci Reactor Materials Irradiation

The Westinghouse Electric Company is developing its eVinci micro-reactor using a number of novel technologies that the NRL is involved with, including heat pipes and structural material irradiation. In response to a short-turnaround request, several advanced high-temperature alloys and graphite couples for the eVinci program were irradiated under pressure at 800°C in the MITR core to explore the surface interactions of these materials. After a full cycle of irradiation the samples were extracted in the NRL hot cells, repackaged, and a subset were shipped to INL for additional analysis.

Advanced Manufactured Fuel Irradiations

The ORNL is developing the Transformational Challenge Reactor (TCR) concept of a gas-cooled, high temperature reactor that utilizes additive manufacturing techniques to produce ceramic and metal core components, including parts of the fuel. The NRL is involved in testing these novel fuel designs using both the pneumatic and graphite reflector (3GV) positions. A new capability was developed to safely irradiate and extract enriched fuel samples in from the MITR 3GV, and the ORNL samples are being tested for quantitative fission gas release using the NRL gamma spectroscopy facilities. Fuel samples provided by ORNL are being irradiated at temperatures up to 750°C in the 3GV while their sweep gasses are monitored. After irradiation the individual fuel samples are being re-packaged for return to ORNL for destructive analysis.

NASA Space Nuclear Propulsion Project Irradiations

In a collaboration between several organizations including INL, ORNL, and BWX Technologies Inc (BWXT), NASA is developing and testing new fuel forms for a very high temperature space nuclear propulsion system. Using hydrogen coolant and propellant, the new propulsion systems are intended for making manned interplanetary travel more practical. The NRL is providing NASA the ability to test its materials, including new fuel forms being produced by BWXT, in pure hydrogen environments under neutron and gamma irradiation. This program, supported by a Small Business Innovation Research collaboration with Koroush Shirvan, has successfully conducted initial irradiations in the MITR pneumatic system, and is designing future irradiations to take advantage of the higher capabilities of the MITR 3GV and M^3 facilities for increased fuel loadings, higher temperatures, and active cooling using flowing hydrogen.

Advanced Material Development Irradiations

The increased collaboration between the INL and MIT has created opportunities for larger irradiations of advanced materials. A dry in-core irradiation was conducted with samples provided through this collaboration, as well as additional materials provided through the NRL Seed Program for MIT faculty research. A variety of ceramic and metallic specimens, including items such as Silicon Carbide (SiC) temperature monitors, yttrium and zirconium hydrides relevant to the NASA Space Nuclear Propulsion program, and fiber optics from Shirvan's group in NSE, were irradiated in a facility in the core that utilized new capsule designs to achieve a wider range of temperatures than has previously been achievable in inert gas irradiations at MITR. After irradiation these materials will be processed in the NRL hot cell facilities and distributed to researchers at MIT, Stony Brook University, and INL for analysis.

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 (NEET) Program. The MITR has been central to the irradiation testing of new cladding concepts from the beginning of the program. Recent emphasis has been on chrome-coated Zircaloy™ cladding as well as SiC-SiC composite materials. Irradiation of these materials continued in the MITR pressurized water loop during the final irradiation cycle of 2020 and the first cycle of 2021. Post-irradiation examination was completed on all samples irradiated to date. The final phase of the program is currently being contracted with DOE and we expect to continue irradiations as the new fuels move to final licensing.

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 US, 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 to eliminate weapons-grade HEU from civilian use world-wide. A major objective of MITR's LEU conversion is to maintain the HEU core performance and a power uprate to 7 MW as has been determined from a previous feasibility study. Recent work in this program has concentrated on establishing specifications and tolerances for the LEU fuel elements, and on understanding and preparing for the upgrades necessary to support LEU conversion. For example, the increase in power will necessitate higher primary coolant flow rates and the effect of higher flow rate on vibration of primary circuit components was investigated.

Neutron Beam Research

A number of projects in this area are dedicated to advanced understanding of the structure of molten salts proposed for coolants and liquid fuel media in advanced high-temperature reactors. NRL staff and UROP students are active in this area using a variety of X-ray and neutron sources around the US. These projects also involve experimental demonstrations of beamline equipment to permit probing molten salts under service-relevant conditions, and development of data analysis techniques. Other projects involve the use of neutron beams at the MITR. For example, a system for thermal tomography of additively manufactured materials under neutron irradiation was tested at one of the beam ports. A new type of instrumentation for neutron diffractometers—multiplexing focusing analyzers—will also be tested at the MITR in a project collaborating with a company that produces neutron generators and funded by the DOE Office of Basic Energy Science. A project to image batteries using neutrons was successfully transferred to the MITR when the National Institute of Standards and Technology (NIST) reactor was forced into an extended outage.

