Nuclear Reactor Laboratory

Facilities and Resources

The MIT Nuclear Reactor Laboratory (NRL) is an interdepartmental center that operates a 5 MW research reactor. The research reactor, which is referred to as the MITR-II, is a heavy-water reflected, light-water cooled and moderated nuclear reactor that utilizes flat, plate-type, finned aluminum-clad fuel elements. 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 has a long history of providing faculty and students from MIT and other institutions with a state-of-the-art neutron source along with an extensive infrastructure to facilitate its use. Its principal mission has been to support 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, countless undergraduate and graduate students have benefited from their association with NRL by being offered an opportunity to pursue their research by utilizing a research reactor that has provided a unique hands-on environment.

Another major role of NRL has always been to support the education and research missions of MIT as well as other local area universities, hospitals, and industries. A secondary but no less important role of NRL has been educating the general public about the benefits of maintaining a strong nuclear science program in the United States. This has been accomplished by providing tours and lectures that describe and clarify different nuclear science and technology programs.

Reactor Administration

NRL's organizational structure is comprised 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, 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 facility, and to provide an environment of support and excellence for researchers and students.

NRL currently employs 53 individuals. The staff is broken down into six groups that include the previously mentioned senior staff, six research staff, five technical staff, 10 technical support staff, one academic staff, three administrative support staff, two technicians, 14 part-time student/operators, and six 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, three are held by women and/or minorities. Long-term employees include an engineer who is both a woman and a minority; the superintendent of operations, who is a minority; a neutron activation analyst, 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. The current roster of 18 active students (licensed and in training) includes five women, four of whom are minorities, and 13 men, six of whom are 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, 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 members of the group are licensed by the US Nuclear Regulatory Commission (NRC), and most hold a senior reactor operator license. At present, there are 34 actively-licensed individuals. 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, and one technician to support details.

The MIT reactor completed its 48th year of operation (its 32nd 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 4.8 MW. Total energy output for fiscal year 2007 was 28,500 megawatt-hours. This translates roughly to 5,950 hours of operation at full power.

Reactor activities during this fiscal year focused on support of reactor experiments, utilization, and equipment upgrades. Emphasis has again been on reactor operating safety and improvement of reactor reliability and availability, with strengthening of the reactor's Continuous Improvement program. The following highlight activities support these initiatives:

- Five major maintenance outages that centered on reactor and experiment equipment maintenance (both preventive and corrective), tests and calibrations, and upgrades
- Launch of WebCAP software as a continuous improvement effort, for ease of deficiency reporting and as a management tracking tool for corrective actions
- Identification of spare parts to have in stock for key reactor components
- Favorable evaluations by three NRC inspections, one independent audit, and one inspection by American Nuclear Insurers

- Improvement of reactor fuel quality control by active communication between MIT, DOE, and the manufacturer to complement the refueling program, which remains strong and active
- Active reduction of on-site storage of spent fuel by close coordination with DOE
- Complete replacement of all battery cells for the reactor's emergency battery system
- Strengthening of the reactor's crane and hoist maintenance, inspection, and training program
- Enhancements of security hardware, such as access control doors, surveillance cameras, and perimeter fencing
- Improvement of experiment shielding to reduce interference between neighboring individual experiments
- Maintenance of International Standards Organization 9001 certification for the neutron transmutation doping (NTD) silicon program
- Addition of 18 new airtight penetrations through the reactor containment wall for installation of optical fiber for expanded data networking
- Improvement of reactor back yard grounds to support truck access, security purposes, and air quality control near fan intakes
- Expanded outreach program in response to increased requests for lectures and tours by local schools and other recognized national education organizations
- Major visits by NRC chairman Dr. Dale Klein, Dr. Adam Cohen of the DOE, and a crew filming for a PBS television production on future energy
- Increased effort to inventory and prepare low-level waste for shipment

In addition, NRL continued its upgrade of reactor and experiment instrumentation to improve reliability and remote access capability with improvements such as:

- Complete replacement of all temperature, humidity, and pressure instruments with remote digital sensors for the annual containment building pressure test
- Completion of a bulk liquid CO_2 system installation, including remote indicators
- Expansion of the coverage area of the reactor intercom system
- Addition of a remote speed control for the pneumatic tube irradiation system's blower, with remote indication of vacuum, replacement of the receiving-end blower, and complete replacement of its circuit breaker and associated wiring
- New digital indication and alarms for containment building differential pressure
- Continuation of student spectrometer experiment upgrade
- Development of digital position indicator prototype for the control blades

Reactor Operations provides a major service in the production of NTD 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 the production of memory chips. This service provides commercial income (approximately $1.2 million annually) that is used to offset operating costs and to provide some support for reactor experiments.

To fulfill one of the stated missions of NRL, Reactor Operations trains up to six MIT undergraduates each year, typically starting in their freshman years, 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 these same topics. In addition, students are taught how to operate the MITR. 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 both 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, two sets of NRC exams were administered on site. Four students obtained reactor operator licenses, three students were upgraded to SRO licenses, and three reactor staff members obtained their licenses. Six MIT students and two reactor staff members are currently in training for license exams in September 2007.

The relicensing of the MITR with a concomitant upgrade in power is in progress. It was previously determined that the MITR could operate at a maximum power of 6 to 7 MW with the existing heat removal equipment. A decision was subsequently 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 the continued operation of the MITR. This mode of operation has been ongoing since 1999.

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 of NRL in their use of the reactor and its irradiation facilities. Some of the 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 (NCT) User Center for animal irradiations and chemical compound development
- Providing researchers with a service-based infrastructure that utilizes the MITR 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

The reactor was well used during the year. An irradiation experiment to study the response of SiC/SiC composite materials to pressurized water reactor (PWR) conditions was the major in-core experimental activity. These materials have been proposed as a replacement for Zircaloy fuel-cladding for PWRs in order to improve fuel performance in loss-of-coolant accidents and thus allow for increased reactor power and higher fuel burnup. A Phase I irradiation was completed in September 2006 and samples were removed for examination at MIT and mechanical property testing at Oak Ridge National Laboratory. A Phase II irradiation was started in December of 2006 containing some new specimens and other specimens continued from Phase I. Phase II is scheduled to continue through September 2007. This project is supported by the DOE and Westinghouse. Several graduate students have participated in both the experimental work and associated fuel clad behavior modeling studies. The irradiation studies at MIT under realistic PWR in-core conditions have been key to the continued interest of DOE in this development.

Other research and utilization highlights achieved during the past year include:

- Support of long-term material damage studies for new types of fusion reactor materials
- Neutron activation analysis to evaluate the connection of trace elements, particularly vanadium, to the occurrence of Amyotrophic Lateral Sclerosis (ALS) through animal tissue samples and human scalp and genital hair samples. This project is conducted in support of a Massachusetts General Hospital study.
- Neutron activation analysis to provide routine ultra-trace element analysis in enriched B-11, a material used as a dopant in semiconductors
- Neutron activation analysis in coordination with the National Institute of Standards and Technology in order to quantify a new certified standard reference materials
- An inductively coupled plasma spectrometer (ICP-OES) was installed and utilized for a variety of trace element analysis studies. Notable applications included boron in tissue in support of boron neutron capture therapy applications, aluminum in nanofluids being studied for heat transfer enhancement, and gold in drug delivery compounds.

- Creation of several protactinium-233 sources for the Woods Hole Oceanographic Institute (WHOI). The researchers use the sources to study ocean circulation and its relation to abrupt climate change.

A number of reactor irradiations and services were performed for research groups outside MIT. Whereas most of the outside users pay for irradiation services at the reactor, educational institutions needing such services for their own academic or research purposes are assisted in this regard by the DOE through its Reactor Sharing Program. This grant reimburses NRL for the costs of providing irradiation services and facilities to other not-for-profit institutions (including teaching hospitals, high schools, and universities). Under this program, 500 students and 50 faculty and staff from more than 30 other educational institutions benefited from visits to and use of the reactor during the past year.

