Nuclear Reactor Laboratory

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 and other institutions with both a state-of-the-art neutron source and the infrastructure to facilitate use of that source. In addition to NRL's role as a major center for neutron research, the staff of NRL is also committed to educating the general public about the benefits of maintaining a strong nuclear energy program by promoting education and training in the nuclear sciences and technologies within the United States.

The reactor, designated the MIT Reactor (MITR), 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 thermal neutron flux available to experimenters is 5×10^{13} neutrons/cm^2 s. 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 are available.

During the past 46 years of operation, MIT undergraduate and graduate students have benefited tremendously from the hands-on experience they have gained at NRL. This is not only a result of students being able to conduct research that has resulted in the successful completion of more than 200 MS and PhD theses, but also a function of the more than 300 students who have participated in NRL's Reactor Operator Training Program. During this time period, cutting-edge research has also been conducted by MIT faculty as well as faculty and scientists from other institutions. Today, the NRL is a world leader in the area of boron neutron capture therapy (BNCT) research. It also boasts state-of-the-art in-core sample assemblies.

MIT Research Reactor

The MIT Reactor completed its 45th year of operation in 2003–2004, its 29th since the 1974–1975 shutdown for upgrading and overhaul. The reactor operated continuously (seven days per week) to support major experiments. On average, the MIT Reactor was operated 70 hours per week at its design power level of 5 MW. Energy output for the MITR-II, as the upgraded reactor is now called, totaled 591,500 megawatt-hours as of June 30, 2004. The MITR-I generated 250,445 megawatt-hours in the sixteen years from 1958 to 1974.

To summarize briefly, the reactor was well utilized during the year, although still more experiments and irradiations can be accommodated in view of the number and versatility of the many experimental facilities. The number of specimen irradiations was 292. There were 53 irradiations in the medical rooms, many in support of the neutron capture therapy program for the treatment of brain cancer and subcutaneous melanoma. Theses and publications on research supported by the reactor are running at about 5 and

20 per year, respectively. Approximately 1,500 people toured the MIT Research Reactor from July 1, 2003, through June 30, 2004.

Reactor Administration and Organization

Significant developments occurred at NRL during the past year. These include the appointments of David E. Moncton as director and Susan E. Guralnik as administrative officer. Professor Moncton joins NRL after serving as the executive director of the Spallation Neutron Source at Oak Ridge National Laboratory and the associate director at Argonne National Laboratory. In addition, he has an appointment in the Department of Physics as an adjunct professor and is the principal investigator for a proposed MIT project to construct a linac-based x-ray laser user facility on the campus of the Bates Linear Accelerator Center. Susan Guralnik is an extremely competent business manager with extensive experience at MIT. They, along with John A. Bernard, director of reactor operations, comprise NRL's management team.

There are currently 44 individuals employed by NRL in 5 main groups: 15 senior staff, 11 technical support staff, 1 administrative staff and 3 administrative support staff, 2 technicians, and 12 part-time student operators/trainees. In general, support staff, student employees, and technicians at the NRL have specific responsibilities to reactor administration and the reactor engineering and reactor operations groups. Reactor senior staff divide their expertise between reactor operations and reactor engineering. Although the existing NRL organization of responsibility was successful in the past, the increased volume of research that has resulted from the INIE grant has made it necessary to further delineate responsibilities within the reactor engineering group with the objective of ensuring that MIT and outside users of the NRL have the best possible assistance in utilizing the reactor and its irradiation facilities.

Reactor Engineering

Dr. Bernard continued to teach subject 22.921 Reactor Dynamics and Control, and to offer review classes on engineering fundamentals for Nuclear Engineering students in the radiological sciences. Both activities make use of the reactor for illustrating theoretical concepts. Reactor engineering staff include Dr. Lin-Wen Hu, Mr. Thomas Newton, Dr. Gordon Kohse, and Mr. Yakov Ostrovsky.

Reactor Operations

The reactor operations group is at present the strongest it has been in the history of the MITR-II. This is due to the strong leadership provided by John A. Bernard, director of reactor operations, and by the reactor superintendent, Mr. Edward S. Lau. The group consists of both full-time employees (mostly ex-Navy nuclear qualified personnel) and part-time MIT students. All members of the group are licensed by the US Nuclear Regulatory Commission and most hold a senior reactor operator license. At present, there are 18 licensed individuals (15 full-time and 3 part-time). All, including the management team, perform reactor shift duties to support the 24/7 operating schedule. In addition to the operators, there are two full-time technicians for reactor mechanical maintenance.

