Nuclear Reactor Laboratory

Facilities and Resources

The MIT Nuclear Reactor Laboratory (NRL), which has served the university and the surrounding community since 1958, is an interdepartmental center that operates a 5-MW research reactor in support of MIT's educational and research initiatives and goals. Its mission is to provide faculty and students from MIT as well as the national scientific and engineering community with both a state-of-the-art reactor facility and the infrastructure to enable and support its use for research and other societal objectives. Highest priority is placed on operating the research reactor in a highly professional manner that is safe to MIT and NRL staff, researchers, the public, and the environment. NRL is also committed to educating the general public by promoting education and training in nuclear sciences and technologies.

The reactor, which is designated as the MITR-II, is NRL's major experimental facility. It is a heavy-water reflected, light-water cooled and moderated nuclear reactor that utilizes flat, plate-type, finned, aluminum-clad fuel elements. The average core power density is about 70 kW per liter. The maximum fast and thermal neutron flux levels available to experimenters are 1×10^{14} and 5×10^{13} neutrons/cm^2-s, respectively. Experimental facilities available at the MITR include two medical irradiation rooms, beam ports, automatic transfer facilities (pneumatic tubes), and graphite-reflector irradiation facilities. In addition, several in-core sample assemblies (ICSAs) are available. The MITR-II is the second of two research reactors that have been operated by NRL. The original reactor (MITR-I) achieved criticality in 1958. In 1973, the MITR-I was shut down to allow conversion to the MITR-II, which offered a higher neutron flux level.

NRL, which has operated for 52 years, has a long history of providing faculty and students with a high-quality neutron source complemented by an extensive infrastructure to facilitate its use. The laboratory's primary objective has been in support of educational training and cutting-edge research in the areas of nuclear fission engineering, radiation effects in biology and medicine, material studies, neutron physics, geochemistry, and environmental studies. Through the years, thousands of undergraduate and graduate students have benefited from their association with NRL by the opportunity to pursue their research by utilizing a research reactor that provides a unique hands-on environment.

Reactor Administration

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

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

NRL supports MIT's affirmative action goals. There are 24 full- and part-time positions held by women and/or members of underrepresented minorities, and, of the 18 engineering and management positions, six are held by women and/or members of minorities. Long-term employees include a research staffer who is both a woman and a minority; the superintendent of operations, who is a minority; a neutron activation technical staff member who is both a woman and a minority; the training coordinator, who is a minority; and the Q/A supervisor, who is a woman. As part of NRL's ongoing mission to train reactor operators, there is always a rotating group of MIT students that includes women and/or members of minorities. NRL participated in the US Department of Energy's program for minority training in reactor operations. One of our current senior reactor operators is a graduate of this program and has become our training coordinator.

Reactor Operations

Leadership is provided by John A. Bernard, director of reactor operations, and by reactor superintendent Edward S. Lau. The reactor operations group, the largest at NRL, is responsible for supporting all laboratory activities when necessary, with priority on the operation and maintenance of the 5-MW research reactor. The group consists of full-time employees and part-time undergraduate MIT students. All 26 members of the group are licensed by the US Nuclear Regulatory Commission (NRC), and most hold a senior reactor operator license. All perform reactor shift duties to support the 24-hour-per-day, seven-day-per-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: the advanced clad irradiation (ACI-2) experiment, the 4DH4 diffractometer, and the 4DH1 student spectrometer.

The MIT reactor completed its 52nd year of operation (its 35th since the 1974–1975 upgrade and overhaul). Beginning in 1994, the reactor adopted a schedule of continuous operation to support major experiments and utilization. The reactor was nominally maintained at a full power of 4.5 MW or higher. Total energy output for FY2010 was 22,300 megawatt-hours. This translates roughly to 5,000 hours of operation at full power.

Several major maintenance projects were carried out in order to improve the safety, reliability, and efficiency of the MIT research reactor, thereby improving the predictability of the reactor operating schedule and the availability of the reactor for experiments and research. These projects are summarized as follows.

The core purge blower and pulley system were replaced. The core purge system continuously draws air across the small enclosed space at the top of the core tank to reduce accumulation of Ar-41 there. Deterioration of the pulley could result in reduced air flow from the enclosed area. The pulley was original equipment, and a new pulley setup was not readily compatible with the blower. Therefore, the blower and pulley were both replaced with updated equipment. Additionally, the core purge system's inlet and outlet filter jars were replaced to improve their air seals. The flow gauge at the blower's discharge was also replaced.