For education of the general public and students at all levels in local and other New England schools, the reactor staff provides lectures and tours periodically throughout the year.

Several new initiatives are also under development by this group, including design and construction of a new in-core cladding testing facility, neutron beam research utilizing NRL's soon-to-be-implemented neutron diffractometer, neutron phase contrast imaging, a web-enabled student spectrometer, and an expanded DOE-sponsored outreach program called the Harnessed Atom.

Reactor Engineering

Dr. Thomas H. Newton is the associate director of reactor engineering at NRL. This group's activities include experimental support and development for in-core experiments such as the advanced clad irradiation, irradiation of fusion insulation materials, and neutronic modeling of proposed experiments. In addition, Dr. Newton is the principal investigator for a research project funded by Argonne National Laboratory that will eventually enable MITR, along with the other research reactors within the high-powered reactor group (University of Missouri Research Reactor Center, NIST, High Flux Isotope Reactor, and Advanced Test Reactor), to be converted from high enriched uranium to low enriched uranium (LEU) fuel. These research activities, which involve neutronic and thermal-hydraulic modeling and design of the LEU fuel and core for future use in the MITR, are of importance because the DOE has made a commitment to convert all research reactors to LEU fuel by 2014.

This group is also providing the engineering support necessary for the installation of a neutron diffractometer, expected to be operational later this year. Other activities of the group include supervision of the management of fuel in the reactor and fission converter and oversight of shipments of spent fuel, as well as other engineering services.

Research Programs and Facilities

In-Core Loop and Materials Studies

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 Generation IV (Gen-IV) reactors. MITR offers a unique technical capability that involves the use and installation of in-core loops that replicate PWR/boiling water reactor (BWR) conditions to study the behavior of both advanced materials and microparticles of advanced fuels for Gen-IV reactors. 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 [LWR]), 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.

To support the advanced materials and fuel research program, MITR is equipped with post-irradiation examination (PIE) 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-ton and 20-ton capacities, and several transfer casks. There is also a fracture-toughness testing capability available to support irradiation testing. Our hot cell facilities can accommodate a Charpy testing machine that could be used for on-site testing of irradiated materials. The PIE facilities are currently being refurbished with funds from DOE's Innovations in Nuclear Infrastructure and Education (INIE) Program. Additional equipment upgrades and purchases to support PIE, such as manipulators, alpha detectors, and ventilation, are also being funded by INIE.

The laboratory plans to continue building upon the successes of several in-core loop and materials studies that were conducted within the past eighteen months. These are summarized below.

SiC Duplex Advanced Clad Irradiation

This project, directed by Dr. Gordon Kohse and Professor Mujid Kazimi, involves the production and testing of candidate duplex SiC/SiC composite cladding materials for LWRs. These materials have potential advantages over conventional metal alloy cladding materials in terms of both improved safety margin and higher burnup. Irradiation testing in prototypical PWR and BWR coolant conditions began in May 2006 and continued though this reporting period. PIE is then planned to measure weight loss, thermal conductivity changes, mechanical property tests, and scanning electron microscopy. The irradiation testing and some of the PIE are being conducted at NRL with the MITR's in-core loop facilities and hot cells.

Advanced Materials Testing Facility

In 2001, MIT recognized the need for an advanced materials test facility (AMTF) and proposed to DOE the assembly of such a facility at the MITR. This proposal was approved as part of the INIE award that MIT subsequently received as the lead member of the New England INIE consortium (the other members are the Rhode Island Nuclear Science Center, the University of Massachusetts-Lowell, and the Rensselaer Polytechnical Institute). Procurement and installation of the equipment are ongoing, as is an upgrade of the MITR's existing hot cells, which are used to support in-core experiments. The combination of the AMTF and MITR will be ideal for carrying out the more basic components of research on materials in a radiation environment. As mentioned, the MITR offers good geometric access and space for up to three independent irradiation tests, it has a sufficiently high in-core flux to simulate accurately the radiation environment in PWR/BWR power reactors, and it has the ability to control chemistry and thermal fields to reflect prototypic conditions.

