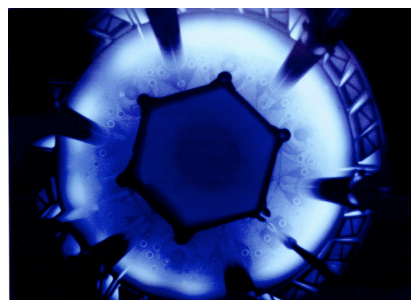


Nuclear Reactor Laboratory

Facilities and Resources

The MIT Nuclear Reactor Laboratory (NRL) 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 national scientific and engineering communities 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 the public, to researchers and staff members, and to 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 the major experimental facility of NRL. 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 available to experimenters are 1×10^{14} and 5×10^{13} neutrons/cm²-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.



MIT Nuclear Reactor

The MITR-II is the second of two research reactors that have been operated by NRL. The original reactor (the 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 celebrated its 50th anniversary in August 2008, has a long history of providing faculty and students with a high-quality neutron source complemented with 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, several thousand undergraduate and graduate students have benefited from their association with the 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 director of NRL. He and John A. Bernard, Lin-Wen

Hu, Edward S. Lau, Thomas H. Newton, and Robert Davine 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 51 individuals. The staff consists of six groups that include the previously mentioned six senior staff, five research staff, four technical staff, nine technical support staff, two academic staff, three administrative support staff, two technicians, 16 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 20 full- and part-time positions held by women and/or minorities, and, of the 18 engineering and management positions, five are held by women and/or 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, 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 minorities. NRL participated in the US Department of Energy's (DOE) 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 28 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-hours-per-day, seven-days-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: advanced clad irradiation (ACI-2) experiment 4DH4, diffractometer, and the 4DH1 student spectrometer.

The MIT reactor completed its 50th year of operation (its 34th 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 FY2009 was 25,300 megawatt-hours. This translates roughly to 5,600 hours of operation at full power.

Major maintenance items performed in FY2009 are summarized as follows:

The reactor's cooling towers were replaced with an upgraded model after nine years of use. The new towers, provided by the same vendor, incorporated a significant number of modifications from the original version. The major improvement was in leak prevention. The internal water cascades are made of a material that is stronger and more resistant to erosion. The new cascades are also designed for improved aerodynamics, therefore reducing air resistance and noise. The new tower design improved maintainability of the fan blades and motors and positioned them farther off the ground to reduce intake of environmental debris. Special filtration screens were installed to clean the cooling tower water before sending it into the rest of the reactor secondary system. Additionally, the variable frequency drive fan controllers were upgraded, and a large new equipment housing was built to protect tower instrumentation from adverse weather.

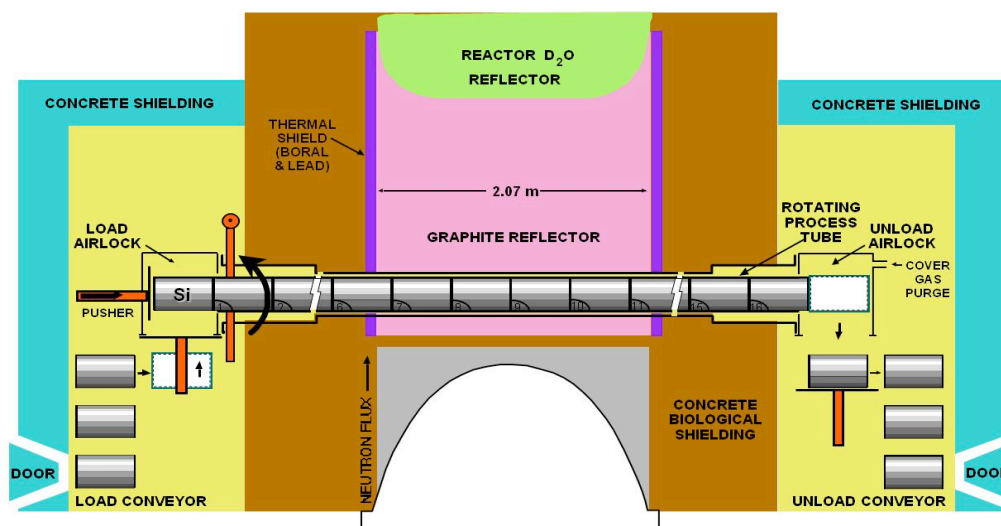
The instrumentation supervisor completed a major effort in upgrading the position indicator system for the reactor control rods. This effort concluded 2.5 years of design, component testing, fabrication, prototype construction and evaluation, final assembly, and safety review, all done in-house by reactor staff. The new system is a low-power, solid-state, light-emitting diode-based system of graphic and digital displays. A variety of human factor features were incorporated in the new units based on experience with the previous analog/rolling-digit displays. Redundancy was provided by having secondary display panels outside the control room (but visible from the console) and by making all the indicator modules interchangeable. All the displays utilize readily available components that come in many compatible varieties should upgrades be desired.

