University of Massachusetts
UMASS Lowell

Pinanski Building
One University Avenue
Lowell, Massachusetts 01854
tel: 978.934.3365
fax. 978.934.4067
e-mail: Leo_Bobek@uml.edu

RADIATION LABORATORY

Leo M. Bobek
Reactor Supervisor

April 9, 2001

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Re: License No. R-125, Docket No. 50-223

Pursuant to the Nuclear Regulatory Commission Issuance of Order Modifying License No. R-125 To Convert From High- To Low-Enriched Uranium (Amendment No. 12) – University of Massachusetts Lowell (TAC No. M86788) dated July 31, 1997 we are submitting the following Report on the HEU to LEU Conversion of the University of Massachusetts Lowell Research Reactor. If you require additional information or have questions, please do not hesitate to contact me.

Sincerely,

Leo M. Bobek,
Reactor Supervisor

cc: M. Mendonca, NRC HQ
T. Dragoun, Region I

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Report on the HEU to LEU Conversion of the University of Massachusetts Lowell Research Reactor

Submitted to the United States Nuclear Regulatory Commission
In Fulfillment of Amendment No. 12 to License No. R-125

University of Massachusetts Lowell
Radiation Laboratory
One University Avenue
Lowell, Massachusetts 01854

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Summary

The University of Massachusetts Lowell Research Reactor (UMLRR) is a one-megawatt, steady-state, pool-type reactor. Operational since 1974, its principal purpose is to provide a multidisciplinary facility for use in nuclear-related education and research.

Preparations for converting the UMLRR from high-enrichment uranium (HEU) fuel to low-enrichment uranium (LEU) fuel first began in 1988. The initial LEU reference core design and safety analysis were completed and submitted to the Nuclear Regulatory Commission (NRC) in 1993. Following two requests for additional information and the subsequent submittals, the NRC approved the fuel conversion order in 1997. Funding from the Department of Energy was approved in 1999 for manufacturing the LEU fuel and core center flux trap element. At that time, the UMLRR staff also began the detailed planning and preparations for the fuel conversion.

With the completion and the delivery of the LEU fuel, the actual process of converting the UMLRR began on July 27, 2000. The receipt and inspection of the new LEU fuel was completed on August 1 and the reactor core was loaded to a critical configuration on August 4. After achieving a final core configuration, the process of evaluating the reactor operating characteristics was undertaken. Several weeks of testing and data analyses ensued. The LEU core was found to operate well within the license technical specifications based upon the design parameters submitted in the safety analysis.

The UMLRR now has operated with the LEU fuel for several months without any difficulties or unexpected occurrences. In addition to an operational capability for several years, the converted UMLRR core provides enhanced facilities for education and research. The fuel conversion process is considered complete and routine operations have proceeded.

Introduction

The University of Massachusetts-Lowell Research Reactor (UMLRR) has been serving the university and surrounding community since 1974. The UMLRR is a one-megawatt, steady-state, pool-type reactor. It is one of three facilities within the University of Massachusetts-Lowell Radiation Laboratory, which also includes a 0.3 MegaCurie Co-60 source and 5.5 MV Van de Graff accelerator. The principal purpose of the UMLRR is to provide a multidisciplinary neutron source for use in nuclear-related education and research. Research activities utilize thermal neutrons for radioactivation purposes and fast (fission spectrum) neutrons for radiation effects research. In addition to its use by various university departments and courses, the reactor is involved with extensive educational outreach activities for pre-college students.

The process for converting the University of Massachusetts Lowell Research Reactor (UMLRR) form high-enrichment uranium (HEU) fuel to low-enrichment uranium (LEU) fuel began in 1988. Several years of design reviews, computational modeling, and thermal hydraulic analyses resulted in a preliminary reference core design and configuration based on 20 standard, MTR-type, flat-plate, 19.75% enriched, uranium silicide (U_3Si_2) fuel elements. A final safety analysis for the fuel conversion was submitted to the Nuclear Regulatory Commission (NRC) in 1993. The NRC made two additional requests for additional information and supplements were submitted in 1994 and 1997. On July 31, 1997, the UMLRR was issued an NRC order modifying the reactor license to convert from HEU to LEU fuel. Due to a lack of Department of Energy (DOE) funding, manufacture of the LEU was not authorized until October 1999. During the interim between the NRC order and the funding authorization, the UMLRR reactor manager (Reactor Supervisor) had retired and was replaced. The new UMLRR Reactor Supervisor initiated an effort to change the LEU reference core configuration to eliminate a complicated control rod modification.