Services

Irradiations and experiments conducted during this reporting period include the following:

- Activation of ytterbium-168 pellets in support of cancer treatment study
- Activation of uranium foils for detector calibration at the Los Alamos National Laboratories and Ciambrone Laboratory at Patrick AFB
- Activation of polyethylene (PE) samples along with Neutron Activation Analysis (NAA) standards for the University of Alabama
- Activation and NAA of ceramic tracer beads for NCS Multistage, LLC
- Activation and NAA of Tungsten Boride sample materials for Specialty Materials Inc. in preparation for neutron damage study
- Activation and NAA of cell culture and samples for MIT Chemistry Department in support of BNCT project
- Activation and NAA of TRi-structural ISOtropic (TRISO) Particles in support of ORNL additive-mixing fuel injection (AMFI) Project
- Activation and NAA of TRISO Particles and yttrium-hydrogen (YH) samples under H environment in support of NASA Fuel Material irradiation project
- Activation and NAA of various sample materials and structural components for the Westinghouse eVinci project
- Irradiation of experimental Fission Chambers and U targets in Thermal Neutron Beam for Los Alamos National Labs Fission Product Yield Study
- Irradiation of Tritium Generator Facility in Thermal Neutron Beam for Kairos Power Tritium Permutation Project
- Neutron radiography of batteries for NIST researchers
- Neutron radiography of a 3D printed stainless steel sample for the NRL Seed Program

- 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—22.01 Introduction to Nuclear Engineering and Ionizing Radiation; 22.06 Engineering of Nuclear Systems; 22.09 Principles of Nuclear Radiation Measurement and Protection; 22.011 Nuclear Engineering: Science, Systems and Society; and 22.921 Nuclear Power Plant Dynamics and Control.

Reactor Operations

Leadership of the reactor operations division is provided by John Foster, director of Reactor Operations, Edward Lau, assistant director of Reactor Operations, and Sarah Don, reactor superintendent who departed from NRL in December 2020 and was succeeded by Marshall Wade. The reactor operations group is responsible for supporting the operation and maintenance of the 6 MW research reactor. The group consists of full-time employees and part-time undergraduate students. The majority 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 24 hours a day and seven days a week operating schedule. In addition, there is one full-time project mechanic to support reactor mechanical maintenance. Reactor operations supported the following NRL research projects in FY2021: pressurized water loop facility, high-temperature in-core sample assembly (ICSA) capsule irradiations, molten fluoride salt irradiations in the Basement Thermal Beam, 3GV vertical thimble irradiations, 1PH1 and 2PH1 pneumatic tube samples, 4DH4 diffractometer, and 4DH1 student spectrometer.

The reactor was maintained at a full power of 5.5 MW or higher. Total energy output for July 2020 to June 2021 was 25,681 megawatt-hours. This translates to 4,352 hours of operation at 5.9 MW.

Major NRL maintenance and upgrade projects accomplished in FY2021 include:

- Conducted the the ventilation system charcoal filters annual efficiency test
- Repaired channel 5 and channel 8 detector connections
- Installed a new blade, drive, and magnet for shim blade 4
- Installed a new drive and magnet for shim blade 5
- Installed a new regulating rod and rebuilt the drive
- Conducted annual control blade worth measurements
- Chemical cleaned the main primary heat exchanger

- Coordinated with MIT Facilities to perform cleaning and maintenance of heating and ventillation electrical equipment in the utility room
- Coordinated with MIT Facilities and contractors to perform an arc flash study on the NRL electrical distribution system
- Replaced HM-A and MM-1 motors
- Coordinated with MIT Facilities to replace the intake and exhaust ventilation system filters
- Installed Primary System Vibration Analysis Equipment for performing Primary System vibration testing
- Coordinated with MIT Facilities to replace air compressor CM-2's compressor
- Replaced the reactor CO_2 tanks
- Replaced the reflector's main circulating pump (DM-1) motor
- Removed the Fission Converter facility's water shutter system
- Conducted annual inventory of heavy water
- Installed the new nuclear safety system across a six week period from late July to early September

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

Because of the COVID-19 public health emergency, the usual allotted time span for second calendar quarter On-the-Job Training requirements for a number of licensed personnel had expired. Anticipating that, reactor staff had previously sent an exemption request letter to NRC, who had reviewed it and approved an extension of the time span to December 31.

Initial Operator Training Program and Requalification Training Program

The reactor operations group trains up to 10 new operators each year in pursuit of an NRC license to operate the MIT nuclear reactor. This diverse group of trainees is comprised mostly of MIT undergraduates typically starting in their first year, but also includes full-time staff, US Navy nuclear program veterans, and select undergraduates from neighboring Boston universities.

The Initial Operator Training Program is rigorous and covers topics ranging from reactor theory and dynamics, radiation detection and safety, and mechanical and instrumentation systems. The level of instruction is comparable to that offered in undergraduate courses covering the same topics. The endpoint of the MITR training program is a multifaceted examination administered by the NRC, consisting of a written examination, an operational examination (reactor startup), an oral board, and a reactor plant walkthrough. Successful student candidates receive a reactor operator (RO) license and continue to support the reactor as part-time operators. After the students gain operational experience, most are offered the opportunity to participate in a second training program that leads to a senior reactor operator (SRO) license. Full-time candidates begin supporting routine MITR operations and evolutions as licensed ROs or SROs.

