MITR-II

O. K. Harling and D. D. Lanning

MITR-III

Otto K. Harling and David D. Lanning

Nuclear Reactor Laboratory and Department of Nuclear Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts USA

ABSTRACT

This paper outlines the successful MIT research project which is currently based on a compact core 5 MW neutron source. In anticipation of the license expiration for the current MITR-II in 1996, studies have been initiated to define the user needs and the reactor design which could meet these needs. An overview of current activities relating to a new or upgraded reactor, MITR-III, are presented in this paper.

I. INTRODUCTION

The MIT Research Reactor has been, is and is expected to continue to be a valuable research tool at the Institute. The initial MITR-I, and now the upgraded MITR-II, has served the research, teaching, and service needs of students and staff from various MIT departments and laboratories as well as users from other universities, teaching hospitals, and industries for thirty-two years. Some appreciation of the value of this facility can be gleaned from the following statistics. A total of 180 doctoral, 271 masters', and 78 bachelors' theses have been completed using the MITR. A total of 800 papers in reviewed technical journals, 231 major technical reports and a total of ~2000 written publications of all types have been based upon work done with this reactor. No less than 90 major technical highlights, i.e. major achievements such as in-pile loops to simulate LWRs or highly accurate measurements of limits on the neutron's charge, have resulted from research at this reactor.

In 1958 the first MITR was made operable;[1] in 1975 the significantly upgraded MITR-II achieved full power;[2] and in 1989 planning for MITR-III was initiated. This paper provides some of the background on the MIT research reactor project, including a description of current facilities. The desired characteristics for an upgraded reactor and various considerations related to MITR-III are outlined in this paper.

II. BACKGROUND OF THE MIT RESEARCH REACTOR

The MIT Research Reactor Project was conceived in the first part of the decade of the 1950's. It was during this period that the "atoms for peace" initiative was enunciated by the US Government and the Atomic Energy Act of 1954 facilitated peaceful uses of the atom. Universities responded to this initiative by the creation of academic departments which specialized in nuclear engineering and by the design and construction of university research reactors (URRs). The construction of URRs was encouraged by the US Government, in particular, by the Atomic Energy Commission and the National Science Foundation.

At MIT, the Institute's president, Dr. James R. Killian was a leader in the effort to establish a department of Nuclear Engineering and to build a first-class research reactor. The organization of an academic department of Nuclear Engineering was put into the able hands of Manson Benedict, who after receiving a doctorate in Chemical Engineering from MIT, had distinguished himself through his contributions to the Manhattan Project. Professor Benedict recruited Dr. Theos J. Thompson from the Los Alamos Laboratory to take charge of the design and construction of the MIT Research Reactor. Dr. Thompson had an excellent background for this task since he had been involved with the design of the Omega West Research Reactor at Los Alamos.

The detailed design and construction of the MITR-I required about three years. This is a short time compared to the time it currently takes to complete projects of comparable complexity. In 1958, when MITR-I went critical, it was the fourth URR to go into operation in the USA and it was the largest or most ambitious of the initially constructed URRs. MITR-I had similarities to the Argonne National Laboratory's CP5 tank type reactor. It was designed to be capable of 5 MW thermal and to be heavy water cooled and moderated. A graphite reflector was used. Fuel elements were MTR type plate elements using a fuel meat which had fully enriched U-235.

The MITR-I was provided with a wide range of experimental facilities, including the following major facilities:

Eleven horizontal beam ports, 4 to 12 in. in diameter, radial to the core

Two horizontal thru ports, 4 and 6 in. in diameter, tangential to the core

Six pneumatic tubes for rapid transport of small samples

Four thimbles in the reflector, 3-1/2 in. i.d. for longer term thermal neutron irradiations

Fission neutron irradiation facility

Thermal column, hohlraum and blanket neutronics facility

Medical irradiation room with a large vertical beam below the core

In-pile irradiation positions based on removal of fuel elements

Many research projects including neutron scattering, blanket neutronic studies, medical irradiations, capture gamma-ray studies, organic reactor coolant stability, nuclear chemistry, neutron activation analysis, etc., were successfully carried out thanks to the availability of MITR-I.