Once DOE funding was authorized, the analysis for a new core configuration began. The UMLRR staff began the parallel development of a detailed Conversion Plan (CP). The CP included procedures for HEU fuel offloading and storage, new fuel receipt and inspection, new fuel loading, and various reactor core physics evaluations. The final CP and new core configuration were reviewed and approved by the UML Reactor Safety Subcommittee (RSSC).

On July 27, 2000, the process of conversion began. This report describes the conversion process activities and presents the results of the reactor physics test data.

LEU Core Configuration Design Change

Among the various changes from the HEU core configuration, the new smaller LEU reference core design (Fig. 1) had required a complicated modification to the reactor power regulating-rod to move it closer to the fuel. This modification involved making a precision "s" shaped bend to the 25 ft long extension tube that couples the rod to its drive mechanism. In 1999, the Department of Energy awarded the UMLRR a grant (DOE Grant No. DE-FG07-991D13742) to support the fuel conversion effort scheduled to take place in 2000. Part of this grant funded a review of the core configuration change that required the regulating rod modification. Subsequently, a new configuration (Fig. 2) based upon 21 LEU fuel elements (19 standard and two partial assemblies) was designed and chosen to eliminate the regulating rod modification. In preparation of the conversion and new configuration, an updated set of specific computational models was developed to verify the changes would not affect the approved safety analysis[1].

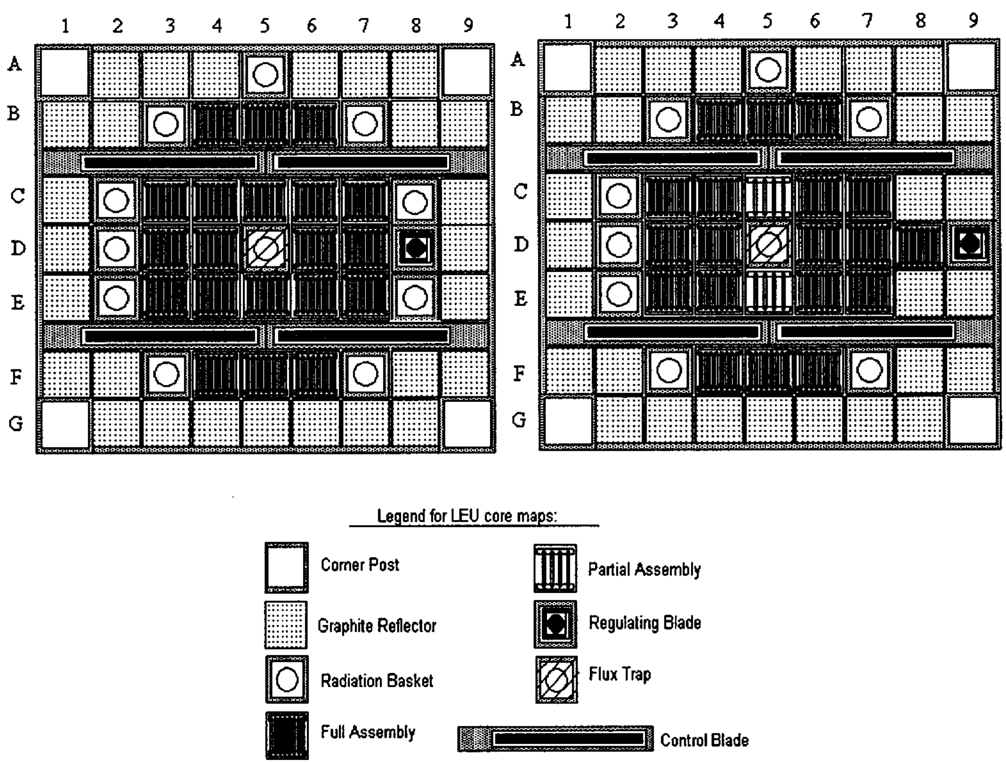


Figure 1: LEU Reference Core Configuration (1993)

Figure 2: LEU Reference Core Configuration (1999)

1. "Calculational Support for the Startup of the LEU-Fueled UMass-Lowell Research Reactor," J. R. White, J. Byard, and A. Jirapongmed, PHYSOR 2000, Pittsburgh, PA (May 2000).

HEU Fuel Offloading

HEU Fuel was offloaded from the reactor core and placed in storage racks located in the bulk-end of the reactor pool (Fig. 3, right). A total of 34 HEU fuel assemblies will remain in storage for approximately two years while analyses and preparations are completed for shipment to the Westinghouse Savannah River Company for final disposition. The UMLRR has in-pool storage capacity for 81 elements, including fuel and other related reactor core components.