Reactor Student Operators

The MITR has traditionally hired several undergraduates per year, usually at the end of their freshman year. The NRL is currently training seven MIT students and four full-time employees to become reactor operators. During this reporting period, three other MIT students have already obtained their reactor operator license. The rigorous training program, directed by Mr. Frank Warmsley, 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 US Nuclear Regulatory Commission (one day written, one day oral). Successful candidates receive a reactor operator (RO) license and are employed 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. Last year one student operator received her SRO. This training program is an excellent educational opportunity because it combines theoretical study with actual work experience in the MIT tradition of graduating students who know both how to design and how to build systems. In addition, students who qualify for the SRO license obtain management experience, because they are employed as shift supervisors. Students who have completed this training program regularly state that it was a high point of their MIT experience.

Organizational Diversity

The NRL actively supports MIT's affirmative action goals. Currently, nine positions out of a staff roster of 44 are held by women and/or minorities; of these nine, five hold engineering or management positions (out of 16 total). During the past year, two of the five individuals who joined the NRL staff are women: Susan Guralnik, administrative officer, and Judith Maro, irradiation service coordinator. Among long-term NRL employees are three members of minority groups: a superintendent of operations and an engineer and a neutron activation analyst, both of whom are women. Among the 10 currently active MIT students at NRL are three women and three minority group members. Also, through participation in the US Department of Energy's program for minority training in reactor operations, NRL has hired one of its graduates, a senior reactor operator who has become NRL's training coordinator.

Safety and Security

Operational Safety

Each and every member of the NRL organization is keenly aware that safe operation of the nuclear reactor at MIT is their top priority. This level of awareness is achieved through continuous training and guidance provided by the NRL management team, reinforcing the cooperation and attentiveness to detail that are essential to reactor safety. As a result of this approach, each and every individual employed at the reactor can be proud of NRL's outstanding safety and operating record, as evidenced by the results of US Nuclear Regulatory Commission inspections. These results are shown in the table below. In addition, on average there have been 1.5 reportable occurrences (RORs) reported to the Nuclear Regulatory Commission per year during the past 20 years. During the past five years, there have been two RORs.

MITR Inspection Record 1997–2004

Inspection Date	Inspection Type	Result
04/07/97	Inspection RRPO/BNCT	No deficiencies
09/16/97	Inspection on safeguards	No deficiencies
09/02/97	Licensing exams	5 RO + 4 SRO, all passed except one RO who passed a subsequent makeup exam
11/18/97	Inspection on reactor operations	No deficiencies
09/08/98	Licensing exams	4 RO + 3 SRO, all passed
10/21/98	Visit on fission converter SAR	Discussion only
12/07/98	Inspection on emergency prep./RRPO	No deficiencies
03/30/99	Inspection on SNM	No deficiencies
06/28/99	Inspection on RRPO/requal./safeguards	No deficiencies
09/30/99	Licensing exams	3 RO + 1 SRO, all passed
04/28/00	Inspection of fission converter	No deficiencies
09/05/00	Licensing exams	3 RO + 4 SRO, all passed except one SRO
01/22/01	Inspection on reactor Operations/requal./safeguards	No deficiencies
06/25/01	Inspection on RRPO	No deficiencies
10/28/01	Inspection on RRPO/security	No deficiencies
09/04/01	Licensing exams	3 RO + 2 SRO, all passed
05/06/02	Inspection on reactor Operations/requal./emergency prep.	No deficiencies
07/09/02	Inspection on RRPO	No deficiencies
09/03/02	Licensing exams	6 RO + 3 SRO, all passed except one RO who passed a subsequent makeup exam, and one SRO
11/04/02	Inspection on BNCT using FC	No deficiencies
06/23/03	Inspection on security/safeguards	No deficiencies
06/25/03	Inspection on reactor operations	No deficiencies
02/02/04	Licensing exams	4 RO + 1 SRO, all passed except two RO, one of whom passed a subsequent makeup exam

03/29/04	Inspection on RRPO/SNM/reactor operations	No deficiencies
06/07/04	Inspection on reactor operations	Report pending, no deficiencies expected

Notes: 1. RRPO is Reactor Radiation Protection Office.
2. QA is quality assurance.
3. SAR is Safety Analysis Report.
4. SNM is special nuclear material.

