

University Research Reactors: Issues and Challenges

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Abstract

University research reactors are underutilized and, as a result, are being decommissioned. The reason for the lack of utilization is shown to be a chronic inability to generate sufficient funds to procure and maintain state-of-the-art instrumentation for prospective researchers. The role of these reactors in nuclear science/engineering education is explored and the rationale for their continued operation is presented. It is argued that base financial support for both reactor operations and the technical support staff needed to interface with experimenters is necessary if these research facilities are not to be irretrievably lost from the educational infrastructure of the United States.

I. INTRODUCTION

The Massachusetts Institute of Technology is one of about thirty universities that currently operates an on-campus research reactor in support of its educational and research mission. Most of those reactors, which are collectively referred to as URRs, were built in either the late 1950s or early 1960s, and most received operating licenses of either twenty or forty years duration. As a result, many of these non-power reactors will be required to undergo relicensing in the immediate future. That effort is in turn prompting university administrations to evaluate the relevance of these URRs. The prospects for the long-term continued operation of more than a few URRs are not promising. For much of the past decade, URRs have closed at the rate of about two per year. That trend has accelerated during the past year with the loss of three of the larger facilities. Moreover, those schools that have opted to relicense have generally done so with the understanding that further reviews of the URR's mission will be made in several years. MIT is among this latter group.

The principal reason for the difficulties now being experienced by the non-power reactor community is lack of utilization by faculty. This is in turn attributed to various factors including the continuing malaise of the nuclear power industry, the fact that many URRs are approaching forty years of age, low flux levels, and an excessive regulatory burden. Many URRs are, in fact, underutilized. However, the aforementioned reasons are not the causative agents. URRs were never linked to the nuclear power industry. The material condition of most URRs is excellent. Research and teaching applications exist that are appropriate to a wide range of flux levels. Regulatory requirements, while certainly not insignificant, have stabilized. The real reason for the lack of utilization is the high threshold that confronts prospective users. Most URRs lack the funds both to equip their facilities with state-of-the-art instruments and to hire technical support staff to design, maintain, and operate these instruments. In contrast, such instruments and staffs are available at the reactors operated by the DOE National Laboratories. Hence, it is not unusual for a faculty member

to conduct research at one of the National Laboratories even though his or her own university operates a URR.

This paper argues strongly for the continued operation of on-campus URRs. The specific objectives of this paper are to: (1) provide background information on the design, utilization, and financing of URRs; (2) delineate the rationale for the continued operation of university research reactors; and (3) suggest that the provision of base support for URRs is the only viable mechanism to ensure the continued operation of these facilities.

II. BACKGROUND

Both test and research reactors may be used to conduct experimental research. The difference between the two is that the latter are limited to a maximum power level of 10 MW, to in-core experiments that are sixteen square inches or less in cross-sectional area, and to in-core loops that do not contain fuel. As a result of these defining characteristics, research reactors are suited for siting on university campuses. URRs have relatively small inventories of fission products. Moreover, most operate at atmospheric pressure and with coolant temperatures of at most 60°C. Hence, there is neither the radioactivity nor the thermal driving potential to create a significant release. The four-decade operating record of the nation's research reactors attests to this conclusion.

Figure 1 is a cross-section of the MIT Research Reactor (MITR). It is a heavy-water reflected, light-water cooled and moderated nuclear reactor that utilizes flat, plate-type finned, aluminum clad fuel elements. The MITR, which currently operates at 5 MW, is located in the center of a gas-tight cylindrical steel building that is equipped with a controlled pressure relief system. Access to the containment building is through either a personnel or a truck airlock. The reactor core consists of rhomboid-shaped elements arranged in a hexagonal pattern. Normally, there are 24 or 25 elements and 2 or 3 in-core irradiation facilities. The core is located at the center of a light-water tank which is in turn surrounded by first a heavy-water tank, then a graphite reflector, a thermal shield, and finally a biological shield. The primary, heavy-water reflector, and shield regions are all separately cooled. Each transfers heat to a secondary coolant that dissipates it to the atmosphere via two cooling towers. Control is achieved using six boron-impregnated stainless steel blades and one cadmium regulating rod. In addition, the reflector can be dumped to a holding tank thereby providing an alternate shutdown-mechanism. The reactivity coefficients of both the coolant and fuel are negative thereby providing passive safety. The average core power density is about 70 kW per liter. The maximum thermal neutron flux available to experimenters is 5×10^{13} neutrons/cm² s.