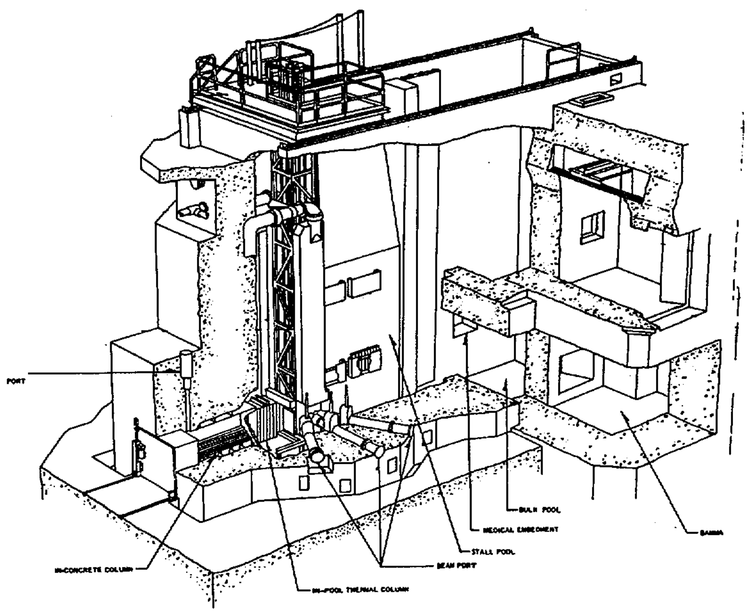


Figure3: Reactor Pool

Operator Training

In preparation of the conversion process, licensed operators and other staff participated in training on July 28, 2000. The purpose of the training was to review the Conversion Plan and schedule, the fuel receipt procedures, the operation and sequence of fuel loading, and the program of physics testing.

LEU Fuel Receipt

The LEU fuel was manufactured and shipped by BWX Technologies, Inc in Virginia. Prior to the fuel manufacture, an un-fueled test element was constructed and underwent successful UMLRR core-fit testing in January 2000.

A total of 27 standard fuel elements and two partial fuel elements were received on July 29, 2000. Shipping containers, each holding one fuel element, were placed inside the

reactor containment building for secure storage. On July 31, each container was opened and the fuel removed. Each element, in addition to the containers, was radiologically surveyed and thoroughly inspected. All the fuel and the containers were found to be satisfactory. The fuel was placed in the fuel storage racks located in the stall-end of the reactor pool (Fig. 3, left). The shipping containers were re-assembled and prepared for shipment back to BWX.

Non-Fuel Components Loading

After the HEU offload, the graphite reflector elements were re-configured in the core to match the new LEU reference core configuration. A total of 28 graphite reflector elements were in place for the final core.

Four water basket elements used to limit core reactivity were installed in the core on July 29, 2000. Two minor difficulties encountered with these water basket elements were associated with their maneuverability. The first minor difficulty noticed was the near neutral buoyancy of the elements, even after complete flooding. A second minor problem was the small handle space on the element, which made hooking and un-hooking the grappling tool difficult. These problems had no significance other than inconvenience and the water baskets were successfully loaded into the core. All the graphite elements were loaded prior to receipt of the LEU fuel.