High Temperature Irradiation Facility

This project is directed by Professor Ronald Ballinger, Professor Mujid Kazimi, and Dr. Gordon Kohse. The High Temperature Irradiation Facility (HTIF) was designed to provide an environment appropriate for test irradiations of high-temperature, gas-cooled reactor materials, and in November 2005 this in-core loop was installed in the MITR. A demonstration test was performed with temperatures up to 1,600 °C. A variety of materials relevant to high-temperature gas reactor design, including SiC, AGR matrix graphite, and nonfueled coated particles, were irradiated. Development and in-pile testing of high-temperature-resistant materials are essential for the Gen-IV reactor programs. The HTIF will be a valuable test facility for research on high-temperature-resistant materials.

Investigation of Nanofluids for Nuclear Applications

Dr. Lin-Wen Hu and Professor Jacapo Buongiorno (Nuclear Science and Engineering [NSE]) led an experimental study of water-based nanofluid heat transfer enhancement. Nanofluids are engineered colloids made of a base fluid and nanoparticles (1-100 nm) in various forms. The presence of the nanoparticles produces four major effects on the thermal-hydraulic behavior of the fluid: increased thermal conductivity, increased viscosity, increased single-phase convective heat transfer, and increased departure from nucleate boiling heat flux. The occurrence and magnitude of these effects depend on nanoparticle loading, material, and shape in ways that are not yet clear. Given their potential for superior heat removal performance, nanofluids are being investigated for numerous applications including electronics, manufacturing, chemical processes, cosmetics, pharmaceuticals, and power generation. A collaborative NRL/NSE research program has been initiated to assess the feasibility of nanofluids for nuclear applications. In principle, the use of water-based nanofluids could improve the performance of any water-cooled nuclear system that is heat-removal limited. Potential applications include PWR primary coolant, standby safety systems, accelerator targets, and plasma diverters. The program comprises the following activities, currently sponsored by the Idaho National Laboratory, NRC, AREVA/Framatome, and INIE:

- Construction of two out-of-pile loops to investigate nanofluid heat transfer enhancement
- Procurement of water-based nanofluids (i.e., C, SiO_2, ZrO_2, Al_2O_3)
- Property measurements: thermal conductivity (transient hot wire method) and viscosity (ultrasonic viscometer)
- Property modeling with molecular dynamics simulations
- Single-phase heat transfer and pressure drop measurements in flow loop
- Single-phase heat transfer modeling, both conceptual and computational fluid dynamics
- Critical heat flux measurements: experiments with heated wire and in flow loop with PWR-equivalent annulus and zircaloy-heated surface
- Nuclear application evaluations: subchannel, safety, and neutronic analyses of PWRs with nanofluid coolant

High-Performance Fuel Design for Next-Generation PWRs

This project is directed by Professor Mujid Kazimi, Professor Pavel Hejzlar (NSE), and Dr. Gordon Kohse. A new type of in-core experiment that has captured the interest of industry and the media and was carried out in the MIT research reactor to test performance of innovative annular fuel designs as a part of the Gen-IV power reactor research effort by NSE has proven to be very successful. The objectives of this project were to determine fission gas release rates and fuel dimensional and structural changes during irradiation and achieve a range of burnups to identify potential performance differences among the fuel types. The annular fuel specimens were designed so that, with the combination of enrichment, inner and outer annulus dimensions, and gap thermal properties, the fuel heat temperature would be similar to that of a reference reactor design. This is the first irradiation of a fueled test capsule at the MIT reactor and one of very few undertaken at any university reactor. At the American Nuclear Society conference in Reno in June 2006, the Westinghouse presentation at the special plenary session on Innovation in Nuclear Technologies by senior vice president and chief technology officer Regis Matzie was fully devoted to MIT's annular fuel project, and, as a result, Westinghouse is putting some of their own funding into further development of this fuel. In September, Reuters published an article "Scientists Develop More Powerful Nuclear Fuel," which reports on this new fuel development and was picked up by a number of media outlets, including MSNBC.