Most URRs are less complex than the MITR. They utilize confinement instead of containment buildings and the

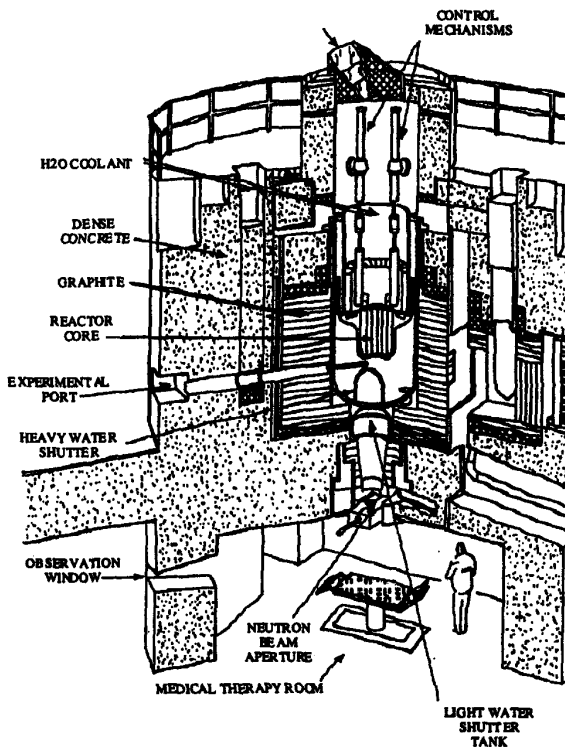


Figure 1: Isometric View of the MIT Research Reactor

core is located in an open pool instead of an enclosed tank. In general, there are two types of URRs. One group, which includes the MITR, uses plate type fuel. The other, designed and built by the General Atomics Company, uses TRIGA fuel. The latter fuel type is designed to have a very strong negative reactivity coefficient of temperature. This is a passive safety feature that allows TRIGA reactors to be safely pulsed to very high power levels because the resulting rise in fuel temperature inserts sufficient negative reactivity to terminate the transient before significant energy is produced.

From the above discussion, the following should be evident. First, URRs constitute a safe means for generating neutron fluxes for use in research. Second, URRs constitute a significant capital investment, one that cannot readily be replaced once an existing facility has been decommissioned.

Table 1 is a list of some of the major research and educational activities that have been conducted at the MITR since it initially achieved criticality in 1958. Research efforts are rarely duplicated and hence each URR has its own unique list. For example, low power URRs would have more educational usage. Also, radiography is a major activity at some URRs, but not at the MITR. However, the items listed in Table 1 are representative of the major types of uses of URRs. A more complete enumeration is given in the proceedings of the international symposium, "Use and Development of Low and Medium Flux Nuclear Reactors," [1]. Several trends are apparent from the table:

1. URRs have never been dependent solely on the nuclear power industry for research activity. Hence, the current state of the nuclear industry in the United States is not

reason to conclude that URRs are no longer necessary. The two are not coupled.

2. Nuclear medicine has always been a major activity at URRs.
3. URRs are multi-purpose entities with no single application being dominant throughout a given operating history. This, of course, reflects the fact that URRs are a means to generate neutrons and not a demonstration of a given technology. As long as there are novel applications of neutrons, there will be new missions for URRs.
4. Research and education are not separable. Each of the projects listed in Table 1 generated both Ph.D. and M.S. level thesis topics as well as numerous opportunities for special projects. The latter are open to undergraduates as well. Theoretical material can be taught in a classroom setting, but true understanding comes only through actual application of knowledge gained from text books. Also, participation in research projects allows students to learn the managerial skills that they will need in order to become effective researchers in their own right.

The third factor of which one needs to be cognizant in order to understand university options regarding URRs is financing. The MITR is again used as an example. The federal government provides fuel assistance to all URRs. This is a very substantial benefit. However, beyond that, there is no direct support to any URR. The MITR attempts to cover its operating costs (electricity, water, reactor instrument/equipment maintenance, secretarial, reactor operator and managerial salaries) by charging users for neutrons. A published charge schedule lists rates associated with each experimental facility. The income generated in this manner is used to defray expenses. MIT, as the reactor owner, covers the deficit with general funds. MIT and one other URR owner are private universities. The remaining URRs are operated by state universities. These often receive a budget allocation from the state government. However, with few exceptions, all URRs need to charge for services. Those charges engender certain consequences:

1. Research reactors that are operated by the National Laboratories do not charge for neutrons. Hence, there is a strong incentive for prospective users to apply for time at a National Laboratory even if a URR is on campus.
2. Funding agencies are reluctant to approve grant requests which include neutron charges for a URR because the same neutrons may be available elsewhere at no cost.
3. The funds raised through the charges are necessary to defray operating expenses. However, they are insufficient to permit the acquisition of state-of-the-art instruments for experiments. Also, they are not sufficiently constant to allow the hiring of technical support staff to maintain and operate these instruments. In contrast, such services are available at the reactors operated by the National Laboratories.

In summary, there is a strong financial disincentive for prospective users to conduct research at a URR. A faculty member who wishes to do so must often design, finance, build, and install his or her own equipment and then pay to use it.

Table 1
Selected Uses of the MIT Research Reactor

1. Neutron capture therapy (NCT) for the treatment of brain tumors using thermal neutron beams.
2. Evaluation of organic coolants.
3. Measurement of delayed neutron yields and half-lives.
4. Lattice studies for the determination of cross-sections and reactor physics parameters for fast reactors.
5. Nuclear physics studies including refinement of the known charge neutrality of the neutron, the effect of gravity on the strong force, and verification of the linearity of wave mechanics.
6. Studies of the uptake of nutrients in humans using the stable isotope method.
7. Neutron activation analysis for the quantification of air pollutants, isotope ratios in geologic formulations, and aerosol distribution.
8. In-core loops that replicate PWR/BWR operating conditions for the evaluation of water chemistry and identifying corrosion mechanisms.
9. In-core loops that enable mechanical property testing in a high-radiation environment.
10. Demonstration of signal validation using analytic redundancy.
11. Evaluation and later production of Dy-165 for the treatment of arthritis (radiation synovectomy).
12. Development and demonstration of generic methods for the direct digital control of spacecraft and terrestrial nuclear reactors.
13. Design and demonstration of a rule-based controller.
14. Track etch studies for the determination of boron distribution in cells.
15. Neutron capture therapy using epithermal neutron beams.
16. Design and construction of a fission converter to produce an enhanced epithermal beam for neutron capture therapy.
17. Student design projects in nuclear engineering.
18. Laboratory courses in reactor physics, nuclear instrumentation, and radiation measurements.
19. Reactor operator training for students.

III. RATIONALE FOR URRS

There would appear to be little reason to operate URRs. Reactors operated at the National Laboratories offer higher flux levels than do most URRs. Moreover, those laboratories also provide instruments and support staff so that prospective users can focus on their research as opposed to equipment setup. Finally, the expense of utilizing a national laboratory's reactor is often less than that of conducting the same experiment on a university campus reactor. However,

URRs do have a role and that role is to maintain the vitality of graduate education in nuclear engineering in the United States. Students need exposure to experimental work in order to grasp the full meaning of their studies. Moreover, to be effective, that exposure should be an integral part of the overall educational experience. On-campus facilities are necessary for this to occur. Without them, our society will not produce the creative people who can both identify and devise solutions to the problems that confront it.

The argument in support of the on-campus operation of research reactors is enumerated below:

1. There is a continuing and growing need for neutron sources in the United States. For example, the U.S. Department of Energy recently sponsored a symposium on neutron science in support of its plans to build a spallation neutron source [2]. Speakers from industry, government, and universities all spoke to this need. Among the disciplines mentioned were structural molecular biology, polymer science, materials research, non-destructive testing, and biomedical studies.
2. Neutrons can be produced from a variety of sources including reactors, accelerators, and accelerator-driven spallation targets. A reactor can provide neutrons for almost all applications. However, the reverse is not true. Certain applications are unique to reactors including (1) reactor dynamics and control studies such as are necessary to develop spacecraft reactors and/or future power production reactors, (2) studies of corrosion mechanisms in materials used in nuclear power systems, (3) medical applications where a large volume neutron source at high flux and a certain energy range is required.
3. Graduate education is most effective when students work on campus in close association with faculty. The process is akin to apprenticeship. Access to on-campus facilities is particularly important for engineering Ph.D.s which require the synthesis of many disciplines such as reactor physics, neutron and photon transport, heat transfer, fluid flow, materials behavior, manufacturing techniques, and advanced computational methods. Also, candidates for engineering Ph.D.s often have to perform many small-scale experiments before testing the overall concept.
4. National laboratories do not offer the extensive training necessary for someone to become a competent experimentalist. Rather, these laboratories depend on universities to supply broadly trained personnel who can then specialize as needed.
5. Time at a National Laboratory reactor is always at a premium. It is often useful if scoping experiments can be performed elsewhere.
6. URRs, even though they were built forty years ago, remain in excellent material condition. This is, in part, because their operation and maintenance has always been subject to stringent quality assurance requirements.
7. URRs do not offer the flux levels available at National Laboratories. However, not all applications require the highest available flux level. Often the fluence, which is the time integral of the flux, is the important parameter and hence a lower flux is acceptable. Also, novel