NRC Oversight

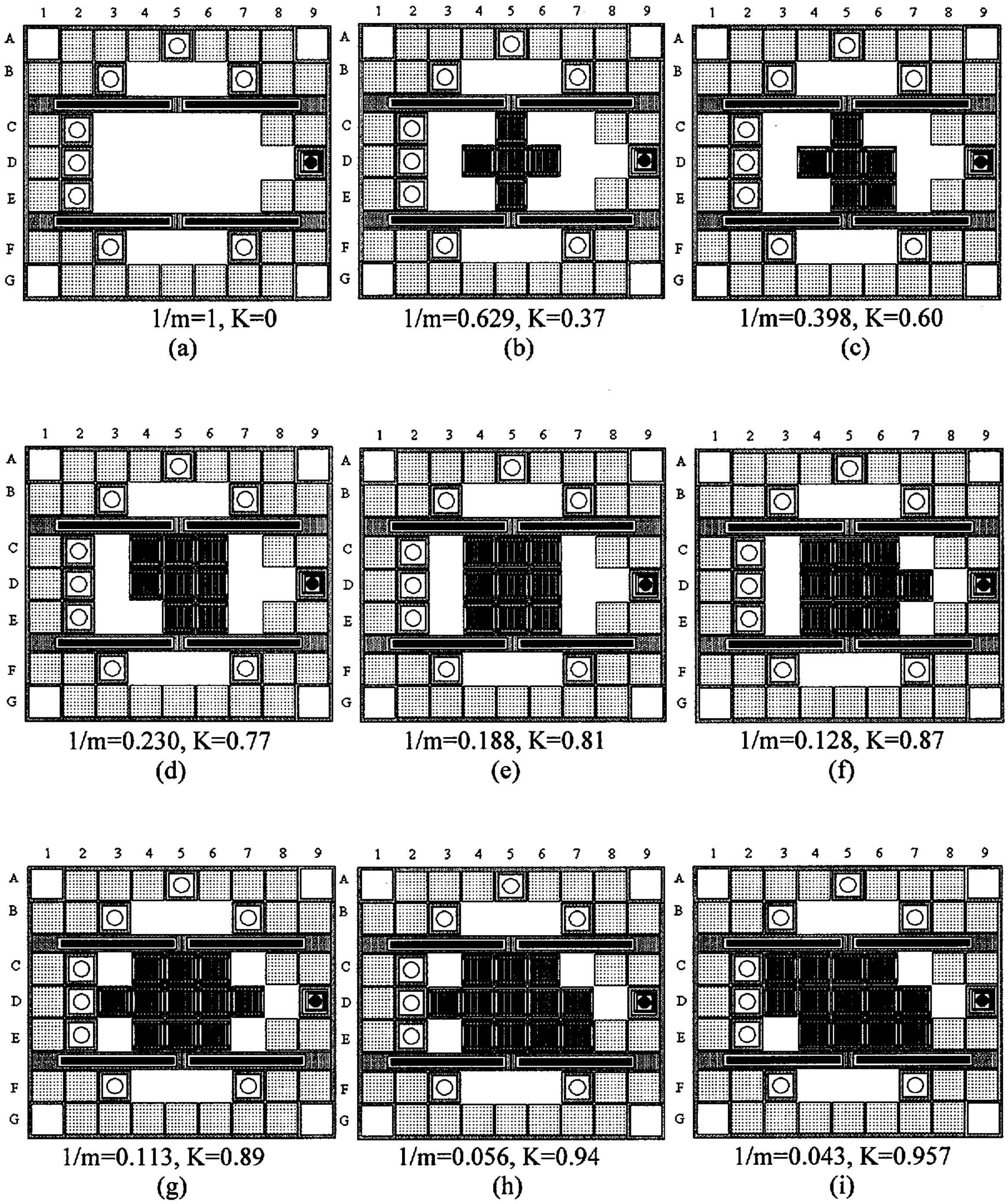
Fuel loading and the initial approach to critical were performed under the observation of a Nuclear Regulatory Commission inspector. The inspector also reviewed the Conversion Plan, training records, health physics practices, and RSSC meeting minutes. A post-inspection exit interview was provided to RSSC members, reactor staff, and a university administration representative. The inspection report was issued on September 12 (Report No. 50-223/2000201) with findings of no safety concerns or issues of non-compliance.

LEU Fuel Loading

Fuel loading for the approach to a critical core configuration began on August 2. Due to the careful nature of this procedure, a critical core configuration was not achieved until August 4, 2000.

Two loading approaches were made (Figs. 4 a-q). The first involved loading the core to a critical configuration using standard fuel elements and without the center flux trap. After several loadings and each subsequent inverse multiplication plot, a total loading of 15 standard fuel elements produced a slightly sub-critical core (Fig. 4-k). Inverse

multiplication plots indicated that the addition of one more fuel element would achieve a critical configuration. This result was consistent with computational models.



1/m=1, K=0 (a)

1/m=0.629, K=0.37 (b)

1/m=0.398, K=0.60 (c)

1/m=0.230, K=0.77 (d)

1/m=0.188, K=0.81 (e)

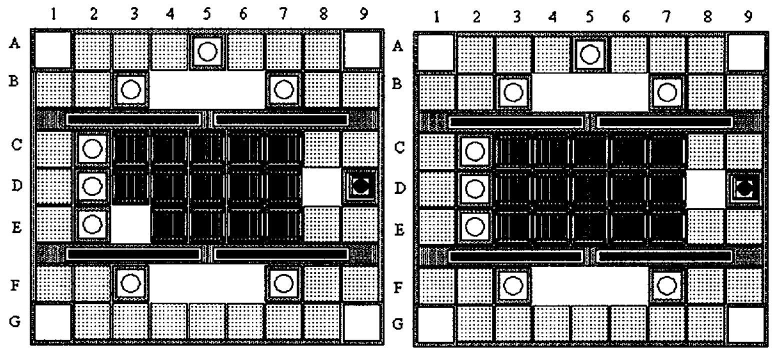
1/m=0.128, K=0.87 (f)