The project specialist completed transfer of the CO₂ cover gas system for the reactor's graphite region to a new system that uses currently available control devices. The old system, including a large gasholder, was retired. One goal of this project is to dismantle and remove the gasholder from the equipment room in order to provide space for installation of new heat exchangers.

The maintenance supervisor led a major effort in identifying and sealing CO₂ cover gas leakage paths. Additionally, new ventilation control devices were installed in many strategic air distribution locations to properly balance air flow within the containment building. This effort aimed to reduce argon-41 activities in the containment's air. The bulk of the project was completed within a month, followed by several months of ventilation and argon-41 data collection for fine-tuning the balance.

A significant maintenance focus over the course of FY2009 was to continue to inventory and package low-level laboratory waste (legacy and current). Two shipments were completed in June 2009. These shipments included five B-25 containers (12,000-pound capacity, certified for use in type A packaging), five B-12 containers (approximately half the size), and five 55-gallon drums of dewatered spent ion column resin.

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, Reactor Operations 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 that cover 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 the 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 was one student candidate for a reactor operator license and four students for upgrade to SRO licenses. All passed. Six MIT students are currently in training for license exams in September 2009.

The 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 the 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, the 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 to Support Nuclear Energy Research

The Advanced Test Reactor National Scientific User Facility (ATR NSUF), centered at Idaho National Laboratory (INL), and MITR have announced a partnership designed to increase user access to national reactor irradiation and testing capability. 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. This partnership with MITR is the first in an expected series of national partnerships designed to enhance the NSUF infrastructure and capability. The MITR will offer a portion of its test capability to the NSUF experimenters. Lin-Wen Hu and Gordon Kohse jointly manage 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. There is also a fracture-toughness testing capability available to support irradiation testing. The hot-cell facilities can accommodate a Charpy testing machine that could be used for on-site testing of irradiated materials.

Nanofluids Laboratory

The Nanofluids Laboratory experimental facilities and associated instrumentations 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 future research projects in general heat transfer and two-phase flow research as well as teaching at both 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), a national laboratory (INL), the DOE Nuclear Education and Engineering Research Program, DOE Innovations in Nuclear Infrastructure and Education (INIE) Program, and the King Abdulaziz City of Science and Technology. These experimental facilities are described briefly as follows:

- Single-phase heat transfer loop: This is a forced convection loop 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. This 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 is composed of 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
- 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 the 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% and was refueled in the previous fiscal year, increasing beam intensity by 20%.

This center maintains and operates the reactor's fission converter, PGNAA, and the thermal neutron beam facilities that are 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 a newly acquired optical microscope with precision stage and image analysis software are 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

One project completed during the past year improved the reactor's infrastructure by upgrading and web-enabling an existing neutron spectrometer system. This program is an important educational outreach activity for NRL. The objective was to refurbish a neutron time-of-flight spectrometry experiment that is installed on one of the thermal neutron beams at the MITR, with the addition of capability to operate the experiment interactively over the internet as part of MIT's iLab program. Student response has been positive, and hardware and software additions have been made to improve reliability and add functionality. Experiments online are being adapted for students at the high school, undergraduate, and graduate levels.

Neutron Scattering Facility

Revitalization of NRL's neutron-scattering capability is almost complete. This program was initiated three 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 will include new neutron-scattering instruments, a neutron diffractometer with polarizing capabilities, and a neutron optics test station. The neutron diffractometer is awaiting installation of new software and will be operational in the very near future. The neutron optics test station is operational. A new program to develop specialized neutron optics was recently funded by DOE. Professor Peter Fisher (MIT) and several outside groups have utilized the neutron optics test station to develop novel neutron detectors. Professor Moncton and Dr. Khaykovich will use this instrument to support a DOE-funded neutron optics research project.

