HEU TO LEU CONVERSION EXPERIENCE AT THE UMASS-LOWELL RESEARCH REACTOR

JOHN R. WHITE
Chemical and Nuclear Engineering Department
University of Massachusetts Lowell, Lowell, MA 01854 -- USA

and

LEO M. BOBEK
Radiation Laboratory
University of Massachusetts Lowell, Lowell, MA 01854 -- USA

ABSTRACT

The UMass-Lowell Research Reactor (UMLRR) operated safely with high-enriched uranium (HEU) fuel for over 25 years. Having reached the end of core lifetime and due to proliferation concerns, the reactor was recently converted to low-enriched uranium silicide (LEU) fuel. The actual process for converting the UMLRR from HEU to LEU fuel covered a period of over 15 years. The conversion effort -- from the initial conceptual design studies in the late 1980s to the final offsite shipment of the spent HEU fuel in August 2004 -- was a unique experience for the faculty and staff of a small university research reactor. This paper gives a historical view of the process and it highlights several key milestones along the road to successful completion of this project.

Introduction

The University of Massachusetts Lowell owns and operates a 1 MW MTR-fueled pool-type research reactor that serves as a nuclear-related research and training center for the University community, and provides irradiation services to a variety of industrial partners. The UMass-Lowell Research Reactor (UMLRR) operated safely with high enriched-uranium (HEU) fuel from early 1975 to the summer of 2000. At that time, the HEU fuel was moved to the fuel storage racks along the pool wall, and a completely new core fueled with low-enriched uranium silicide (LEU) fuel was loaded. After a few weeks, the startup tests for the new core were completed, and we have been operating successfully ever since with the new LEU fuel. Finally, in August 2004, the HEU to LEU conversion process came to full closure with the shipment of the 31 spent HEU fuel elements from UMass-Lowell to the Department of Energy (DOE) Savannah River Site. The actual process for converting the UMLRR from HEU to LEU fuel covered a period of more than 15 years. This paper highlights some of the key technical aspects of the HEU to LEU conversion. In particular, the paper gives a historical overview of the complete process, including: (1) the preliminary design work in the late 1980s, (2) the regulatory approval process in the mid 1990s, (3) the final design and analysis studies in 1999-2000, (4) the actual conversion process in 2000, and (5) the recent HEU fuel shipment that completed the overall conversion effort.

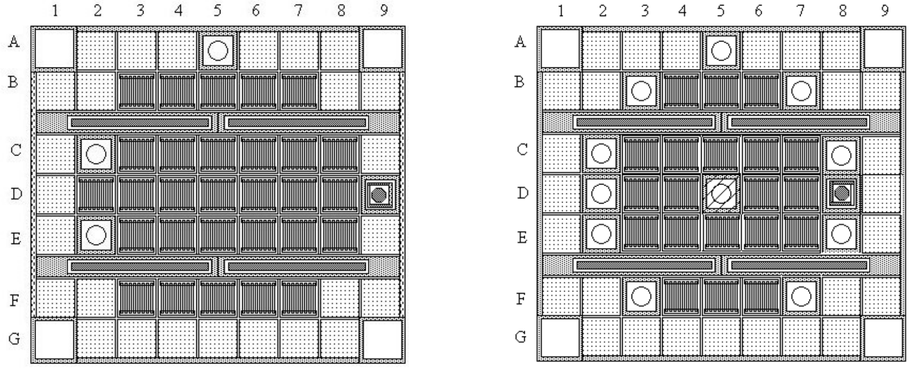
Historical Perspective (1988 -1999)

The process for converting the UMLRR from HEU fuel to LEU fuel began in early 1988. This effort was initiated in direct response to the 1986 NRC ruling that limited the future use of highly enriched uranium in domestically licensed research reactors in the U.S. [1]. At that time, we had limited in-house computational capability within the Nuclear Program at UMass-Lowell; so much of our initial effort was focussed on developing computer models and benchmarking a set of tools for the physics and safety analysis of research reactors. Our early work [2]-[3] centered on the development of a physics model for the existing HEU core and the comparison of reactivity and flux measurements from the initial HEU startup tests [4] with the computed results. Based on the confidence gained from excellent comparisons to measured data from our early HEU models, we then used these same methods to perform some preliminary design and safety computations for several candidate LEU configurations [5]. This work continued with the evolution of a particular LEU assembly design containing 16 standard LEU plates and two aluminum end plates. This specific LEU16-18 element design was then used within a variety of possible configurations to arrive at a preliminary core design that could be used to drive the initial safety studies [6]-[7].