1/m=0.113, K=0.89 (g)

1/m=0.056, K=0.94 (h)

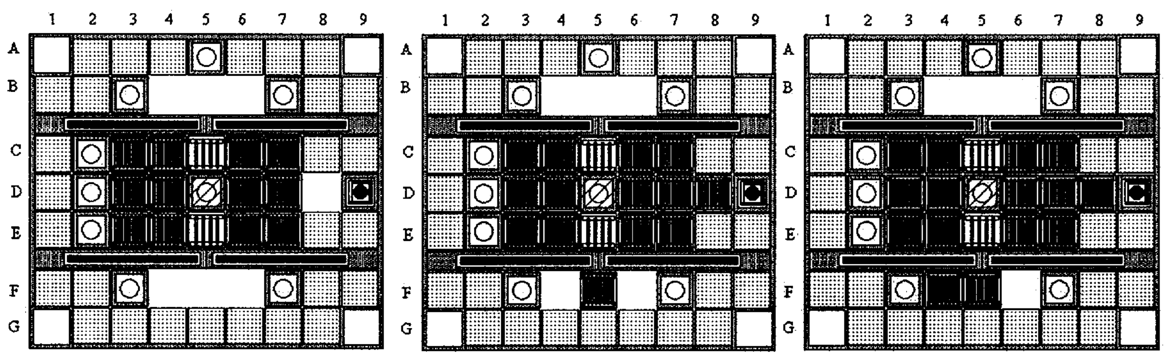
1/m=0.043, K=0.957 (i)

Figure 4 (a-i) Approach to Critical

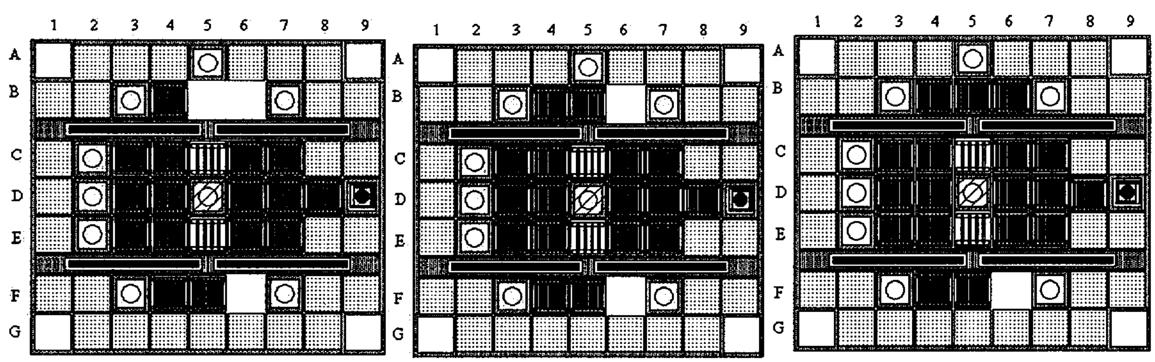


1/m=0.025, K=0.975 (j) | 1/m=0.017, K=0.983 (k)

At this point, the three center fuel elements (core-row 5) were removed and replaced with the center flux trap and two partial elements (Fig. 4-l). After loading two additional standard fuel elements, the approach proceeded with subsequent loadings of only one fuel element until a super critical core was achieved with 18 standard fuel elements and two partial fuel elements (Fig. 4-q). This configuration was one standard fuel element more than was predicted by conservative computational methods. Using the reactor period method, the core excess reactivity of this configuration (designated M-1-1) was estimated to be approximately 0.26% Δk/k.



1/m=0.057, K=0.942 (l) | 1/m=0.026, K=0.974 (m) | 1/m=0.019, K=0.981 (n)



1/m=0.010, K=0.99 (o) | K≈1 (p) | ρ_{excess}=0.26%Δk/k (q)

Figure 4 (j-q) Approach to Critical

The last fuel element for the reference LEU core (Fig. 2) was added August 7. The reactivity of this core (designated M-1-2) was measured to be 2.3 %Δk/k. Conservative modeling had predicted a core excess reactivity of 3.2 – 3.7% Δk/k.