Due to COVID-19 pandemic restrictions, only one NRC licensing examination was conducted from July 2020 through June 2021, with one full-time SRO candidate passing her examination in March 2021. Presently, 10 candidates are preparing for NRC licensing examinations, of which nine are MIT undergraduates training for their RO qualifications and one is an MIT undergraduate training for his SRO qualification. The NRL will host additional NRC licensing examinations in September 2021 and February 2022 for these candidates.

Following successful completion of the Initial Operator Training Program, operators begin continuous training through an NRC-mandated Requalification Training Program. The objectives of this program are to verify that licensed individuals remain proficient on routine operations, to refresh knowledge of operations that are performed infrequently, to provide for the timely review of facility and procedural changes by all licensed personnel, and to ensure improvement of any areas of performance weakness that are identified. These objectives are accomplished through monthly lectures, on-the-job training, and annual written and oral examinations. The Requalification Training Program is managed by an in-house requalification program coordinator, and it is audited annually by the NRC to ensure all requirements are satisfied.

Security

In FY2021, NRL security continued to meet NRC regulatory requirements. The annual Independent Audit was performed in person on site in June 2021, including a physical security review which was recently added to the routine Independent Audit. No regulatory violations were identified.

In FY2021, security hardware upgrades were implemented at the NRL, managed by MIT Information System and Technology (IS&T) via contractor Barr & Barr, and security contractor Siemens Building Technologies. All motion sensors and proximity switches were upgraded, along with all biometric readers and card readers, in order to ensure compatibility with the campus-wide Genetec security management system. Reactor staff performed an independent safety review on the new biometric technology, which was also reviewed and approved by the MIT Reactor Safeguards Committee. The reactor's Physical Security Plan was updated accordingly, with the revised Plan filed with the NRC, demonstrating that the upgrade did not reduce the effectiveness of reactor security.

In May 2021, following completion of the security hardware upgrade, Reactor Operations coordinated with IS&T and MIT Police to perform a system-wide comprehensive test of the MITR security system, assisted by technicians from Siemens Building Technology. Issues identified during the test were resolved satisfactorily.

The aging condition of the existing cameras from 2009 remains an open concern. The 19 new digital cameras that were installed by IS&T in FY2017 as Phase One of an overall camera upgrade continued to operate with minimal problems. Reactor Operations continues to interface with appropriate government agencies for funding for Phase Two camera upgrades.

During FY2020, one of the two Sentry Radiation Monitoring System (RMS) units became defective. The Sentry-RMS units were commissioned in June 2018 under a DOE grant as an alternative security system for the reactor, entirely independent from the principal systems described in the reactor's Physical Security Plan. In FY2021, a new DOE grant was secured to repair the defective unit and restore its functions.

Annual training of the MIT Police for 2020 and 2021 was conducted by recorded lecture, rather than in person, because of the ongoing COVID19 public health emergency. For security reasons, the material was provided on physical media to MIT Police senior management, who arranged for it to be viewed by all continuing officers, all new officers, and all civilian dispatchers working at MIT Police Headquarters. Any officers having questions afterward are encouraged to contact the NRL trainer.

Emergency drills were conducted with MIT Police and all other related on-campus emergency response organizations in November 2019 (radiological emergency exercise), December 2019 (medical emergency drill), December 2020 (combined radiological and medical emergency tabletop exercise via videoconference), and June 2021 (NW12 building evacuation drill). The medical drills also included off-campus agencies: Cambridge Fire Department, Professional Ambulance, and Mount Auburn Hospital. All drills were performed satisfactorily, documented, and generated many lessons learned to share among all participants.

Environment, Health and Safety Activities

In FY2021 all Environment, Health, and Safety (EHS) Level II inspections were completed. One was done on March 10–12, 2021, and the second was completed in June 2021. The EHS coordinator led these inspections, along with NRL's EHS lead contact and an EHS safety officer. Also included were Reactor Operations staff members for cross-training, and representatives of area users when inspecting different areas.

Reactor Radiation Protection

Radiation protection coverage is provided by the Reactor Radiation Protection Program of the EHS Office. Although, this is a separate organization within MIT, it is very responsive to the NRL management team. Personnel include William McCarthy—an assistant director for EHS who serves as the reactor radiation protection officer, two EHS officers, one full-time technician, 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 NRL are as low as reasonably achievable in accordance with applicable regulations and Institute committees. Joe MacLeod, an EHS officer from the safety program, serves as NRL-EHS team member under 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.

Appointments, Awards, and Events

During the past year, we were fortunate enough to hire or promote the following people:

- Sara Hauptman, senior reactor operator
- Guanyu Su, postdoctoral associate
- Adam Carleton, utility worker
- Nesrin Cetiner, irradiation scientist
- Marshall Wade,promoted to superintendent
- Alex Kingsbury, promoted to training supervisor

Dane Kouttron, Research Engineer received an Infinite Miles Award.

> "Dane's diligence and consistently high-quality output regularly exceed our expectations. He has a genuine drive to assist the NRL and MIT to accomplish their missions and goals. His humility and quest for greater understanding is his motivation to achieve higher goals. I enthusiastically nominate Dane for the 2021 Infinite Mile Award with my highest recommendation, because he is a person who will contribute above and beyond in anything he believes to be of value."

Gordon Kohse
Managing Director for Operations
Principal Research Engineer