Long-Term Experience Operating With LEU At Uprated Power

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Background

Like many university research reactors, the Ohio State University Research Reactor (OSURR) began its life as an HEU-fueled, low-power training and research reactor of the open pool, MTR-type design. Facility construction began in 1960, with initial operation of the reactor in March 1961. There followed over 25 years of safe and reliable operation, providing instructional and research services to the University community and external users.

As a low-power facility, utilization of the OSURR for research applications was quite limited. While proving to be a versatile instruction tool for classroom instruction, laboratory demonstrations, and basic reactor physics and engineering experiments, serious research utilization of the reactor was not feasible. For example, high sensitivity neutron activation analysis (NAA), materials damage studies, and radiation detector device testing was precluded by the relatively low neutron fluxes available. At its maximum operating power of 10 kilowatts of steady-state thermal power, peak total neutron flux for in-core irradiation positions was about 4 x 10^{11} nv [1].

Initially, such limitations were not an immediate concern for either users or OSURR staff, from both a capabilities and a financial perspective. Users requiring higher neutron fluxes could apply for access to the Battelle Research Reactor, a 2 megawatt facility within a half-hour drive of the University, or the Air Force Institute of Technology (AFIT) research reactor at Wright-Patterson Air Force Base, a 10 megawatt facility, about an hour's drive away. The state also was home to the NASA Plumbrook Research Station, featuring a 60-megawatt test reactor. Furthermore, the University was willing to provide an in-house ("hard money") budget adequate to support OSURR operations with a full compliment of staff (four full-time employees plus student assistants).

The situation began to change in the 1970s. The three other research reactor facilities based in the state as noted above began to cease operations. Likewise, University budget priorities changed and the OSURR facility budget was reduced by about 50% in the late 1970s. While OSURR staff made efforts to generate external funding and had some measure of success doing so given the limitations of the reactor, it became clear that further operation at 10 kilowatts was unlikely to generate significant or adequate funding to maintain the viability of the facility.

There were suggestions for uprating to power of the HEU-fueled reactor to something in the range of 100 kilowatts. This was deemed reasonable since the original reactor design (although not the system installed for the OSURR) allowed for power up to one megawatt of steady-state thermal power. However, it was clear that such an effort would require significant funding for both licensing studies and hardware changes. Given that the facility budget was in the process of being reduced, not increased, little serious consideration was given to such an undertaking. There was also concern that demonstrating the integrity at higher operating power of HEU fuel that had been submersed in demineralized water for 25 years would be problematic at best.

In the mid-1980s, OSURR staff became aware of efforts to encourage research reactors to convert from HEU to LEU fuel. It became evident that such conversion would eventually be required, and that they might provide an opportunity for facility upgrade. The conversion would require core analysis and the tools needed for this could be used to analyze higher-power operation as well as maintaining the original operating power. The LEU fuel would be freshly fabricated, thus avoiding the question of the integrity of the older HEU fuel when operated at higher power.

The final decision to undertake the fuel conversion and power upgrading effort was made with the understanding that a reasonable effort would be made to actually carry out the power uprating work, not leave it as the design stage. Too often studies are undertaken and no real, tangible results are eventually obtained. The OSURR staff insisted that the facility would voluntarily and proactively undertake the effort only if a tangible, positive benefit would result.

Fuel Conversion

Like many universities, Ohio State provides matching funds for programs funded by external sources, on a competitive basis and considering the overall contribution to the university mission of a given program. For the fuel conversion and power uprating project, we proposed a 1:1 match between DOE and University funds. This was eventually approved by University administrators, and proved an effective means of leveraging external funding.

DOE provided initial funding for fuel conversion studies in July 1985. Initial computational studies began in August 1985, with primary emphasis on neutronic and thermal hydraulic calculations directly related to fuel conversion. Code packages were obtained from various sources and installed on local computing platforms. These included the usual suite of neutronic and thermal analysis codes, based on both analytical and Monte Carlo techniques. Core modeling, simulation, and neutron transport calculations included studies done with MORSE, DIF3D, VIM, LEOPARD, and PARET for transient analysis. We used NATCON for some of the thermal hydraulic analysis, and KENO for criticality analysis. Models of the OSURR core fueled with LEU were analyzed for various operating powers, which established the boundaries over which uprated power while maintaining natural convection cooling would be feasible. This scoping approach saved time and allowed us to pursue parallel pathways towards the ultimate goal of choosing an uprated power.

Much of the computational work was performed by students as part of their academic programs, which resulted in various publications and theses over a period of years [2-5]. Such work supported the overall mission of the facility in contributing to education and research activities by students and faculty.

The initial LEU-fueled configuration operating at 10 kilowatts showed a smaller core, owing to the higher ^{235}U content of a given fuel assembly compared with an HEU assembly. This caused some concern regarding reactivity margins and worth of control rods and experiment facilities, which required a stepwise approach when doing the actual conversion and uprating activities. It was decided to make the fuel conversion and power uprating a two-step process. The OSURR would be initially licensed to operate using LEU fuel but limited to 10 kilowatts of steady-state thermal power. After testing of this core design under operational conditions, and after experience had been gained operating the reactor in this arrangement, a separate application for upgrade power operation would be made. This approach actually resulted in some degree of convenience, as we were able to complete engineering tasks related to high power operation during this initial operational phase at low power.