The culmination of all the early in-house design studies, physics modeling, and thermal hydraulic analyses, along with some help from the Reduced Enrichment for Research and Test Reactors (RERTR) group at Argonne National Laboratory (ANL) [8], was a preliminary reference fuel design and core configuration based on 20 standard, flat-plate, 19.75% enriched, uranium silicide (U_3Si_2) fuel elements, with a combination of radiation baskets and graphite or water reflector elements filling most of the remaining 9x7 array locations within the UMLRR grid plate. A sketch of the 1993 LEU design, along with a typical 29-element HEU core configuration for comparison, is shown in Fig. 1. Some of the key characteristics of the 1993 LEU core design are listed below:

- The LEU assembly design has 16 uranium silicide fuel plates with 12.5 grams of U235 per plate and 2 aluminum end plates (LEU 16-18 assembly), whereas the HEU element had 18 full plates with 7.5 grams of U235 per plate,
- The LEU core is a small 20-element high leakage core,
- The LEU configuration contains a central flux trap facility with high fast and thermal fluxes (more than a factor of three better than any experimental location in the HEU core),
- The LEU fuel arrangement gives good blade worth symmetry for ease in operation and a high shutdown margin,
- The regulating blade is moved inward one position (D9 to D8) in its low-worth orientation, and
- The LEU core gives equal or improved performance relative to the HEU core -- except for the fluxes in the thermal column side of the core (reduced by about a factor of two).

Based on the physics and safety studies for the 1993 LEU design, a final safety analysis for the HEU to LEU fuel conversion was submitted to the Nuclear Regulatory Commission (NRC) in 1993 and the base LEU design was approved later that year [9]. The NRC did make two additional requests for information based on the 1993 design and the appropriate supplements were submitted in 1994 and 1997. Finally, in July 1997, the UMLRR was issued an NRC order modifying the reactor license to convert from HEU to LEU fuel. However, due to insufficient DOE funding, manufacture of the LEU fuel for the UMLRR was not authorized until October 1999. During the interim between the NRC order and the funding authorization, the UMLRR reactor supervisor retired and was replaced. Upon review of the proposed LEU core configuration, the new supervisor initiated a design change to eliminate the modification to the regulating blade that was included as part of the 1993 core design.



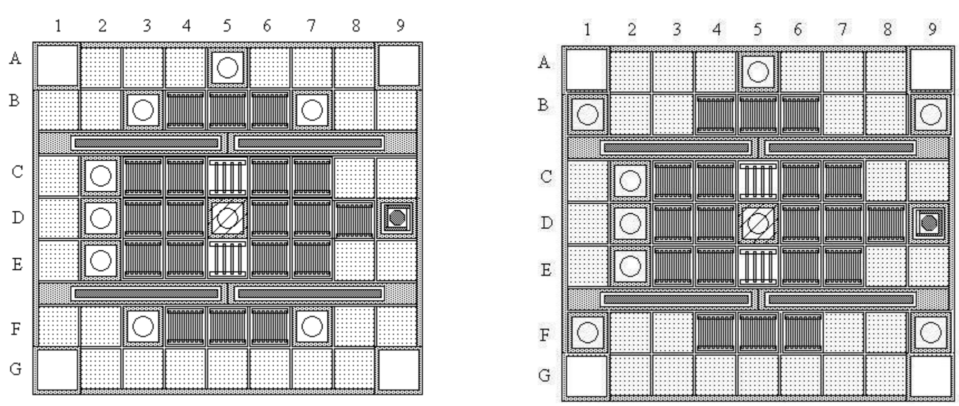
29-Element HEU Core Configuration 20-Element 1993 LEU Core Layout

Fig 1. HEU reference and preliminary LEU core designs for the UMLRR.

Actual Core Conversion (1999-2000)

In the summer of 1999, with the pending HEU to LEU conversion nearing reality, a major effort was undertaken to update our local modeling and calculational support capabilities at UMass-Lowell, to revive and improve upon the LEU computational models from the early 1990s, and to readdress the proposed movement of the regulating blade from the D9 position to the D8 position. This work produced the proposed new reference core configuration displayed on the left side of Fig. 2. This 21-element core with 19 full fuel elements and 2 partial elements was chosen as the best candidate for the initial startup of the LEU-fueled UMLRR. This design does not require any physical changes to the HEU core other than the replacement of the fuel assemblies and the re-configuration of the graphite reflectors and water/radiation baskets. While it does introduce some asymmetry in the blade worth distribution, the thermal column fluxes were improved without much sacrifice in the neutron levels seen in the primary in-core irradiation locations. The study also provided a wealth of computational information to help guide the actual core conversion process and to support the continued use of the experimental facilities within the new LEU core configuration [10]-[12].