In-Core Sample Assembly and Cooled Irradiation Facility

A titanium tube has been built for the insertion of samples into the reactor core for high flux irradiations. This project, funded by Composite Technology Development, Inc., and directed by Thomas Newton, was used to test fusion magnet insulation materials for suitability in simulated fusion radiation environments. A water-cooled lead shield was developed to lower the reactor gamma component and provide a cooled environment for the sample irradiations.

Generation-IV Program

In addition to providing a first-class, state-of-the-art facility for research that responds to present-day issues and concerns, NRL is looking ahead in order to meet future challenges. One particular challenge that needs to be addressed is the reliance of the United States on fossil fuels. Currently only 20 percent of the country's energy resources are provided by nuclear power. The proposed Gen-IV Program is a major research and development initiative to design, build, and operate Gen-IV reactors that will provide the United States with an economical, safe, and reliable energy source. NRL is uniquely qualified to be a key contributor to the design and performance of experiments evaluating the advanced materials and fuels needed for Gen-IV reactors.

Neutron Capture Therapy Program

Directed by Professor Otto K. Harling (NSE), neutron capture therapy for cancer research is the leading NCT research program in the United States and is considered to be among the top in this field worldwide. Professor Harling's group maintains, develops, and operates high-performance irradiation facilities for NCT-related research utilizing the MITR. This research program has been supported primarily by DOE and comprises the following facilities and capabilities:

- High intensity, high purity beams of thermal and epithermal neutrons that approach the theoretical optimum for 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 project supports, 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 prior to 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 (HRQAR). 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.

Innovations in Nuclear Infrastructure and Education Program

The DOE established the INIE Program to provide qualified universities and reactor facilities with funds 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. The decision to implement this program is proving 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 has 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.

Now in its fifth year, this program has led to renewed interest in utilization of the MITR. INIE has supported numerous research initiatives conducted by NSE faculty members and researchers. Funds received during the fourth year of INIE were used for: upgrades to the NCT user facility; design and construction of the PIE facility for in-core irradiations of advanced fuels and materials, which will ultimately support research for the next generation of power plant initiatives; for equipment in support of phase contrast imaging research; and for two MIT graduate students conducting research in the areas of neutron interferometry and NCT.

NCT User Center

INIE provided funds to begin offering facilities at MIT as a NCT User Center. It is the only such program in the United States and is essential for a viable research and clinical program in NCT. The center is made up of the aforementioned state-of-the-art neutron facilities that have been developed for NCT research and are in operation at the MITR. INIE funds supported the following upgrades during the past year:

- Purchase of a new optical microscope with precision stage and image analysis software
- Experiments to study the role of the vascular endothelium in mediating the onset of radiation-induced gastrointestinal syndrome as well as leakage of the gap junctions comprising the blood-brain barrier (Professor Coderre, MIT)
- Biodistribution and therapy experiments in tumor-bearing mice to study the effectiveness of boronated liposomes as tumor targeting agents for BNCT. HRQAR was also performed on biodistribution samples to determine the uniformity of tumor boron uptake. (Professor Hawthorne, University of Missouri)
- Boron quantification in newly synthesized boronated metalloporphyrin compounds as possible tumor targeting agents for BNCT (Michi Miura, Brookhaven National Laboratory)