After the 9/11 terrorist attacks on the United States, security and operating procedures at nuclear power plants and nuclear research facilities, including university research reactors, were intensely scrutinized. Consequently, NRL staff have had to take on the additional task of educating various regional and local government officials, the media, and the general public about safety and security at the NRL. This was accomplished through a series of interviews, tours, lectures, and press releases.

In addition, many years ago MIT established a very effective means of insuring safe operation of the reactor by appointing independent individuals to a committee known as the MIT Reactor Safeguards Committee. Members of that committee are from MIT as well as from industry, and meet regularly during the year. They are ultimately responsible for overseeing all nuclear safety issues related to the reactor and insuring that reactor operation is consistent with MIT policy, rules, operating procedures, and licensing requirements.

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. Program personnel includes an EHS deputy director 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 surveillances, 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 is reasonably achievable (ALARA) in accordance with applicable regulations and Institute policies. In addition to the above, the deputy director also serves as the EHS lead contact to NRL under the recently formed EHS-MS organizational structure.

Relicensing and Redesign

Relicensing of the MITR with a concomitant upgrade in power is in progress. It was previously established that the MITR could operate at a maximum power of 6-7 MW with the existing heat removal equipment. A decision was subsequently made to submit the licensing documents for a power increase from 5 MW to 6 MW. On 8 July 1999, a formal application was submitted to the US Nuclear Regulatory Commission 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. The process of relicensing is long and arduous and involves many interactions and communications between NRL and the NRC. One major form of communication is a series of questions (from the NRC) and answers (provided by the NRL) on technical specifications and safety analyses. The NRL has responded to the third installment of the first set of questions received from the NRC. Until relicensing approval process is completed, the NRC has authorized the continued operation of the MITR. That mode of operation has been ongoing since 1999.

Reactor Upgrades

In addition to previously reported upgrades (such as cooling towers) made in conjunction with the reactor's relicensing, a significant number of reactor systems were upgraded, augmented, and/or replaced during the past year. These include:

- Main primary coolant pumps (2) replaced with new high-output, energy-efficient stainless steel pumps with variable frequency drive controllers
- Main secondary coolant pumps (2) replaced with new high-output, energy-efficient stainless steel pumps with variable frequency drive controllers
- Four of the six reactor shim blades, magnets, and drives replaced
- Main and auxiliary intake and exhaust ventilation damper gaskets replaced
- Reactor cooling towers retrofitted with upgraded cascade material to improve air flow and cooling efficiency
- Reactor floor hot cell and hot box manipulators and HEPA filters upgraded and refurbished; hot box equipped with heat sensor and fire suppression
- Perchloric acid hood refurbished for experimenter post-irradiation examinations

Major Reactor Services

The MITR produces about $1.2M worth of neutron transmutation doped (NTD) silicon per year. This is commercial income and the funds are used to offset operating costs. The market for NTD silicon remains strong despite improvements in the chemical production of the material, and the MIT program continued for a successful ninth year.

Approximately 10 metric tons of Si crystals were accurately irradiated in shielded, automated irradiation facilities at the MITR.

Reactor Irradiations for Groups Outside MIT

A number of reactor irradiations and services were performed for research groups outside MIT. Most of these represent continuations of previous research. Recipients include Dr. Alan B. Packard of Boston Children's Hospital, for the evaluation of copper and gold for arthritis treatments; Dr. Alan P. Fleer of Woods Hole Oceanographic

Institution, to determine natural actinides and plutonium in marine sediments; Dr. Rebecca Chamberlain of Los Alamos National Laboratory, for the calibration of ultra-sensitive neutron monitoring devices by thermal neutron fission of uranium foils; and Best Industries (Springfield, VA) and Implant Sciences (Wakefield, MA), for isotope production for cardiovascular research.