The measured reactivity for the reference core configuration was considered less than optimum for long-term operations. After consultation with the Reactor Safety Subcommittee Chairman, it was decided the simplest method to achieve reactivity gain would be to move the water basket elements from adjacent to the fuel to the core periphery, and to move graphite reflectors elements in their place. The agreed upon core change was made on August 8. This core configuration designated M-1-3 (Fig. 5) proved to be satisfactory (see *Reactivity Evaluations*).

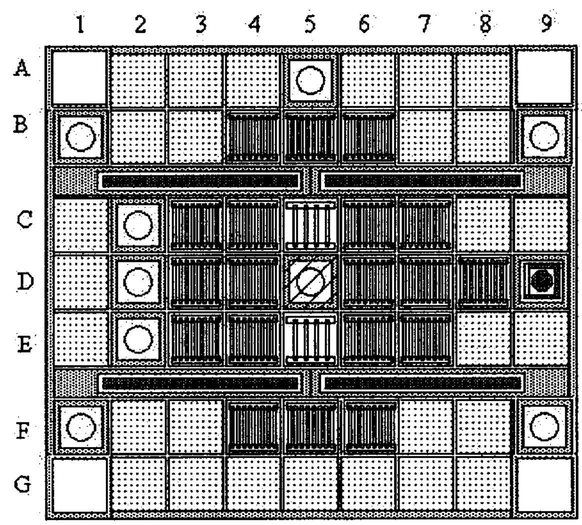


Figure 5: LEU Final Core Configuration (M-1-3)

Refer to Figure 2 for a component legend. Note control blade number designations 1 through 4 begin at the lower left core position and proceed clockwise.

Reactivity Evaluations

Calibrations of the control blades and regulating rod for core configuration M-1-3 were performed using the stable positive period method. The mid-point of the control blade motion was recorded and the reactivity was calculated from the period data using the six delayed neutron group inhour equation. A cosine fit of the data was used to generate a differential reactivity versus position worth curve for each blade. These data were then integrated to form the integral reactivity versus rod position curves (Figures 6 through 10).

Reactivity Data (Core M-1-3)

	Measured	Predicted *(VENTURE 2-D)*
Control Blade # 1:	2.53 %Δk/k	2.68 %Δk/k
Control Blade # 2:	2.38 %Δk/k	2.62 %Δk/k
Control Blade # 3:	3.34 %Δk/k	3.30 %Δk/k
Control Blade # 4:	3.19 %Δk/k	3.37 %Δk/k
Regulating Rod:	0.28 %Δk/k	0.39 %Δk/k
TOTAL Control Blades:	11.72 %Δk/k	12.0 %Δk/k
Core Excess:	3.97 %Δk/k	*(Tech. Spec. Limit: < 4.7% Δk/k)*
Shutdown Margin:	7.10 %Δk/k*	
Min. Shutdown Margin:	3.76 %Δk/k*	*(Tech. Spec. Limit: > 2.7% Δk/k)*

* Conservatively includes Total Worth of 0.5 %Δk/k for all movable samples and combined flooded beam-tube worth of 0.153% Δk/k.

The measured reactivity data were in good agreement with the VENTURE 2-D model predicted values, with the exception of the regulating rod. Despite the lower than expected worth, the regulating rod reactivity is sufficient to compensate for the small changes in reactivity that occur due to experiments and temperature effects.

In-core Facilities

A new design feature of the LEU core of particular interest is the core-center flux trap. A reactivity evaluation of this new experimental facility was performed by comparing the critical control blade heights with no experiment apparatus (sample bayonet) installed, with a water-filled sample bayonet installed, and with an air-filled sample bayonet installed.

Water-Filled Sample Bayonet:	+0.029% Δk/k
Air-Filled Sample Bayonet:	+0.254% Δk/k

The UMLRR license technical specifications limit the maximum reactivity of movable samples to 0.1% Δk/k and secured samples to 0.5% Δk/k. As most in-core samples are placed in a water-tight bayonet, samples to be irradiated in the flux trap will be treated as secured samples under the technical specifications.