During the computational analysis phase of this work, the OSURR staff worked with DOE in specifying the fuel assembly design. DOE needed time to fabricate the fuel. The OSURR staff also prepared the licensing documents. An order specifying conversion of the OSURR to LEU and appropriate license amendments were processed in mid-1988 to clear the way for fuel shipment and receipt. The HEU core was removed and the initial LEU core installed in late 1988.

Early LEU core geometries were specified for 10 kilowatt operation and required little in excess reactivity. Control rod worths and shutdown margin were the primary focus of configuring and operating the LEU core. Tests were completed and operation with LEU began in early 1989. This allowed measurements to be made of the neutron environment in and around the core, for comparison with predicted flux and spectral distribution, as well as comparison with the HEU core. Experience of other reactor conversions, such as the Michigan FNR and the ORR, led us to believe that we would experience some degradation inn the in-core neutron energy distribution (e.g., loss of thermal neutron flux), but relatively little change in ex-core facilities owing to higher leakage of epithermal neutrons.

Figure 1 shows one of the early OSURR LEU core geometries. This is a fairly symmetric arrangement of fuel assemblies, maintaining control rod worth by loading fuel assemblies around and near the control rod positions. The east core face is left unreflected by graphite elements, which was not the case with HEU. As experience was gained operating the LEU-fueled OSURR, the core geometry evolved as experimental facilities were added or higher excess reactivity was required for uprated power operation.

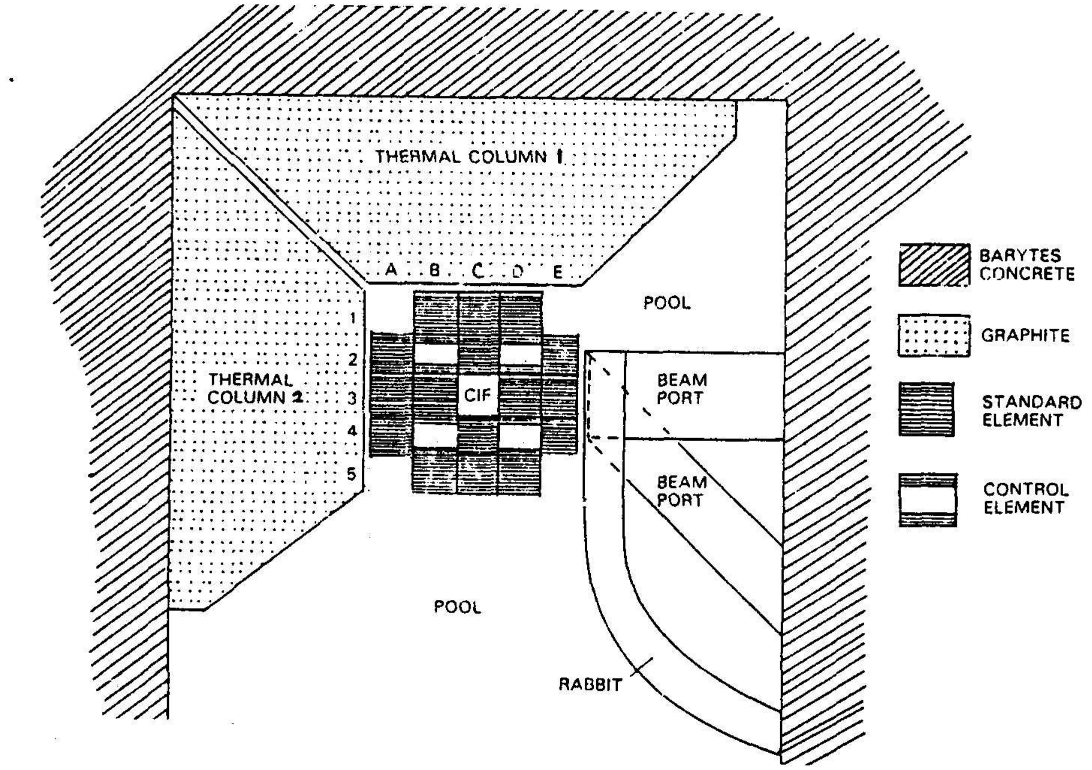

Figure 1
An Early OSURR Core Geometry Using LEU

Removal of the HEU core required storage of the HEU assemblies while the LEU core was loaded. Fortunately, a pool of sufficient depth and wall thickness, originally built for experiments, was available for modification as a secure storage facility, within the confines of the reactor building. The lack of available shipping casks for the HEU assemblies made this unavoidable. We could not afford to wait until the HEU fuel shipped before installing the LEU core. As it turned out, the HEU assemblies were not shipped until several years after completion of the conversion/uprating work, owing to the lack of available shipping casks.