From the beginning of the MIT reactor project, it had been recognized that the research reactor would require eventual rebuilding and upgrading. This farsighted approach included provision for funding a reactor upgrade. After several years of planning, which involved a number of graduate student thesis projects, the decision to rebuild the MITR was made in the early 1970's. To direct the major renovation, David D. Lanning was brought to MIT from the Hanford Laboratories. Professor Lanning, a Ph.D. graduate from the MIT Nuclear Engineering Department, already had considerable experience with the MITR-I while he was Superintendent of Operations.

Major design goals for the upgraded reactor included:

Improved thermal flux intensity and quality at the horizontal beam ports.

Enhanced safety, especially with regard to potential loss of core cooling.

Improved operational characteristics, including fuel life, reliability of components and control systems.

The upgraded MITR-II, see Fig. 1, features a completely redesigned core and reflector. The compact hexagonal core, 15 inches wide by 2 ft. high, operates at 5 MW with a power density of ~ 0.1 MW/liter. Core cooling is with H_2O while the reflector tank, which wraps around the lower part of the core tank, uses D_2O. To remove the 5MW of heat from the much compacted core without major changes to the heat removal systems, the aluminum fuel plates were grooved, resulting in a doubling of the heat transfer coefficient. Uranium loading in the fuel elements was substantially increased and each of the elements in the 27-element core has ~ 500 gms of U-235. Fuel elements can be rotated to three different radial positions and are constructed so that they can be flipped upside down to optimize fuel burnup. Burnups of ~ 45 percent are achieved, resulting in an average fuel element life of approximately four and one-half years or 900 full power days.