- A measurement campaign in Bariloche, Argentina as part of the International Dosimetry Exchange for BNCT that is led by MIT. These data allow dose prescriptions to be consistently expressed between the two BNCT centers in the Americas and complement those previously obtained at four centers in Europe (Dr. Sara Liberman, Argentine National Atomic Energy Commission). Centers in Birmingham, UK and Casaccia, Italy have since invited MIT to characterize their epithermal neutron beams, for which clinical protocols are being prepared.
- Biodistribution experiments including HRQAR to investigate the ability of boronated nitroimidazoles to target hypoxic regions of SCCVII tumors (Dr. Peter Binns, MIT and Professor David Lee, Harvard Medical School)
- BNCT therapy experiments using two different boron-containing monoclonal antibodies in rats with stereotactically implanted F98 brain tumors (Professor Rolf Barth, Ohio State University)
- Studies to test the feasibility of using boron-containing carbon nanotubes as radiation detectors (Professor Timothy Swager, MIT).
- Preliminary studies to apply a newly developed peptide that selectively targets tumor acidosis as a possible agent for BNCT (Professor Yana Reshetnyak, University of Rhode Island, and Professor Don Engelman, Yale University)
- PhD thesis research for an MIT student to determine if multiple injections of boron compounds can improve the uniformity of tumor uptake and overall efficacy of BNCT

In addition, a Swedish venture capital firm has expressed interest in collaborating with MIT on a clinical trial to test the efficacy of BNCT for recurrent glioblastoma. Discussions with the company are still at a very early stage and are expected to continue during the next fiscal year.

Phase Contrast Imaging

This project is directed by Dr. Richard Lanza. Phase contrast imaging uses the wave properties of neutrons to greatly increase spatial resolution and contrast in materials imaging. A beamline and detector system for implementing this technique was installed at NRL. A new approach is now being examined that can lead to phase tomographic imaging, which would enable us to produce three-dimensional images of materials that cannot be distinguished by their density and absorption.

In-Core Loops

This portion of the MITR INIE program involves the design and construction of a post-irradiation examination facility for in-core irradiations of both advanced fuels and materials. The advanced fuels work is directed by Professor Mujid Kazimi. The materials studies are primarily coordinated by Professor Ronald Ballinger. Both are assisted by Dr. Gordon Kohse and Yakov Ostrovsky. The MITR staff person who interfaces with these projects is Dr. Lin-Wen Hu.

Educational Innovations

NRL hosted nuclear engineering students from across the US who participated in a thermal hydraulics experiments course for nuclear engineers that utilized NRL's INIE-funded Thermal Hydraulics Laboratory.

Infrastructure Enhancements

INIE funds were responsible for several important upgrades to the MITR. The improvements include:

- A new manipulator in reactor floor hot cell #1
- Repair of hot cell #2 manipulators
- Local and remote area radiation monitors for hot cells now functional
- Parts purchase for repair of shim blades/regulating and position indicators
- A new HPGe detector for neutron activation analysis (NAA) activities.

Environmental Research and Radiochemistry

Dr. Lin-Wen Hu has taken on the role of overseeing the operation of NRL's environmental research and radiochemistry laboratories. The MITR is currently equipped for both prompt and delayed gamma NAA. For the former, a prompt gamma spectrometer was built as part of the NCT 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 is equipped with five pneumatic tubes that can be used for NAA. One offers a thermal flux of $5x10^{13}$; the other four offer thermal fluxes of 4 to $8 x10^{12}$. 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 four 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/or service-oriented collaborations were continued with several MIT research laboratories as well as with other educational and research institutions, including Harvard, the California Institute of Technology, Tufts University, the University of Connecticut, and WHOI.

The following list represents some of the ongoing research activities conducted at NRL involving NAA:

- Analysis of 24 samples of Bovine Liver 1577c, which is primarily used for testing contaminants in food products. This was part of a program initiated by NIST for the next generation of certified standard reference material.
- Several trial irradiations of hair were completed to investigate levels of vanadium, magnesium, and manganese to attempt to correlate their incidence with ALS, also known as Lou Gehrig's disease. This study is being conducted by Dr. Robert H. Brown and Dr. Xudong Huang of Massachusetts General Hospital.

- Trace element analysis was conducted on various types of fish to demonstrate the advantages of using NAA to determine mercury contamination, which is severely neurotoxic, particularly to fetal development during the gestational period. This demonstration is a hands-on exercise that serves as an educational tool underscoring the Food and Drug Administration's warning against fish consumption by pregnant women. This annual exercise is being conducted by Lin-Wen Hu.