Power Uprating:

The goal of the power uprating work was to operate the OSURR at as high a power as possible while maintaining safety margins for protection of the fuel boundary integrity and personnel exposures. An early decision was to maintain natural convection as the primary mechanism of heat removal. This simplified engineering and licensing issues. Early scoping calculations indicated that operating power in the range of several hundred kilowatts should be possible.

Eventually, we focused on a goal of 0.5 megawatts as the final operating power. Calculations indicated that natural convection cooling would be possible at this operating power, maintaining acceptable fuel plate temperature and ONB margin. Reactor pool shielding (wall thickness, water depth) was also estimated to be adequate in keeping personnel exposures in acceptable ranges from an ALARA perspective. The cost of installing hardware adequate to support this operating power was also deemed manageable.

From an experimental perspective, operation at this power level was estimated to provide in the range of 2-3 x 10^{13} nv flux in the optimum in-core irradiation position. This was desirable as it provides capability for more sensitive neutron activation measurements, as well as a wide dynamic range for testing neutron sensors and other devices.

Hardware required for high power operation included a heat removal system, a decay tank to reduce ^{16}N activity, and a core "shroud" to direct coolant flow from the bottom to the top of the core. Much of this work was done concurrently with LEU core testing and initial operation. A request for a license amendment to allow uprated power operation was prepared.

Once permission to operate at higher power was secured, the power increase was accomplished in a stepwise manner, with testing performed at intermediate power levels leading up to full power operation. At each successive power step, measurements of coolant outlet temperature, neutron flux, and gamma exposure rate were made. The final operating power was attained several weeks after beginning this process.

Experience Since Completion of the Program

Conversion to LEU resulted in unavoidable changes in the neutron energy spectra of various experimental facilities. In general, for in-core irradiation positions, the overall neutron flux increased by about 9% when compared with the LEU core. While seemingly counterintuitive, this is understandable given that the LEU core is more compact than the HEU core because of the higher fuel loading per fuel assembly. However, the thermal neutron flux decreased about 2%, while the epithermal neutron flux increased by about 27%. Thus, the LEU core features a "harder" neutron spectrum. This was expected based on the experience of others.

For external irradiation positions, minor changes in the neutron energy spectrum and total flux were observed. In the "Rabbit" facility, for example, the total flux over all neutron energies was reduced about 4% from that of the HEU-fueled OSURR. The thermal neutron component of the flux decreased about 3%. Some of this change can be attributed to core geometry, as there are fewer fuel assemblies adjacent to the Rabbit position with the LEU core.

The small changes in neutron flux did not adversely affect OSURR operation or utilization. As a general-purpose, non-optimized facility, small changes such as those noted from the fuel conversion do not have significant impact.

Minor changes in reactivity worth were observed for control rods and experimental facilities. The changes in control rod worth were small and did not adversely affect meeting licensing requirements of shutdown margin and excess reactivity. The most significant change was the reduction in reactivity worth for experiments mounted in Beam Port 1. This is attributed to the lack of core reflection along the east face, which tends to tilt the neutron flux away from the Beam Port positions. Loss of reactivity worth has rendered one of our experiments, a reactivity oscillator, non-functional because of the loss of reactivity effects in this position. We are unable to observe the small power oscillations this experiment induced in the HEU core, which is a consequence of the lower reactivity worth of this experiment in Beam Port 1.

Fuel performance has been trouble-free. Periodic sampling of pool water radioactivity has not revealed the presence of any fission products. Annual inspections of fuel assemblies and control rods have not revealed any defects or failures. In one inspection we noted a small brown "stain", or discoloration, near the top edge of the fuel plates in one fuel assembly. It was not clear if this discoloration was a result of changes in the fuel plates, or the presence of foreign material in contact with the fuel element. For conservatism, this assembly was removed from the core and replaced with an unirradiated fuel assembly of similar ^{235}U loading.

Operation at uprated power has also been without serious incident. Higher available neutron flux has made NAA studies more sensitive. There is also a wider range of flux available for testing neutron sensors over a greater range of their operational design. Radionuclides produced for experiments have been made with higher specific activities. There has been interest in using the reactor for radiation damage studies, which would have been difficult with low-power operation. Faculty in other departments have expressed interest in developing experimental capabilities such as radiography and neutron diffraction.

Higher power operation initially caused some degradation in the pool liner near the Beam Port penetrations, causing slow leakage of pool water through the cracked surfaces of the liner and eventually to areas external to the reactor pool. This required a maintenance outage to refinish the liner. A newer, more radiation and thermal-resistant material was used to coat the concrete surfaces. There has been no further leakage in the three years following that work.

Conclusions

Fuel conversion and power uprating of the OSURR has been a successful and useful endeavor. The fuel conversion requirement was met, and useful changes to the facility were made concurrently with the conversion effort. These have enhanced facility capability and increased its utilization. We believe that the facility lifetime has been extended as a result. Given the history of other research reactor facilities in the state, we feel this has been a positive outcome. Hopefully, other university research reactors considering such changes can learn from our experience.

References

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