VIEW OF M.I.T. RESEARCH REACTOR, MITR – II, SHOWING MAJOR COMPONENTS AND EXPERIMENTAL FACILITIES

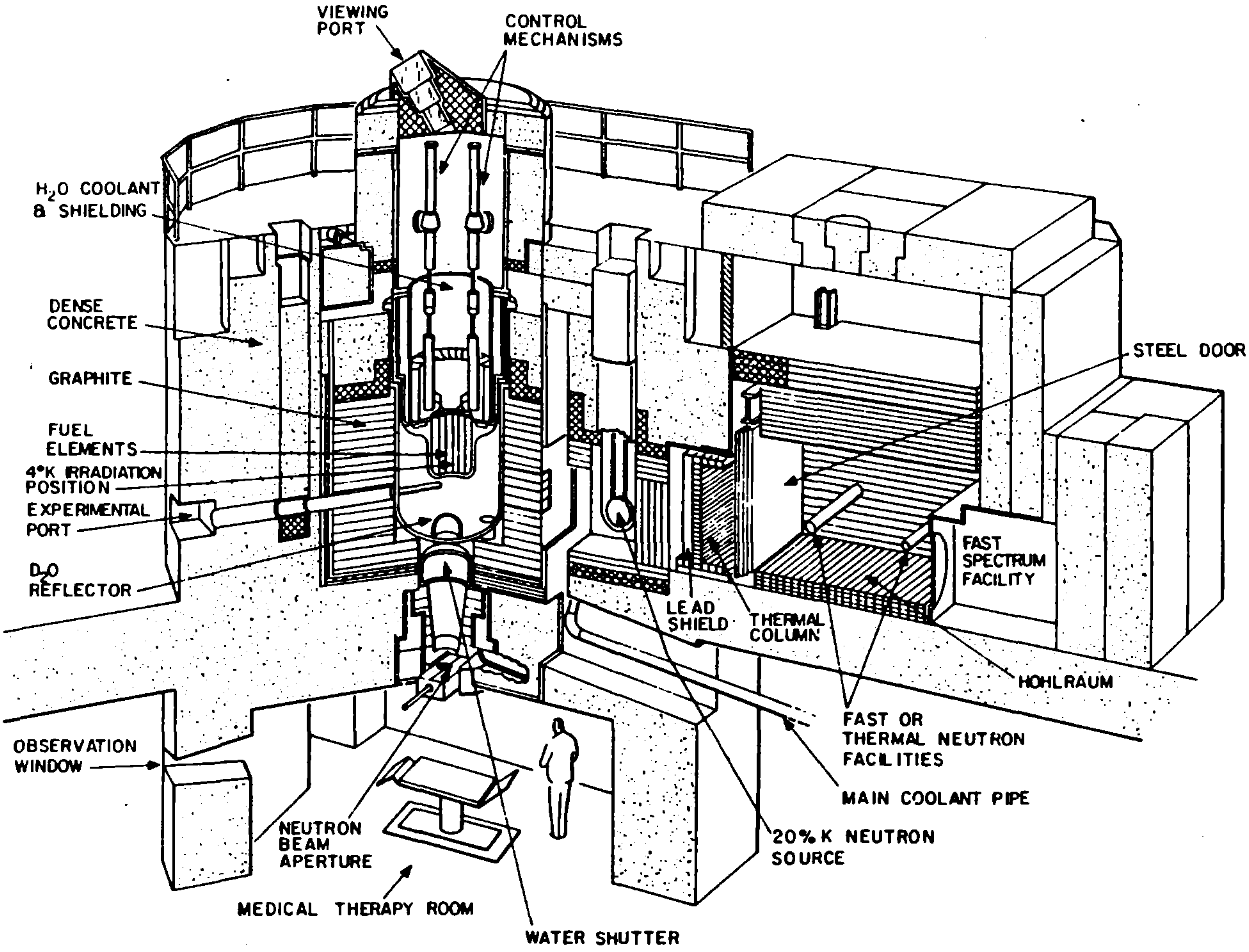

Figure 1

Another feature of the MITR-II core is the available option of poisoning the upper half of the core. This still permits operation at a full 5 MW and provides significantly increased flux, e.g. 30-50 percent increases of the beam tube flux.

Beam tubes in MITR-II are tangential to the bottom of the core and view a well moderated thermal flux where it peaks in the D_2O reflector. The tangential arrangement, the compact core, and the good moderation provided major improvements in beam tube thermal neutron flux intensity, and decreases in undesired backgrounds from fast neutrons and gamma rays..

A summary of important performance changes achieved by upgrading MITR-I to the MITR-II design (both reactors at 5 MW) is given below.

Neutron Flux

1. Increased thermal flux at horizontal beam ports, a factor of 3X for the total thermal flux and a factor of 9X at 3 Å, $\phi_{th} = 10^{14}$ n/cm^2-sec.
2. Fast neutron and gamma ray contamination of the thermal beams was greatly reduced.
3. In-core fast neutron flux was increased to more than 10^{14} n/cm^2-sec, $E_n > 0.1$ MeV.
4. The medical beam contamination by fast neutrons and gamma rays was significantly decreased.

Safety Improvements

1. No loss of coolant due to pipe rupture; pipes enter core tank near top of tank.
2. Natural convection demonstrated.
3. Seismic safety enhanced.
4. Light water primary system, resulting in reduced tritium problems.
5. Heavy water reflector, provided backup scram, and an extra tank wall to defend against loss of core cooling.
6. Remote shutdown and cooling capability.

Operational Improvements

1. Control rod magnets moved away from core radiation.
2. Elimination of tritium contamination on in-core components and experiments.

3. Access to core and in-core facilities through pool.
4. Fuel assemblies with improved heat transfer and long burnup lifetime.

III. MITR-III

General Considerations, Issues, and Options

The following considerations or issues must be understood and dealt with in planning for the MITR-III. We have begun to deal with these but are nowhere near a final resolution of some of these issues.

1. MITR-II's license expires July 1996.
2. What type of reactor is best suited to MIT's and the other users' needs? For example, should it be a general purpose neutron source, such as the MITR-I and MITR-II, or should there be strong emphasis on developing specific nuclear technology, e.g., gas cooled reactor design, or specific scientific applications such as neutron scattering.
3. Options include: a new reactor, an upgrade, relicensing, decommissioning.
4. Location of MITR-III
5. User base
6. Funding for MITR-III: a) construction, b) operation.

Desired Reactor Characteristics

Our current list of desired reactor characteristics is based upon discussions with a variety of reactor users. A distilled list of user requirements modified by the review of the authors in order to assure reasonable compatibility and to give consideration to the current and projected levels of utilization is presented below:

1. In-core Irradiation Experiments

Current and projected needs for in-core irradiation space for radiation damage studies and in-pile test loops is significant. Therefore, a somewhat larger core, with space in and above the core to accommodate three or four complex rigs or loops is desired. A fast flux somewhat higher than 10^{14} n/cm^2-sec E > 0.1 MeV and larger in-core test holes, ~ 3 in. in diameter compared to the current maximum of 2 in. diameter per fuel element, are desirable.