The actual conversion process took place during the summer of 2000. The receipt and inspection of the new LEU fuel was completed in late July 2000 and, guided by the pre-analysis of the critical loading from Ref. 11, the LEU reactor core was loaded to a critical configuration on August 4, 2000. After achieving a final core configuration, which differed slightly from the proposed 1999 layout to allow greater excess reactivity (see Fig. 2), the process of evaluating the reactor operating characteristics was undertaken. After several weeks of reactivity evaluations, thermal flux mapping, reactivity coefficient measurements, etc., the new LEU core was found to operate essentially as designed. The key startup results along with some direct comparisons of the measured and computed results for the new LEU-fueled UMLRR are summarized in Refs. 13-14. These comparisons highlight several operating characteristics of the new core and they provide a direct evaluation of the models and methods used to design and characterize the new LEU core.



Target LEU Startup Core (M-1-2 Core) Actual LEU Startup Core (M-1-3 Core)

Fig 2. Target and actual LEU startup core designs for the UMLRR.

Shipment of HEU Fuel

The final step of the HEU to LEU conversion process was to remove the used HEU fuel from UMass-Lowell and ship it to a Department of Energy (DOE) storage facility. The original plan was to ship the spent HEU fuel in the summer of 2001, but lack of funding at DOE delayed the proposed shipment date until 2002. During the interim, the events of 9/11 occurred. A result was substantial security changes to spent fuel shipment regulations, making such shipments essentially impossible without additional expert technical assistance.

In early June of 2004, UMass-Lowell received confirmation from DOE that funding would be made available to ship the used HEU fuel. For policy and legal reasons, DOE would not directly be responsible for shipments from universities, but would fund technical assistance. We began contract negotiations with NAC International, a company that provides spent fuel shipment services throughout the U.S. and the world. In July, NAC performed a site engineering assessment at UMass-Lowell and all the details of the final contract for shipment were worked out. NAC would be responsible for coordinating all activities outside of the university campus. This included informing and obtaining approvals from the appropriates agencies of all involved states, the Nuclear Regulatory Commission, the Department of Transportation, and the Department of Energy. In general, NAC would handle all the technical and engineering aspects of the transfer and shipment, including security during transport.

During the period of contract negotiations, the reactor supervisor and director of radiation safety developed a Fuel Shipment Quality Assurance Program and related procedures to meet NRC regulatory requirements. The UML Reactor Safety Subcommittee (RSSC) met to discuss the details of the shipment, and to review and approve the quality assurance program. The QA program was then sent to the NRC for regulatory review and approval. During this time, NAC devised a five-day schedule to perform the fuel removal and shipment process. Several factors were considered for the start date: (1) the shipment had to occur prior to the academic year, (2) part of the transportation route included the State of New York and the shipment would not be allowed one week prior or during the national political convention taking place there, and (3) to minimize the impact on university activities, part of the schedule had to include a weekend. As a result, the schedule converged on a start date in mid August.

The UMLRR is housed in a domed containment building. On one side of the containment structure is an exterior vehicle door with a clear 10 ft wide and 12 ft high opening. Inside the access door is an area sufficient to drive a large forklift into containment and close the door. The spent HEU fuel consisted of 31 MTR flat-plate elements. The UMLRR pool used for storing the spent fuel is approximately 12 feet wide by 16 feet long and 30 feet deep. The pool floor loading is 3000 lbm/ft^2. Containment is equipped with a twin-rail polar crane. A 15-ton and a 2-ton crane are available to support cask-loading operations. Both crane hooks can be wetted. NAC employed the use of two LWT shipping casks, along with use of a transfer cask to shuttle baskets containing up to seven elements from the spent fuel pool to the LWT. Each LWT is capable of holding three fully loaded baskets.

The actual process for shipping the HEU fuel began on August 12th with the staging of the NAC shipping casks and support equipment in the parking lot adjacent to the reactor building. The UMass-Lowell Police Department provided a 24-hour security and work-zone safety perimeter around the parking lot, preventing vehicle and pedestrian traffic. The NAC equipment and procedures were tested and the transfer of HEU fuel from the reactor building into the shipping casks began the next day. The fuel transfer operations were completed within 30 hours and the process of dismantling and packaging the NAC equipment for transportation was completed the following day. The Massachusetts State Police then performed a high-level vehicle inspection, specific for transportation vehicles carrying hazardous materials. On August 17th, the HEU fuel shipment left UMass-Lowell under State Police escort and arrived safely at the DOE Savannah River Site, Aiken S.C., the next day. A total of 31 irradiated HEU fuel assemblies were shipped. This last step in the whole HEU to LEU conversion process went smoothly and was rather uneventful. This step brought final closure to our 15+ year journey.