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 Spallation Neutron Source (SNS), is under construction at the Oak Ridge National Laboratory and is widely anticipated to revolutionize this field and enable the United States to regain leadership lost to Europe decades ago. The SNS will catalyze a new generation of instrument development, a new generation of neutron scientists, and therefore 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). For 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. The facility is available to other users. Relative to the latter, the MITR-II is equipped with two pneumatic tubes that can be used for NAA. One offers a thermal flux of 5×10^{13} n/cm²-s; the other offers thermal fluxes of 8×10^{12} n/cm²-s. One of the tubes is automated so that samples can either be ejected to a hot cell within the reactor containment or transferred via a pneumatic tube to a laboratory in an adjacent building. In addition to the pneumatic tubes, there are two water-cooled facilities in which large numbers of samples can be simultaneously irradiated in a uniform flux. Samples in these facilities are rotated.

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 NRL's associate director of the research, development, and utilization group. She and her staff have developed a strong 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
- Supporting the Neutron Capture Therapy User Center for animal irradiations and chemical compound development
- 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

Reactor Engineering

Dr. Thomas H. Newton is associate director of reactor 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, advanced cladding irradiations, and irradiation of fusion insulation materials. This group also performs neutronic modeling of proposed experiments for evaluation of neutron fluxes, reactivity, and heat generation. Engineering support for the installation, upgrade and operation of a neutron diffractometer has continued as well. Other activities of this group include supervising the management of fuel in the reactor and fission converter, overseeing shipments of spent fuel, and other engineering services in support of the reactor. 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 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 for use in 2013. The MITR is expected to be the first reactor worldwide to use this fuel.

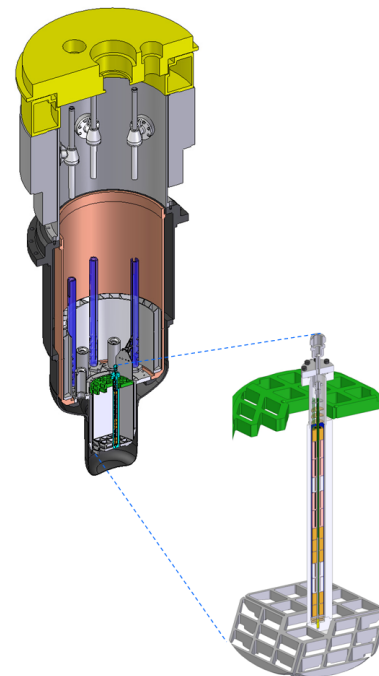
With ongoing support from the RERTR program, neutronic and thermal-hydraulic modeling tools for the MITR conversion study have been developed and benchmarked for both steady-state and transient conditions. These models are being used to compare the current HEU fuel with proposed LEU fuels. Burn-up modeling tools using both Monte Carlo and diffusion theory methods are also being developed so that the fuel life, reactivity, and neutron fluxes 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 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 2014.

In-Core Loops

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. MITR offers a unique technical capability that involves the design and use of in-core loops that replicate pressurized water reactor (PWR)/boiling water reactor conditions to study the behavior of advanced materials and scoping study 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. 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), the capability to control chemistry and thermal conditions to reflect prototypic conditions, its 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 that included 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.

An upgrade and redesign of the In-Core Sample Assembly (ICSA) was fabricated and test-fitted in February 2009. The goals of the ICSA 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. Design of a gamma heating susceptor that would allow irradiation at up to 800°C is under way. Several industry and research users have expressed interest in using this facility.

As a result of the partnership between the MITR and INL's ATR NSUF, several projects and experiments are ongoing: in-core irradiation of SiC high-temperature sensor materials for the Colorado School of Mines, joint development of in-pile measurement crack growth instrumentation with INL and design and fabrication of a new ICSA for future NSUF experiments, and demonstration of a high-temperature ICSA gamma heating module for future NSUF experiments.

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 (INIE) 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. The INIE Program 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. From 2003 through 2009, 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 student research assistantships.

Investigation of Nanofluids for Nuclear Applications

Dr. Lin-Wen Hu and professor Jacapo Buongiorno (NSE) led a research group to study the heat transfer enhancement of nanofluids. Nanofluids are engineered colloids made of a base fluid and nanoparticles (1–100 nm) in various forms. The presence of the nanoparticles alters the thermal-hydraulic behavior of the fluid: increased thermal conductivity, increased single-phase convective heat transfer, and enhanced critical

heat flux and accelerated quenching. Given their potential for enhanced heat transfer performance, nanofluids are being investigated for numerous applications including electronics, manufacturing, chemical processes, and power generation. A collaborative NRL/NSE research program has been initiated to assess the feasibility of nanofluids for nuclear applications. Potential applications include PWR primary coolant, emergency core cooling systems, and severe accident cooling. Another application being evaluated is to use the nanofluids to pretreat the heated surface to enhance boiling heat transfer. The program is sponsored by AREVA, Electric Power Research Institute, King Abdulaziz City of Science and Technology in Saudi Arabia, a gift from a private donor, ABB Corporate Research, NSF, and INIE.