The stack base access was modified from just a hatch to room-size housing for improved personnel fall protection. Access to the base of the reactor stack requires climbing down a 20-foot-long staircase. To improve fall protection, the handrail of the staircase was extended upward to ensure an ample grip area for personnel using the stairs. This meets new Occupational Safety and Health Administration requirements. The new access area is now covered within the protective housing and is therefore weather-proofed. It is equipped with new lighting, an intercom, a small freight lift, and an automatic roll-up door. General lighting in the stack base area was also improved. Planning and procurement started about a year ago with consultation from the MIT Environment, Health, and Safety Office (EHS). Reactor staff performed the installation.

The reactor security system went through a major upgrade. Reactor staff installed some specialty security equipment and supervised various contractors such as Siemens Building Technologies and Wise Construction on facility-wide installation of closed-circuit television systems, sensors, switches, transmitters, gates, doors, and data closets. Logistical support for the installation was provided by MIT Facilities, the MIT Security and Emergency Management Office (SEMO), the MIT Police, and MIT Information Services and Technology (IS&T). The Reactor Radiation Protection Office provided radiological training and issued dosimetry for all contract workers to allow dose monitoring. Planning and design work started in December 2008. A request for funding of the upgrade for $1.4 million was approved in July 2009, with funding provided by the National Nuclear Security Administration of the Department of Energy (DOE). Construction started in late August 2009 and was completed in January 2010. Final acceptance and assurance tests by both reactor staff and DOE were completed in March 2010.

More than 30 reactor reflector system leak tapes were replaced with new leak detection units. This is the first stage in an effort to transition all reactor leak tapes to the new units. Reactor staff accepted the performance of the new tapes after more than a year of field testing to ensure reliability. Replacement and installation are labor intensive and will be performed only during extended outages following sufficient reactor cool-down time so as to minimize personnel dose exposure. The new tapes are made of materials that are more durable and can be better secured to piping and flanges. They are also color-coded for ease of identification.

All four picoammeters in the control room main console for neutron power indications were replaced with upgraded units. The new picoammeters contain added functions such as auto-ranging and communication ports for remote signal transmission. These units replaced those for nuclear channels 7, 9, and linear N-16. The channel 8 picoammeter will be put to use when the ion chamber for the channel is replaced in the next fiscal year.

The drive for reactor control shim blade 4 was rebuilt, and its electromagnet and neutron absorber section were replaced. The drive for reactor control shim blade 6 was also rebuilt and its electromagnet replaced. The drive for reactor control shim blade 2 was rebuilt, and its electromagnet was replaced along with the proximity switch and tube. The neutron absorber section for reactor control shim blade 5 was replaced as well.

A new mezzanine was constructed at the southeast quadrant inside the containment building. This mezzanine will become the new location for the D_2O helium gasholder upon its relocation from the equipment room during the heat exchanger replacement outage in order to make room for new equipment room piping. (The actual D_2O helium gasholder in the equipment room will be removed and then retired or refurbished. The graphite CO_2 gasholder, in better condition, will also be removed from the equipment room and placed on the mezzanine for use as the new D_2O helium gasholder.)

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

On April 23, the reactor was shut down as planned for an extended outage to replace its main heat exchangers and all associated primary and secondary piping. Final preparation activities were completed the week of April 26, and reactor staff began removing the existing heat exchangers and piping the week of May 3. By early June, removal was completed and the construction phase began. This work will continue into the early part of the next fiscal year.

Reactor operations provides a major service in the production of neutron transmutation doping silicon for international suppliers. This silicon is currently used primarily for power devices such as thyristors in hybrid cars, for solar power panel development, and for producing memory chips. This service provides commercial income (approximately $1 million annually) used to offset operating costs.

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

During this reporting period, one set of NRC exams was administered on site. There were four student candidates for reactor operator licenses and one student candidate for an upgrade to an SRO license. All passed. Three MIT students are currently in training for license exams in September 2010.

Relicensing of the MITR-II with a concomitant upgrade in power is in progress. It was previously determined that the MITR-II could operate at a maximum power of 6 to 7 MW with the existing heat-removal equipment. A decision was then made to submit the licensing documents for a power increase from 5 to 6 MW. On July 8, 1999, a formal application was submitted to NRC to relicense the reactor for an additional 20 years and to upgrade the power level to 6 MW. The relicensing package included a complete rewrite of the safety analysis report and the technical specifications. Until the relicensing approval process is completed, NRC has authorized continued operation of the MITR. This mode of operation has been ongoing since 1999.