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 by the DOE through its reactor sharing program. A grant to NRL reimburses the costs of providing irradiation services and facilities to other not-for-profit institutions (including teaching hospitals and middle and high schools). Under this program, 500 students and 50 faculty and staff members from over 30 other educational institutions benefited from visits to and use of the MITR during the past year.

Most participants in the reactor sharing program wish to do neutron activation analysis, to utilize the fission spectrum facilities, to conduct laboratory exercises for their classes, or to receive tours. However, the MIT Reactor is capable of providing support for other types of activities as well, such as the use of neutron scattering for research in chemistry, physics, and materials science. The MIT Reactor was designed as a beam tube facility, and it is equipped with neutron spectrometers for both diffraction and inelastic scattering measurements. These facilities are currently underutilized, and it is our hope to stimulate research in this area.

Research Activities

Innovations in Nuclear Infrastructure and Education Program

Fortunately, after two decades of declining support for university research reactors, there is renewed interest in maintaining the United States' leading edge in nuclear engineering education and research. This positive direction is due, in large part, to the efforts of many dedicated individuals (academic and government) who envisioned and made possible a way to improve the nation's nuclear educational infrastructure by providing major new funding opportunities to support university research reactors. As a result of these actions and a subsequent recommendation by the Nuclear Engineering Research Advisory Committee, the US Department of Energy initiated the Innovations in Nuclear Infrastructure and Education (INIE) Program. This program was established 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. To date, this program has been exceptionally beneficial to NRL and to the researchers who utilize the reactor's facilities. The following is a synopsis of research being conducted at NRL with funding from INIE.

BNCT User Facility

This portion of the MITR INIE Program is under the leadership of Professor Otto K. Harling. He is assisted by Dr. Kent Riley and Dr. Peter Binns. The MITR staff person who interfaces with the BNCT group is Mr. Thomas Newton. Upgrades and research projects supported by INIE include:

Upgrades to NCT Facilities

—The old wiring and manual control system were replaced with a new digital dose monitoring system and automated beam control.

—Addition of a new beam shutter that was designed, manufactured, and installed during 2003 in order to accommodate the future irradiation needs of both experimental and clinical users of the facility. A series of interchangeable plugs for different uses that fit into that shutter was also designed.

—Trouble shooting with the new control system was performed and extensive testing has proven its satisfactory performance in both manual and automatic modes.

—The influence the new shutter and shield box design have on the radiation environment at the position of the sample/animals was investigated experimentally by a series of dosimetry characterizations of the beam.

—The thermal neutron beam used in animal experiments was computationally modeled in three dimensions using MCNP, a continuous-energy code capable of simulating neutron, photon, and electron transport. The model has been updated to reflect recent modifications in the beam line.

Experiments

—Evaluation of Novel Boronated Amino Acids (Dr. George Kabalka, Departmentt of Chemistry, University of Tennessee).

—The Combination of Radiation Therapy (BNCT) and Gene-Mediated Immunoprophylaxis for Glioblastoma Multiforme (Prof. Henry Smilowitz, Department of Pharmacology, University of Connecticut Health Center)

—Boron Distribution in Each Structure of Normal Rat Brain after Intravenous Injection of Boronophenylalanine-Fructose (Dr. Yasushi Shibata MD, Department of Radiology, Beth Israel Deaconess Medical Center, Boston)

—Therapy Irradiations with Boronated Porphyrins (Dr. Michi Miura, Medical Department, Brookhaven National Laboratory)

Neutron Interferometry

This portion of the MITR INIE Program is under the direction of Professor David Cory. He is assisted by a graduate student, Dmitry Pouchine. The MITR staff person who interfaces with this project is Mr. Thomas Newton. The INIE funds for the project were used to support Mr. Pouchine. Some accomplishments include:

- Shutter, collimator, and shielding were installed at 4DH4.
- Primary monochrometer (graphite crystal) was installed.
- Measurements of alignment and Bragg peak in progress.

A secondary monochrometer, polarizer, and interferometer placement are pending.