New Initiatives

DOE Nuclear Engineering Infrastructure Support Program

In 2009, DOE initiated a program to succeed its INIE Program, which ended in 2008. As a result of a proposal submitted to DOE, John Bernard was awarded funding for this program, which will support several NRL and NSE projects.

Compact Ultrabright Intense X-ray Science and Technology Center

David Moncton, William Graves, and Franz Kaertner (Research Laboratory of Electronics) have initiated a proposal to design and install a compact ultrabright intense X-ray light source at NRL. The goal will be a laboratory-sized inverse Compton scattering source that offers unprecedented small source size and ultrashort pulse length, enabling entirely new imaging and time-resolved X-ray methods. In addition, its output flux and brilliance rival modern synchrotrons, bringing the most advanced scientific and medical X-ray probe into the university, industrial, and medical laboratory. The initial phase will also involve fundamental research on coherent electron emission from photocathodes, and the fully coherent sources targeted in Phase II will revolutionize imaging of condensed matter, small molecules, and proteins in the way that optical laser holography transformed optical imaging. A hard X-ray source with the energy resolution and time duration achieved at the transform limit will usher in a new era in nonlinear atomic physics, inelastic X-ray scattering studies of fundamental electron excitations in condensed matter and will affect fundamental physics research enabling coherent nuclear spectroscopy and nuclear optical clocks with unprecedented precision. The mission of CUBIX requires a combination of research in superconducting accelerators, ultrafast lasers at the attosecond frontier, and nanofabrication technology at limits approaching atomic resolution. There are currently no centers in the world that bring these three fields together to generate hard X-rays from compact sources.

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.

Modern approaches to safety combine personal expertise and strong training with a methodology for continuous improvement. NRL is now using a continuous improvement program that has three major goals: reducing unplanned shutdowns, minimizing environmental releases, and limiting personnel exposures as per the "as low as reasonably achievable" principle. The program, which is computer based, allows all NRL employees to provide input on how to improve reactor operations and safety whenever they see a "condition" of concern, including nuclear, radiological, and industrial safety. Condition reporting is the driver for a series of assessment and follow-up actions.

Reactor Radiation Protection

Radiation protection coverage is provided by the Reactor Radiation Protection Program of the Environment, Health, and Safety Office (EHS). While this is a separate organization within MIT, it is very responsive to the NRL management team. Personnel include a deputy director for EHS serving as the reactor radiation protection officer (William McCarthy), an EHS officer (Patricia Drooff), 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 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 have worked closely with the Reactor Radiation Protection staff to ensure the successful enhancement of NRL's ALARA Program. The major successes achieved include:

- An increased level of awareness pertaining to dose reduction, which is now at the forefront of conducting day-to-day operations of the MITR
- Enhanced communication of work activities coupled with the ALARA process resulting in practical application of a number of specific dose reduction techniques
- A 30% reduction in annual collective dose from the previous year
- Implementation of methods to measure programmatic effectiveness and a system to ensure future resources are applied to sustain dose reduction activities

The ALARA Program enhancement process was divided into three categories: establish ALARA program policies and procedures, field test program elements, and assess results.

During 2008 and 2009, the increased focus on ALARA-related policies, procedures, and metrics has resulted in several enhancements to the facility day-to-day practices in conducting work safely and efficiently. Plans and lessons learned have been captured throughout the year and lay the framework for continued enhancements. The staff is committed to ensuring that continued incorporation of ALARA practices will be sustained during the normal course of business.

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 will be implemented by Reactor Operations, MIT Facilities, MIT Information Sciences and Technology, and MIT Security and Emergency Management Office. The major subcontractor will be Siemens Building Technologies. The contracts were completed in June 2009 and were under final review by DOE. Installation is expected to start in early August 2009.

Professional Activities in Support of NRL's Mission

NRL has always maintained a very close working relationship with the 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. John Bernard, the 2008 TRTR chair, and NRL staff successfully hosted the 2008 TRTR Annual Meeting last September on Cape Cod. Approximately 150 individuals attended the meeting. Participants included managers and directors of research reactors, educators, administrators, regulators, and research scientists and engineers. This meeting also presented an opportunity for the research reactor community to meet with individuals who work for DOE and the NRC.

David E. Moncton
Director

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