Reactor Research Facilities and Services

Partnership with Idaho National Laboratory

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

Postirradiation Examination Facility

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

Nanofluids Laboratory

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

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

Neutron Capture Therapy User Center

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

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

- A high-resolution polymer track etch technique for viewing boron capture reactions in stained tissue sections

The thermal and epithermal neutron medical irradiation facilities are the only beams licensed by NRC for clinical trials. The fission converter-based epithermal neutron beam line has been augmented to include an optional lithium filter that improves beam penetration and increases the therapeutic ratio for deep-seated tumors by as much as 15 percent; it was refueled in the previous fiscal year, increasing beam intensity by 20 percent.

This center maintains and operates the reactor's fission converter, PGNAA, and the thermal neutron beam facilities used primarily for boron drug testing and characterization. Dedicated laboratory space in NW13 is used to support these experiments by, for example, maintaining cell lines and injecting animals before irradiation as well as harvesting samples and preparing them for analysis. Laboratory equipment such as a cryostatic microtome and an optical microscope with precision stage and image analysis software is used to perform high-resolution quantitative autoradiography. This technique can image boron capture events in polymer track detectors superimposed on stained tissue sections with microscopic resolution, and this capability exists only at MIT.

Neutron Spectrometer Experimental Facility

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

Neutron Scattering Facility

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

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

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

Environmental Research and Radiochemistry

NRL's environmental research and radiochemistry laboratories are equipped for both prompt and delayed gamma neutron activation analysis (NAA). Relative to the former, a prompt gamma spectrometer was built as part of the BNCT program to measure the boron content in the blood and tissue of patients and experimental animals and is now available to other users. Relative to the latter, the MITR is equipped with two pneumatic tubes that are commonly used for NAA, primarily for analysis of trace metals. One offers a thermal flux of 5×10^{13}, and the other offers a thermal flux of 8×10^{12}. Several of the tubes are automated so that samples can either be ejected to a hot cell within the reactor containment or be transferred via a pneumatic tube to a laboratory in an adjacent building. In addition to the pneumatic tubes, there are four water-cooled facilities in which large numbers of samples can be simultaneously irradiated in a uniform flux. Samples in these facilities can be rotated. ICP-AES is also available at NRL. NRL's NAA laboratory is equipped with three Hp(GeLi) detector systems with Genie 2000 software.

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

Reactor Research, Development, and Utilization

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

- Supporting research in the area of advanced materials and fuel research
- Providing researchers with a service-based infrastructure that supports the US initiative for designing and building the next generation of nuclear reactors as a means of reducing the country's reliance on fossil fuels

- Providing researchers with a service-based infrastructure that utilizes the MITR-II for trace element analysis, isotope production, and irradiation services
- Supporting an outreach program to the educational community to encourage understanding of nuclear energy and its applications
- Supporting MIT's educational missions by providing Independent Activities Period lectures, hosting Undergraduate Research Opportunities Program students, and offering lab courses for professionals, undergraduates, and advanced secondary school students
- Expanding the user base for underutilized experimental facilities

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

- Activation of yttrium foils for an ongoing clinical trial at the Massachusetts General Hospital and Memorial Sloan-Kettering Cancer Center focusing on spinal cord cancer removal therapy
- Activation of gold-198 seeds and ytterbium pellets for brachytherapy, xenated silicon chips for trace element analyses, and fusion material laminates and Ge wafers for material science studies
- Irradiation of SiC in a 2PH1 pneumatic facility for non-destructive irradiation damage detection studies (funded by ATR NSUF) conducted at the Colorado School of Mines
- Activation of a copper disk for use at the Bates Linear Accelerator facility to test a SWORDS bomb detector vehicle
- Activation of uranium foils for detector calibration at the Los Alamos National Laboratories
- Activation of ocean sediments for the Woods Hole Oceanographic Institute
- Activation of Teflon and Si wafers for the University of Alabama
- Activation of crystal samples for neutron damage studies conducted by the Department of Earth, Atmospheric and Planetary Sciences
- Activation and NAA of ultra-high-purity B-11 for a trace element analysis conducted by Ceradyne Boron Inc.
- Activation and NAA of shielding materials for NSE for a new accelerator design
- Experiments at the 4DH1 radial beam port facility by MIT undergraduate and graduate students, including measurements of leakage in the neutron energy spectrum to determine reactor temperature, measurements of neutron wavelength and time of flight, and measurements of attenuation coefficients for eight shielding materials
- Use of the reactor for training MIT student reactor operators and for MIT nuclear engineering classes (22.06 Engineering of Nuclear Systems, 22.09 Principles of Nuclear Radiation Measurement and Protection, 22.921 Nuclear Power Plant

Dynamics and Control, and the reactor technology course for nuclear power executives)

- Use of the facility and source handling services for handheld gamma spectrometer development and testing for Symetrica Inc.
- Neutron transmutation doping of Si wafers for the Lawrence Berkeley National Laboratory and subsequent use of the wafers for further neutrino detector research