Besuch FRM = 22.10.90
Bill Whittemore,

evtl. TRIGA fuel ...
for MITR-III

2. Medical Irradiation Beams

Increased epithermal flux for treatment of deep-seated tumors by neutron capture therapy is desired. Alternate sites for medical beams, e.g. from the side of the reactor, should be considered. Fluxes of 3-10 x 10^9 n/cm^2-sec 1 eV < E < 20 keV are reasonable goals.

3. Neutron Scattering

Tangential beam tubes, with beam-tube source flux of at least $\phi_{th} = 1 \times 10^{14}$ n/cm^2-sec. are desirable. Provision for a rethermalizer at liquid helium temperature to produce a cold neutron source should be considered. Even though these spectrometer beams are not as intense as national laboratory beams, there is a broad research program that can be carried out in solid state physics, chemistry and material science, see, e.g. "New Materials," Science, Vol. 247, 9 Feb 1990.

4. Neutron Activation Analysis

All current short and long term thermal neutron irradiation facilities should be maintained. A thermal flux of greater than 5 x 10^{13} n/cm^2-sec is desired for at least one facility. Low flux gradients and cooling for sensitive samples is important.

5. Other Thermal Neutron Irradiation Facilities

Thermal neutron irradiation facilities for larger sample volumes, e.g. > 6 in. diameter samples at flux levels of 5 x 10^{13} - 10 x 10^{13} n/cm^2-sec, are needed. Cooling using reactor or moderator water is desirable.

Reactor Design Considerations and Goals

The general design goal for MITR-III can be stated, to improve the facility such that its usefulness is enhanced while allowing safe and economic operation of the facility with a high availability for all users.

More specific goals include:

1. Improving certain experimental capabilities, see above.
2. Improving the safety and operation.
3. High availability, ≥ 80%.
4. Licensability.

5. Plant personnel exposures < 10% of 10CFR20 limits.
6. No sheltering or evacuation plans for general public.
7. Investment protection, risk of exceeding design conditions not to exceed 1 x 10^{-5} events/year.
8. Yearly operating costs less than $1 million.

Some design restrictions:

1. Urban siting on the current site.
2. Power level less than 10 MW.
3. Use of LEU fuel.
4. Use of the existing reactor block and containment building.
5. Use of existing heat removal capabilities; or limits on pipes, pumps, heat exchangers or flow rates for increased heat transfer.
6. Restrictions on power or power density for safety considerations such as natural circulation cooling after shutdown.
7. License limit considerations such as existing containment design limits.

The full listing of the design requirements will be developed by the use of an integrated design approach. This approach includes a functional analysis and the use of probablistic risk assessments (PRA) for the assessment of design options.

Status of the MITR-III Project

In 1989 a preliminary study of MITR-III options was initiated using student resources and some faculty and professional staff. After examining a wide variety of options including the entire range from a new reactor on a new site to decommissioning and elimination of a research reactor at MIT, the tentative conclusion was reached to:

Upgrade the current research reactor and maintain the general philosophy of a general purpose neutron source which has served the users' needs well in the past.

To move this concept toward realization, a detailed design study effort, requiring several man years of effort, must be carried out. Currently, due to resource limitations we are only able to mount a modest study effort which cannot meet the requirements for the development of a detailed design and cost estimates. We intend to make strong efforts to obtain the resources needed for the design of MITR-III and for its realization in the period when the current MITR-II license expires.

IV. SUMMARY

This paper provides some background on the successful MIT Research Reactor Project which was initiated in the early 1950's. We have also outlined the considerations involved and the options available for an MIT reactor after the current license expires in 1996. These considerations include the projected user needs and reactor design aspects including core design, safety and licensability.

In the present climate of a dwindling number of university research reactors, we believe that every effort should be made to keep the MITR facility operating in order to continue the teaching and research that will be required for the future in the nuclear sciences and in nuclear technology.

V. ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of L. Clark, Jr., and J. A. Bernard in preparation of this paper.

VI. REFERENCES

[1] Thompson, T.J., "The MIT Research Reactor," Proceedings of the Second Conference on Peaceful Uses of Atomic Energy, 417 (1958).

[2] L. Clark, Jr., and D. D. Lanning,"Research Reactor Redesign and Upgrade," Proceedings of the Symposium on "Use and Development of Low and Medium Flux Research Reactors," Supplement to Vol. 44, Atomkernenergy-Kerntechnik, 118 (1984).