Phase Contrast Imaging

This portion of the MITR INIE program is under the direction of Professor Richard Lanza. He is assisted by a graduate student, Vivian Leung. The MITR staff person who interfaces with this project is Mr. Edward Lau. The following are activities supported by INIE:

- Calibration of cooled CCD Camera.
- Initial data acquisition software.
- Acquired and tested imaging plate system for neutron imaging.
- Awaiting delivery of amorphous silicon imager.
- Redesign of new beam port using pinhole collimator with Bi and sapphire filters.

In-Core Loops

This portion of the MITR Program involves the design and construction of a post-irradiation examination facility (PIE) for in-core irradiations of both advanced fuels and materials. The advanced fuels work is under the direction of Professor Mujid Kazimi. The materials studies are coordinated by Professor Ronald Ballinger. Both are assisted by Dr. Gordon Kohse and Mr. Yakov Ostrovsky. The MITR staff person who interfaces with these projects is Dr. Lin-Wen Hu. The emphasis during the first year was on the design of a very high temperature loop that will allow studies related to GEN-IV fuel and materials design. INIE funds, which were fairly small for this project for the first year and which increase significantly in year two, were used to partially support Dr. Il Soon Huang, an MIT PhD with considerable industrial experience, to assist with loop design.

Gen-IV Program

In addition to providing a state-of-the-art research facility that responds to present day issues and concerns, the MIT NRL is also looking ahead in order to meet future challenges. One particular challenge that needs to be addressed is the United States' reliance on fossil fuels. Currently, only 20 percent of the United States' energy resources is provided by nuclear power. Reluctance to increase that percentage is due to the public's concern that nuclear energy is not a safe or environmentally sound alternative. The proposed Generation-IV (Gen-IV) Program, a major research and development initiative to design, build, and operate Gen-IV reactors to provide the United States with an economical, safe, and reliable energy source, will counter that perception. The MIT

NRL is uniquely qualified to be a key contributor to the design and performance of experiments for the evaluation of the advanced materials and fuels that are needed for Gen-IV reactors.

Neutron Capture Therapy

Neutron capture therapy for cancer research, directed by Professor Otto K. Harling, continued for the 18th year with support from DOE. A phase I/II trial for glioblastoma multiforme and metastatic melanoma ended last year, and results from this study are being analyzed as the follow-up finishes. The epithermal neutron irradiation facility has continued to operate reliably and is able to safely administer the neutron fields required for BNCT clinical investigations.

DOE-supported upgrades of BNCT facilities at the MITR are complete. A high intensity and high purity thermal neutron beam is now available at the MITR and is presently employed for basic research related to BNCT. The upgraded facility is also fully licensed for clinical trials and includes all capabilities required for irradiating human subjects. The fission converter–based epithermal neutron beam line (FCB) 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.

The neutron facilities at the MITR have been extensively utilized as a DOE (INIE) supported user facility open to researchers both within and outside MIT. Research groups based at universities and national laboratories from around the country have used the BNCT facilities for in-vitro and in-vivo experiments designed to investigate the efficacy of new, tumor-seeking capture compounds and to study the radiobiology of neutron capture therapy. The MIT program in neutron capture therapy is the leading BNCT research program in the United States and is considered to be among the top in this field worldwide

Nuclear Medicine

Several state-of-the-art neutron facilities for NCT research are in operation at the MITR. The recently constructed epithermal neutron irradiation facility (FCB) is now licensed by the US Nuclear Regulatory Commission. It has an intensity of ~$5x10^9$n/cm^2-sec with low inherent beam contamination, which approaches the theoretical optimum. If the FCB is used at maximum intensity, tissue tolerance can be reached in less than 10 minutes. The high beam purity results in a useful treatment depth of ~9 cm, using current capture compounds. Therefore, the FCB is well suited to treating deep-seated cancers. The FCB is currently the only operating epithermal neutron beam in the United States that is suitable for clinical studies. Currently it is also the best NCT epithermal neutron beam in the world.

A high intensity, ~$1x10^{10}$n/cm^2-sec, and low contamination thermal neutron beam is also available at MITR. This facility has its own medical irradiation room separate from the FCB's irradiation room. The thermal neutron facility is well suited for small animal studies and for clinical studies of NCT where tumors are less than ~4 cm deep. There is currently no other comparable facility for thermal neutron irradiations in the United States.