Reactor Engineering

Dr. Thomas H. Newton is associate director for engineering at NRL. This group's activities include support and development for experiments such as the in-core sample assembly, the high-temperature irradiation facility, and advanced cladding irradiations. This group also performs neutronic modeling of proposed experiments for evaluation of neutron fluxes, reactivity, and heat generation. Work with ex-core experiments including the installation, upgrade, and operation of a neutron diffractometer has continued as well. Other activities of this group include engineering support of upgrades to reactor mechanical and instrumentation systems, supervising the management of fuel in the reactor and fission converter, overseeing shipments of spent fuel, and other engineering services as needed. In addition, Dr. Newton is the principal investigator for the program to convert the reactor to low-enriched uranium fuel.

Research Programs

Conversion of the Reactor to Low-Enriched Uranium Fuel

The Reduced Enrichment for Research and Test Reactors (RERTR) Program under DOE has committed to converting all research reactors using highly enriched uranium (HEU) to low-enriched uranium (LEU). Although a number of lower power reactors have been converted under this program, the remaining five US reactors with higher power densities (the MITR, the University of Missouri Research Reactor Center, the National Institute of Standards and Technology Reactor, the High Flux Isotope Reactor at the Oak Ridge National Laboratory, and the Advanced Test Reactor at INL) require the development of fuels with significantly higher densities. Such a fuel, a monolithic U-Mo fuel with a uranium density of about 16 g/cm^3, is under development and is expected to be qualified and approved for use in 2014. The MITR is expected to be the first reactor worldwide to use this fuel.

With ongoing support from the RERTR program, neutronic and thermal-hydraulic modeling tools for the MITR conversion study have been developed and benchmarked for both steady-state and transient conditions. These models are being used to compare the current HEU fuel with proposed LEU fuels. Burn-up modeling tools using both Monte Carlo and diffusion theory methods are also being developed so that fuel life, reactivity, neutron fluxes, and power peaking can be evaluated over time. Such models are being used to determine core performance and to develop a fuel management strategy that will reduce power peaking in the LEU core while meeting experimental as well as fuel supply needs.

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

Studies on mixed HEU-LEU cores show that it also appears feasible to introduce LEU into the current core to allow testing under nominal operating conditions during the transition. Introduction of LEU fuel into the MITR is expected to begin in 2015.

In-Core Loops and Sample Irradiation Facilities

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

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

An upgrade and redesign of the ICSA was fabricated and test-fitted in February 2009. The goals of the redesign were to provide positive sweep gas flow and allow for a wider range of feedthroughs to accommodate temperature and other in-core measurements or active control of irradiation parameters. The redesigned ICSA was demonstrated as a test bed for high-temperature irradiations during December 2009 with funding from ATR NSUF. Capsules equipped with gamma susceptors were used in conjunction with a neon/helium gas mixture control system to maintain constant irradiation temperatures in the range of 500–850°C. Irradiation programs have been funded to utilize this facility for testing advanced high-temperature materials (MAX phases) and advanced in-core thermocouples and fiber optic sensors. The ICSA was also used to irradiate molybdenum targets to investigate the feasibility of generating n-γ^{99}Mo for use in producing the medically important isotope Tc. This project was undertaken in cooperation with GE with funding from the National Nuclear Security Administration.

The following projects are ongoing as a result of the partnership between the MITR and ATR NSUF: in-core irradiation of SiC high-temperature sensor materials for the Colorado School of Mines and joint development of in-pile measurement crack growth instrumentation with INL.

Innovations in Nuclear Infrastructure and Education Program

From 2003 through 2009, NRL was provided with funds under the Innovations in Nuclear Infrastructure and Education Program to improve instrumentation, maintain highly qualified research reactor staff, establish programs that fully integrate the use of university research reactors with nuclear engineering education programs, and establish internal and external user programs. DOE's decision to implement this program was a great success and proved to be a good first step toward ensuring that the United States preserves its worldwide leadership role in the field of nuclear science and engineering. Prior to INIE, university nuclear science and engineering programs were waning, undergraduate student enrollment was down, and university research reactors faced the real possibility of closure. INIE started the process of drawing a new blueprint with positive goals and objectives that will support educators, students, and researchers today as well as in the future. This program also led to renewed interest in utilization of the MITR. INIE supported important infrastructure improvements to the MITR as well as numerous research initiatives conducted by NSE faculty members, MIT and outside researchers, and graduate students in research assistantships. Funds from INIE were used to purchase new heat exchangers for the MITR. This project, when completed, will allow the reactor to stay at high power during the summer months and thereby improve its efficiency.