Summary Experience

Our overall experience with this project was very positive at each stage of the process. Since we did not have a lot of prior experience with many of the tasks involved, a pro-active approach with the U.S. Nuclear Regulatory Commission (NRC) was taken. For example, we routinely requested guidance and oversight as needed, and even invited NRC inspectors to be on site to observe the actual LEU startup process and the shipment of the HEU spent fuel. Our interaction with the U.S. Department of Energy (DOE) was also quite positive. DOE provided both the financial support and technical guidance needed for completion of this project. In particular, assistance from DOE provided support for the design analyses, fuel material and fuel assembly fabrication, and for the shipment of the used HEU assemblies to a DOE facility. In addition, the technical assistance provided by the RERTR group at Argonne National Laboratory was invaluable, especially in the early stages of this effort. Finally, with the combined effort of a number of University staff and students, the design, implementation, and operation of the new LEU core was quite successful and the final HEU fuel shipment, which brought closure to the conversion process at the UMLRR, was completed without incident. The LEU core, with some post-conversion improvements, has been in full operation for over 4 years now, and we expect that it will continue to provide enhanced operational capability to support the education and research mission of the UMLRR for many years to come.

References

[1] U.S. Nuclear Regulatory Commission, “Limiting the Use of Highly Enriched Uranium in Domestically Licensed Research and Test Reactors,” U.S. Federal Register, Vol. 51, No. 37 Feb. 25, 1986.

[2] J. R. White, J. E. Stoddard Jr., and J. P. Phelps, "Verification of the Computational Models for the Physics Analysis of the University of Lowell Reactor," Trans. Am. Nuc. Soc., 56, 574 (June 1988).

[3] J. R. White, J. E. Stoddard, Jr., and J. P. Phelps, "Physics Analyses for the HEU to LEU Conversion at the University of Lowell Research Reactor," 1988 International Reactor Physics Conference, Jackson Hole, Wyoming (Sept. 1988).

[4] J. P. Phelps, “Startup Report for the LTI Reactor,” Lowell Technological Institute (May 1975).

[5] J. E. Stoddard, Jr., "Conversion from High Enriched Uranium Fuel to Low Enriched Uranium Fuel for the University of Lowell Research Reactor," M.S. Thesis, University of Lowell (May 1989).

[6] R. S. Freeman, "Neutronics Analysis for the Conversion of the ULR from High Enriched Uranium to Low Enriched Uranium Fuel," M.S. Thesis, University of Massachusetts Lowell (May 1990).

[7] A. Amarnath, "Thermal Hydraulic Analyses of the HEU and the Proposed LEU Core Configurations of the UMass-Lowell Research Reactor," M.S. Thesis, University of Massachusetts Lowell (Sept. 1993).

[8] Letter from J. E. Matos, ANL to J. R. White, UMass-Lowell (January 1993).

[9] “FSAR Supplement for Conversion to Low Enrichment Uranium (LEU) Fuel,” Document submitted for review by the NRC for conversion of the UMass-Lowell Research Reactor (May 1993).

[10] J. R. White and R. D. Tooker, “Modeling and Reference Core Calculations for the LEU-Fueled UMass-Lowell Research Reactor,” ANS 1999 Winter Meeting, Long Beach, CA (Nov. 1999).

[11] J. R. White, J. Byard, and A. Jirapongmed, “Calculational Support for the Startup of the LEU-Fueled UMass-Lowell Research Reactor,” Proceedings of Topical Meeting on Advances in Reactor Physics and Mathematics and Computation, Pittsburgh, PA (May 2000).

[12] J. R. White, A. Jirapongmed, and J. Byard, “Preliminary Characterization of the Irradiation Facilities Within the LEU-Fueled UMass-Lowell Research Reactor,” Proceedings of Topical Meeting on Advances in Reactor Physics and Mathematics and Computation, Pittsburgh, PA (May 2000).

[13] “Report on the HEU to LEU Conversion of the University of Massachusetts Lowell Research Reactor,” submitted to the US Nuclear Regulatory Commission in fulfilment of Amendment No. 12 to License No. R-125 (April 2001).

[14] J. R. White and L. Bobek, “Startup Test Results and Model Evaluation for the HEU to LEU Conversion of the UMass-Lowell Research,” 24th International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR 2002), San Carlos de Bariloche, Argentina (Nov. 2002).

[15] “Safety Analysis Report for the NAC Legal Weight Truck Cask,” NAC International, Docket No. 71-9225 T-88004 (May 2004).