The third neutron facility available at MITR is a prompt gamma neutron activation analysis facility. This facility is designed for rapid ^{10}B analyses in small samples of blood and tissue. These analyses are essential for NCT research and for accurate dosimetry in clinical studies. A high sensitivity of ~18 cts/s/μgm allows rapid and accurate analyses of samples as small as 0.1 ml with typical ^{10}B concentrations of 10 ppm. An ICP-AES, and ICP-MS are also available at the NRL and are particularly well suited to very small samples, <0.1 ml.

A specialized irradiation facility for use in high-resolution track etch autoradiography is also available at MITR. High resolution quantitative track etch autoradiography (HRQAR) developed in the Harvard/MIT program permits mapping of the microscopic boron concentration in tissue with a spatial resolution of about 2 micrometers. This is an invaluable aid in determining the potential effectiveness of neutron capture compounds.

Radiation Science Technology

The NRL supports radiation science technology, a subdiscipline in the Nuclear Engineering Department, by providing relevant research opportunities. The NRL also contributes to a specially designed laboratory and demonstration course. This course, 22.09/22.104 Principles of Nuclear Radiation Measurement and Protection, is appropriate for all students in nuclear engineering. Research topics and support for health physics students were provided by NRL projects, especially the BNCT and dose reduction projects of Professor Otto K. Harling.

Dr. John A. Bernard, who is certified as a health physicist by the American Board of Health Physics, continued to teach subject 22.581 Introduction to Health Physics. This course uses the MIT research reactor to provide practical examples of health physics issues.

Materials

Dr. Lin-wen Hu is planning to conduct experiments for the evaluation of heat transfer enhancement characteristics of nano-particles in fluids. Several recent reports in the literature have shown a significant increase in heat transfer properties, by as much as 50 percent, when small amount of nanoparticles are suspended in a base liquid. Selected types of nanoparticles of the size about 10 nm will be tested to compare their performance. Application of nanoparticles may prove to benefit next-generation nuclear reactor designs by providing alternative fluid selection with improved heat transfer characteristics beyond the existing water, gas, and liquid metal coolants.

In-core Materials Studies

The NRL has a unique technical capability that involves the use and installation of in-core loops that replicate PWR/BWR conditions to study the behavior of both advanced materials and micro-particles 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. The MITR is arguably the best suited university reactor for carrying out such basic studies because of its relatively high power density (similar to an LWR), the capability to control the chemistry and thermal conditions to reflect prototypic conditions, its easy-access geometric configuration, and space for up to three independent irradiation tests. While similar studies could in principle be carried out at national laboratory reactors such as the ATR, the costs would be far greater. The reason is that large national laboratory reactors are optimized for large-scale, fully integrated tests and not the smaller scale, faster turnaround basic studies needed at the earlier stages of research. Access to the high flux in the core is also much more difficult in the larger reactors because of pressurization of the core. The MITR is unpressurized and the core is only about 12 feet below the lead reactor lid.

Three in-core experiments were installed for irradiation during the past year. These are:

—**Innovative LWR Fuel Irradiation.** An innovative nuclear fuel design that has been undergoing irradiation in the MIT reactor since February 2004. This is the first irradiation of a fueled test capsule at the MITR, and one of very few undertaken at any university reactor. The experiment aims to test a new fuel design and manufacturing technique, which if successful could improve the safety and economics of light water reactors (LWRs). This project is led by Professor Mujid Kazimi of the MIT Nuclear Engineering Department.

—**Investigation of Shadow Corrosion**. This loop was installed and operated in February 2004 and removed in May 2004. The objective of the experiment was to expose several different types of Zircaloy material (BWR reactor fuel cladding) to simulated BWR coolant in the core of the MITR. A variety of materials were placed in contact with or in close proximity to the Zircaloy specimens and the effect of these “shadow materials” on corrosion rates were evaluated under BWR coolant conditions. This project is led by Professor Ronald Ballinger, who has joint appointments in MIT’s Departments of Nuclear Engineering and Materials Science and Engineering.

—**Investigation of Electro-Chemical Potential Effect on Shadow Corrosion**. This loop was installed and operated in June 2004 and was removed in July 2004. This experiment is the continuation of the shadow corrosion study performed previously. The objective of the experiment is to measure the electro-chemical potential (ECP) difference between Zircaloy and Inconel under neutron and gamma irradiation conditions. This project is also led by Professor Ronald Ballinger.