New Initiatives

DOE Programs

In 2008, DOE's Office of Nuclear Energy (NE) initiated the Nuclear Energy University Program, consolidating its university support programs and thereby replacing INIE, which had been a significant benefit to the university nuclear engineering and research reactor community. Under the new program, 20 percent of NE funds appropriated for its research and development programs are now designated for universities and research institutes through a competitive solicitation process. One of the NE university programs of particular importance to NRL is the Research Reactor Infrastructure Program (RRI), which supports infrastructure and equipment upgrades for university-based research reactors and laboratories. As a result of a proposal submitted in response to an FY2010 RRI solicitation, John Bernard was awarded RRI funding that allowed purchase and installation of major equipment to support ongoing NRL and NSE research projects. This equipment included:

- A high-speed/resolution video camera used to provide valuable information (e.g., bubble nucleation, bubble diameter, boiling transition, bubble departure frequency) to aid in the understanding of the fundamental mechanisms of boiling heat transfer.
- A laser flash thermal diffusivity measurement instrument that supports NRL's postirradiation examination capabilities.
- Dissolved oxygen and hydrogen instrumentation that supports the MITR's light water reactor in-core loop program. Water chemistry measurements are vital to the operation of the loops in order to demonstrate that irradiations are being carried out under relevant conditions.
- A thermal conductivity analyzer (KD2 Pro)/viscometer. Since thermal conductivity and viscosity are two of the thermal physical properties that cannot be predicted by existing theories/correlations and need to be measured, this acquisition significantly supports several ongoing NRL/NSE research projects related to new engineered fluids, such as colloidal dispersions of nanoparticles, or low global warming potential refrigerants, whose thermal physical properties do not exist in the literature.

John Bernard was recently awarded RRI funding for FY2011 that will be used to purchase and install equipment that will augment existing reactor operation and reactor radiation protection safety systems.

National Science Foundation

David Moncton, William Graves, and Franz Kaertner (Research Laboratory of Electronics) have initiated a proposal through the National Science Foundation's Instrumentation for Materials Research-Major Instrumentation Projects program to support research on and development of coherent light sources. The goal is to develop next-generation accelerator and laser technologies for future coherent light sources and to ensure dual use for future large-scale facilities and compact sources while reducing costs. The proposed program would also lead to a prototype of a new generation of compact ICS sources that will enable a wide range of important science to be undertaken, help educate the next generation of physical scientists and engineers in this field, and facilitate the proliferation of this technology to many laboratories worldwide.

Safety and Security

Operational Safety

Many years ago, MIT established a very effective means of ensuring safe operation of the reactor by appointing independent experts to the MIT Reactor Safeguards Committee. This committee, whose members are from MIT as well as from industry, is ultimately responsible for overseeing all nuclear safety issues related to the reactor and ensuring that reactor operation is consistent with MIT policy, rules, operating procedures, and licensing requirements. However, *all* members of the NRL organization are keenly aware that safe operation of the nuclear reactor at MIT is their top priority. This level of awareness is achieved through the commitment and continuous training provided by

NRL's management team. An environment of cooperation and attentiveness to detail among reactor employees and experimenters regarding all reactor safety matters is essential. As a result of this approach to safety, each and every individual employed at the reactor can be proud of NRL's outstanding safety and operating record, which is evidenced by the results of NRC inspections.

Reactor Radiation Protection

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

ALARA Program

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

- An increased level of awareness pertaining to dose reduction, which is now at the forefront of conducting day-to-day operations of the MITR
- Enhanced communication of work activities coupled with the ALARA process, resulting in practical application of a number of specific dose reduction techniques
- A 50 percent reduction in annual collective dose from the previous year
- Implementation of methods to measure programmatic effectiveness and a system to ensure that future resources are applied to sustain dose reduction activities

Security

Reactor superintendent Edward Lau led a seven-month effort to coordinate with the DOE National Nuclear Security Administration in completing a design for a major upgrade of reactor security infrastructure. This effort led to the creation of two contracts (installation and three-year maintenance) for a total of $1.4 million. The new design incorporates strategic placement of many state-of-the-art security devices and was reviewed by the MIT Committee on Reactor Safeguard. Installation was implemented by Reactor Operations, MIT Facilities, IS&T, and SEMO. The major subcontractor was Siemens Building Technologies. The contracts were completed in June 2009 and reviewed by DOE. Installation began in August 2009 and was completed in spring 2010.

Professional Activities in Support of NRL's Mission

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

David E. Moncton
Director

More information about the Nuclear Reactor Laboratory can be found at http://web.mit.edu/nrl/www/.