technologies exist to augment flux. For example, the MITR is being equipped with a fission converter that will yield a superior epithermal neutron beam for clinical trials of neutron capture therapy [3]. Additionally, the use of aluminum/aluminum-fluoride moderators has been reported to improve the epithermal flux in TRIGA reactors by a factor of two [4].

8. URRs offer an intangible benefit that comes with the routine availability of an on-campus reactor. Namely, those using it are exposed to the administrative controls and attitudes needed to ensure the proper operation of complex, safety-constrained systems.
9. Students from many disciplines can learn from a URR. For example, mechanical engineers who might one day design a fuel shipping cask can see the transportation of fuel first hand. Also, those interested in waste disposal or the identification of illicit material transfers can get an understanding of radiation and its measurement.
10. Individuals from a broad range of backgrounds can benefit from URRs. For example, journalism majors would not normally be given the opportunity to visit a National Laboratory. But they can tour a URR. So can members of the general public.

IV. SOLUTION

The solution to the crisis that is now enveloping the nation's remaining thirty URRs is for the federal government to provide base financial support. In addition to the fuel assistance that is now provided, this support should include the cost of operating each reactor, the expense associated with equipping each URR with instruments appropriate to its suitability for research, and funds to hire the technical staff needed to assist prospective users. The allocation of funds should, of course, be on a competitive basis with proposals subject to peer review. A facility would have to demonstrate that the funds would be used to advantage. This proposal is not original. Other facilities in the United States, such as accelerators, receive such support. Also, the National Organization of Test, Research, and Training Reactors has argued for it for years. Finally, support of this type was recommended in a report issued by the National Academy of Sciences [5]. Nevertheless, such support has not been forthcoming. What is made available are research grants in nuclear engineering. These are excellent vehicles for nuclear engineering departments. However, they provide little benefit to URRs even if the research is conducted at a URR. For example, many URRs offer a neutron activation analysis (NAA) capability. Suppose a grant is received to use NAA to identify and quantify air pollutant sources. Most of the grant will be spent on student research assistantships and on costs associated with sample collection including equipment purchases. A portion of faculty salaries and secretarial support may also be charged to the grant at some universities. The cost of irradiating the samples will be a minor part of the overall budget, probably less than 10%. Thus, while the URR is supporting a large research volume at the university, actual income to the URR is derived only from neutron charges and this will be small.

A further advantage to this proposal is cost. First, the expense of decommissioning existing URRs would be

deferred until some later date. Second, the United States has spent substantial sums during the past two decades on advanced scientific projects that were never built. Examples include fusion machines, the Advanced Neutron Source, and the Supercollider. The existing thirty URRs could be re-energized for a relatively small sum, on the order of tens of millions of dollars. Moreover, these could be kept operational for an even smaller amount.

V. CONCLUSIONS

Many university research reactors are poorly utilized and as a result are being decommissioned by their respective universities. This constitutes an irretrievable loss to the teaching of nuclear engineering. The irony of the situation is that the demand for neutron sources within both the academic and industrial communities is growing and that research reactors that are operated by the National Laboratories are oversubscribed. URRs have difficulty attracting users because they must charge for their services whereas such services are available at no cost at the National Laboratories. The cumulative effect of this disparity is that URRs do not generate sufficient income to make upgrades, and hence are no longer equipped with state-of-the-art instrumentation. This in turn further discourages utilization. Base funding of URRs is required so that URRs can properly equip their facilities and hire the technical staff needed to support prospective researchers. This support could be provided at a relatively small cost. It is incumbent upon both university administrators and the political leadership of the United States to recognize this issue and to act in a positive and responsible manner before the remaining thirty URRs are lost forever.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

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