Neutron Beam Tube Research

The prompt gamma neutron activation analysis facility was used both for research and in support of the neutron capture therapy clinical trials.

Environmental Research and Radiochemistry

Dr. Lin-Wen Hu has taken on the role of overseeing operation of the NRL's environmental research and radiochemistry laboratories. The MITR is currently equipped for both prompt and delayed gamma neutron activation analysis. Relative to the former, a prompt gamma spectrometer was built as part of the Neutron Capture Therapy 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 are used for neutron activation analysis (NAA). One offers a thermal flux of $5x10^{13}$; the other four offer thermal fluxes of $8x10^{12}$. Several of the tubes are automated so that samples can either be ejected to a hot cell within the reactor containment or else 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.

The NRL NAA laboratory has 4 Hp(GeLi) detector systems with Genie-2000 software. A new computer and new software were installed. Two detectors were rebuilt and installed this year. MIT also participates in the US Department of Energy's reactor sharing program, and the bulk of those funds is used to cover irradiation charges for NAA-based research.

The 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, California Institute of Technology, Tufts University, University of Connecticut, and the Woods Hole Oceanographic Institution. The following table shows some of the NAA projects that were either completed this year or are ongoing.

Ongoing Research Using Neutron Activation Analysis at MITR

Institution	NAA Activity
Boston College	Geochemical analysis of rock and soil samples to determine the abundance of a suite of trace elements such as Co, Cr, Sc, Rb, Ss, Ta, Hf, Th, U, and the rare earth elements as natural tracers of a variety of different geological processes in igneous and metamorphic geochemistry and soil studies. (Professors Christopher Hepburn and Rudolph Hon, Boston College)
Children's Hospital	Cu-64 is prepared by neutron irradiation of natural-abundance copper metal as a means to evaluate new copper complexes for testing as possible PET imaging agents for multi-drug resistance in cancer. (Alan P. Packard, PhD)

Harvard University	Sn-112 samples were irradiated with the goal of investigating the response characteristics of various detectors of electrons in the several hundred KeV energy range and was used as part of an apparatus to measure the angular correlations in the neutron decay process. The main result of the experiment was an essential improvement of the characteristics of detectors with plastic scintillators and liquid scintillators. (Professor Boris Yerozolinski, High Energy Physics Laboratory)
Massachusetts General Hospital Case Western Reserve University	An in-depth investigation on the metal ions content of brain tissue from different neurodegenerative conditions, using INAA to study concentrations of certain transition metal ions that increase in the brains of individuals with Alzheimer's disease (AD) as compared with age-matched control individuals, indicating that metal ion metabolism is dysregulated in the AD brain. (Dr. Xudong Huang, Massachusetts General Hospital, and Dr. Atwood, Institute of Pathology, Case Western Reserve University.)
MIT	Geochemical studies of samples obtained during the Hawaiian Scientific Drilling Project and Ocean Drilling Cruises using NAA, as well as studies of lavas erupted in the southern Indian Ocean that are related to the long-lived Kerguelen hotspot. (Professor Frederick Frey, Earth, Atmospheric, and Planetary Sciences, MIT)
	Measurement of mercury and other metals in comparative tissue from autistic and control patients, to study the role of heavy metal exposure, especially mercury, in order to explain the documented rise in the prevalence of autism. (Dr. John Machuzak , Lincoln Laboratory, and Dr. George Grady, University of Massachusetts Medical School)
UMass-Lowell Lowell, MA	Irradiation of NaOH for contamination and control exercise. (Professor Clayton French)
	Use of rare elements as environmental tracers for sewage and other discharges to aquatic systems. (David K. Ryan, PhD)
Washington University	Irradiation and analyses of scandium particles to study the flow pattern in high pressure slurry bubble column reactor and gas-solid riser. (Professor Muthanna Al-Dahhan)
Woods Hole Oceanographic Institution	Elemental analysis of marine particulate material and seawater utilizing NAA for the analysis of rare earth elements and thorium-233, and the production of tracer amounts of osmium-191 and protactinium-233. (Professor Alan Fleer and Drs. Michael P. Bacon and Roger Francois, Woods Hole Oceanographic Institution)

Within MIT, research support has been provided to several departments. This research support includes analysis of various environmental and biological samples for trace and toxic metals by faculty from several departments, including the Department of Civil and Environmental Engineering and the Department of Chemical Engineering. In addition, Professor Kenneth C. Czerwinski (Nuclear Engineering Department) and several students use both gamma and neutron irradiation for the study of possible host matrices for use in waste storage.