New Research Initiatives

Neutron Spectrometer Experimental Facility

One of the initiatives during the past year has been to improve 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 is 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. An initial implementation of the LabVIEW controlled experiment was installed and tested during the spring term of 2006–2007. Student response was positive, and hardware and software upgrades are currently underway to improve reliability and add functionality in preparation for putting the experiment online. Experiments online will be adapted for students at the high school, undergraduate, and graduate levels.

Neutron Scattering

Although neutron scattering had a long and distinguished history at NRL, it was not actively pursued after the retirement of Professor Cliff Shull. However, a revitalization of NRL's neutron scattering program was initiated two years ago under the direction of Professor Moncton with the assistance of Dr. Boris Khaykovich. As a result of their efforts, this project (which includes installation of new neutron scattering instruments; a neutron diffractometer with polarizing capabilities; and a neutron optics test station) is now nearing completion. Initial tests and first experiments are expected to start by the end of 2007.

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 currently 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 of MIT to conduct early phases of some experiments more quickly than at large facilities and to test and develop new neutron optics components.

Safety and Security

Operational Safety

Many years ago, MIT established a very effective means of ensuring safe operation of the reactor by appointing independent individuals to a committee known as 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 excellent guidance 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. These results are shown in Table 1.

Modern approaches to safety combine personal expertise and strong training with a methodology for continuous improvement. NRL is now utilizing 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), a separate organization within MIT. Personnel include a deputy director for EHS serving as the reactor radiation protection officer (Frederick F. McWilliams); an EHS officer serving as the assistant reactor radiation protection officer (Douglas W. LaMay); two technicians; and part-time secretarial support. Routine activities include but are not limited to radiation and contamination surveillance, experimental review and approvals, 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. In addition to the above, the deputy director also serves as the EHS lead contact to NRL under the EHS Management System organizational structure.

Table 1. MITR Inspection Record, 2002–2007

Inspection Date	Inspection Type	Result
06/23/03	Inspection on security/safeguards	No deficiencies
06/25/03	Inspection on reactor operations	No deficiencies
02/02/04	Licensing exams	4 ROs + 1 SRO, all passed except 2 ROs, 1 of whom passed a subsequent makeup exam
03/29/04	Inspection on RRPO/special nuclear material/reactor operations	No deficiencies
06/07/04	Inspection on reactor operations	No deficiencies
08/05/04	Special inspection on safeguards	No deficiencies
09/07/04	Licensing exams	8 ROs + 5 SROs, all passed
09/06/05	Licensing exams	6 ROs + 6 SROs, all passed
11/14/05	Inspection on RRPO/reactor operations	No deficiencies
09/05/06	Licensing exams	6 ROs + 5 SROs, all passed except 2 ROs, 1 of whom passed a subsequent exam, and 2 SROs, 1 of whom passed a subsequent exam
10/16/06	Inspection on security/safeguards	No deficiencies
10/16/06	Inspection on reactor operations/ requalification/emergency preparedness/RRPO	No deficiencies; one unresolved item
3/12/07	Licensing exams	2 ROs + 2 SROs, all passed except 1 SRO
05/07/07	Inspection on reactor operations/ requalification/emergency preparedness/RRPO	No deficiencies; unresolved item closed

[a]Reactor Radiation Protection Office
[b]Reactor Operator
[c]Senior Reactor Operator

Professional Activities in Support of NRL's Mission

NRL has always maintained a close working relationship with the Organization of Test Research and Training Reactors, (TRTR) which represents research reactor facilities across the nation from government, major universities, national laboratories, and industry. The management of NRL is looking forward to hosting the 2008 TRTR Annual Meeting. 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, as chair-elect for 2008, will be hosting this organization's annual meeting in the fall of 2008. Participants will include managers and directors of research reactors, educators, administrators, regulators, and research scientists and engineers. This meeting also presents an opportunity for the research reactor community to meet with individuals who work for the 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/.