New Initiatives

Idaho National Laboratory

DOE is reorganizing the existing INEEL and Argonne West laboratories to create a new laboratory, the Idaho National Laboratory (INL), that will be the lead institution for nuclear engineering and reactor development. On March 3, 2003, MIT signed an agreement with Battelle Memorial Institute to partner in a bid for the contract to operate the newly formed national laboratory whereby MIT would lead a consortium of universities intended to provide the intellectual driving force for accomplishing the mission of this new laboratory—namely, the development of a new generation of nuclear power reactors. During the past several months, MIT's Department of Nuclear Engineering and the MITR have collaborated closely with Battelle in the preparation of a proposal to bid on this contract. That proposal was recently submitted, and if Battelle's bid is successful, this will be an excellent opportunity to generate DOE funding to operate the MITR. Research on materials and fuels for both existing and Gen IV reactors would benefit from an MITR-INL association. The relatively low cost MITR could be used for fast turnaround irradiations and innovative research. Some advantages for the MITR include:

- Funding for materials research experiments
- Hiring of staff to support experimenters
- Opportunities for innovations in other research areas
- Contributions to a new research reactor that may be built at INL

Pressure Vessel Steel Irradiation

Another initiative that is currently under design at the MITR is a temperature-controlled facility for the irradiation of steel specimens. The immediate objective is the irradiation of pressure vessel steels in the 288-650 °C temperature range to fluence levels of 0.5 x 10^{19} n/cm^2(E > 1 MeV). This facility will be developed based on a fission converter design, and will be installed in one of the large (30.48 diameter x 55.88 cm long) beam ports that are external to the MIT reactor core. The fission converter will consist of a cylindrical arrangement of UO_2 (enriched in U^{235}) fuel rods which, when exposed to the thermal flux from the reactor core, will create a fast neutron environment that achieves the specified fast flux distribution throughout the entire facility volume. The facility design achieves the maximum flexibility for any anticipated irradiation program. The mechanical and thermal design of the facility will allow operation at temperatures up to and including 650 °C.

Advanced Materials Test Facility

In 2001, MIT recognized the need for an Advanced Materials Test Facility (AMTF) and proposed the assembly of such a facility at the MITR to DOE. 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 Rhode Island Nuclear Science Center and University of Massachusetts-Lowell.) Procurement and installation of the equipment are ongoing. Also ongoing is an upgrade of the MITR's existing hot cells, used to support in-core experiments.

The combination of the AMTF and MITR will be ideal for carrying out the more basic components of the research on materials in a radiation environment. To reiterate, the MITR offers good geometric access and room 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 there is an ability to control the chemistry and thermal fields to reflect prototypic conditions. A facility such as this would complement the testing capabilities of large national laboratory reactors such as the Advanced Test Reactor, which are best suited for fully integrated experiments. In most cases, MIT's AMTF would be relatively inexpensive for basic research projects, saving a factor in the range of 3–10 in cost over doing the same type of basic research at a large national laboratory reactor. On the other hand, the large reactors are essential for integrated testing, because those types of experiments cannot be carried out at a university research reactor.

Neutron Scattering

Neutron scattering had a long and distinguished history at the MITR, but has not been actively pursued since the retirement of Professor Cliff Shull. With the resurgent interest in neutron scattering and imaging research, driven by the DOE's commitment to the Spallation Neutron Source (SNS) project, it is timely to consider what contribution the MITR can make in the future. In the upcoming year, we intend to explore the possibilities for supporting R&D related to new instrument technologies being developed for the SNS project, and also to look carefully at what those technologies would offer in terms of performance for new instruments based on the MITR. With a strategy aligned with the SNS project, it is likely that programmatic funding could be attracted from DOE and/or NSF and lead to the rebirth of neutron scattering research at MIT.

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Director

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