A similar measurement for the radiation basket located in core position D-2 yielded the following results:

Water-Filled Sample Bayonet:	No measurable reactivity effect
Air-Filled Sample Bayonet:	-0.010% Δk/k

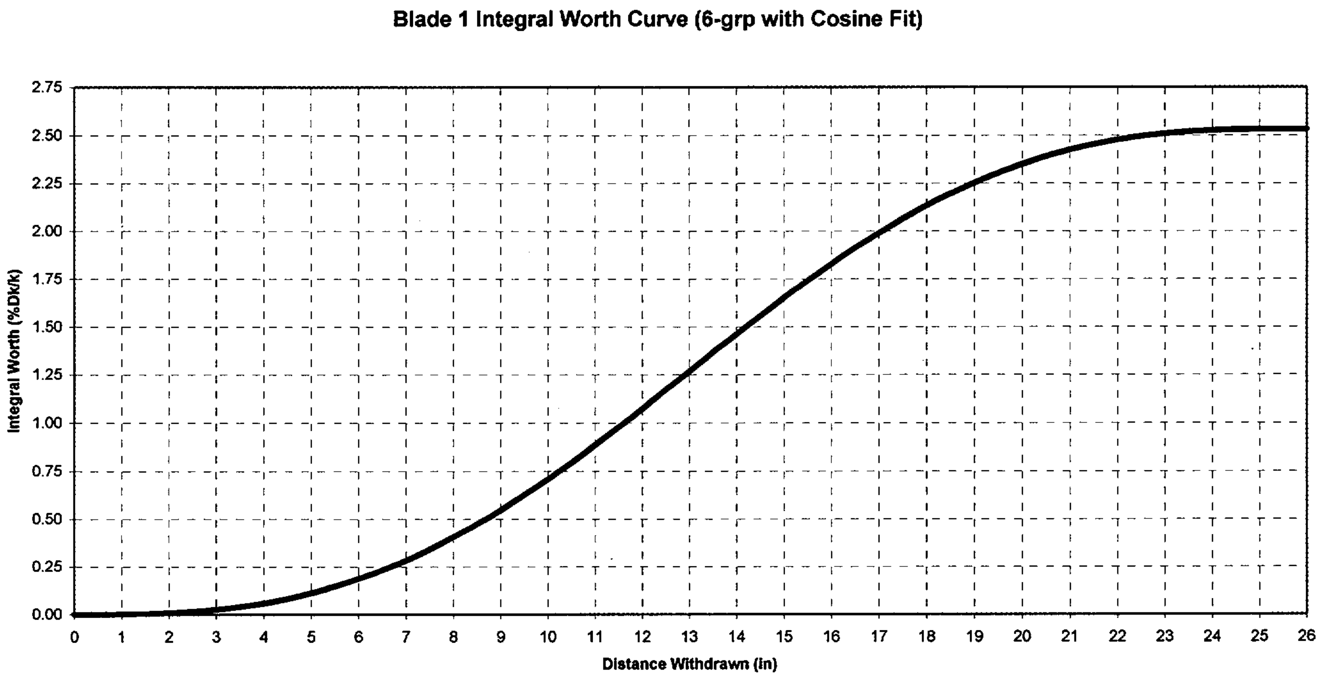


Fig. 6: Blade 1 Integral Worth Curve

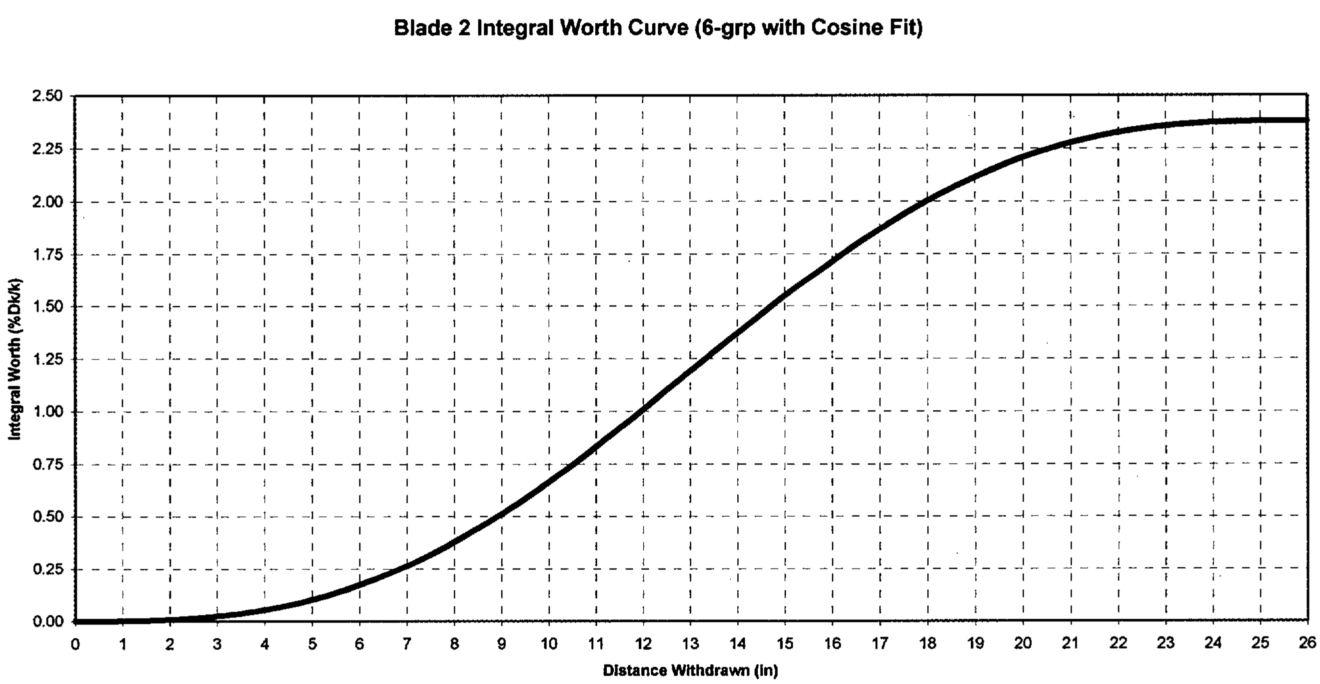


Fig. 7: Blade 2 Integral Worth Curve

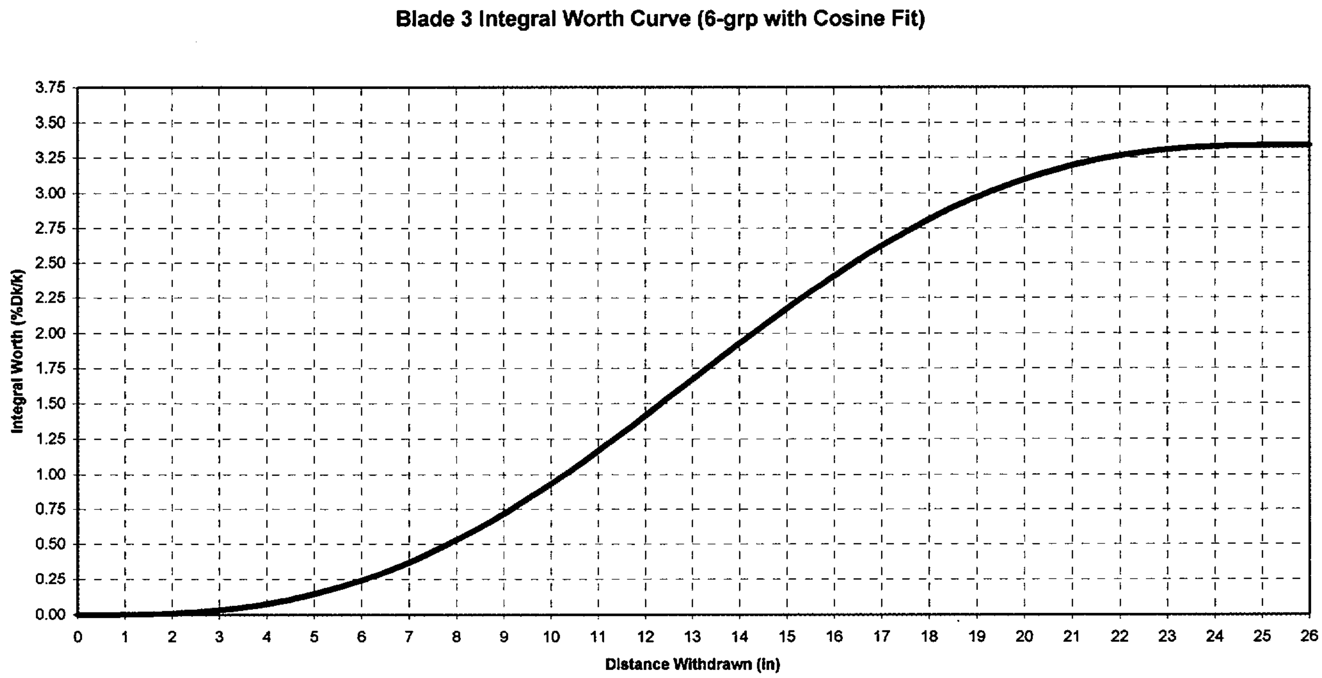


Fig. 8: Blade 3 Integral Worth Curve

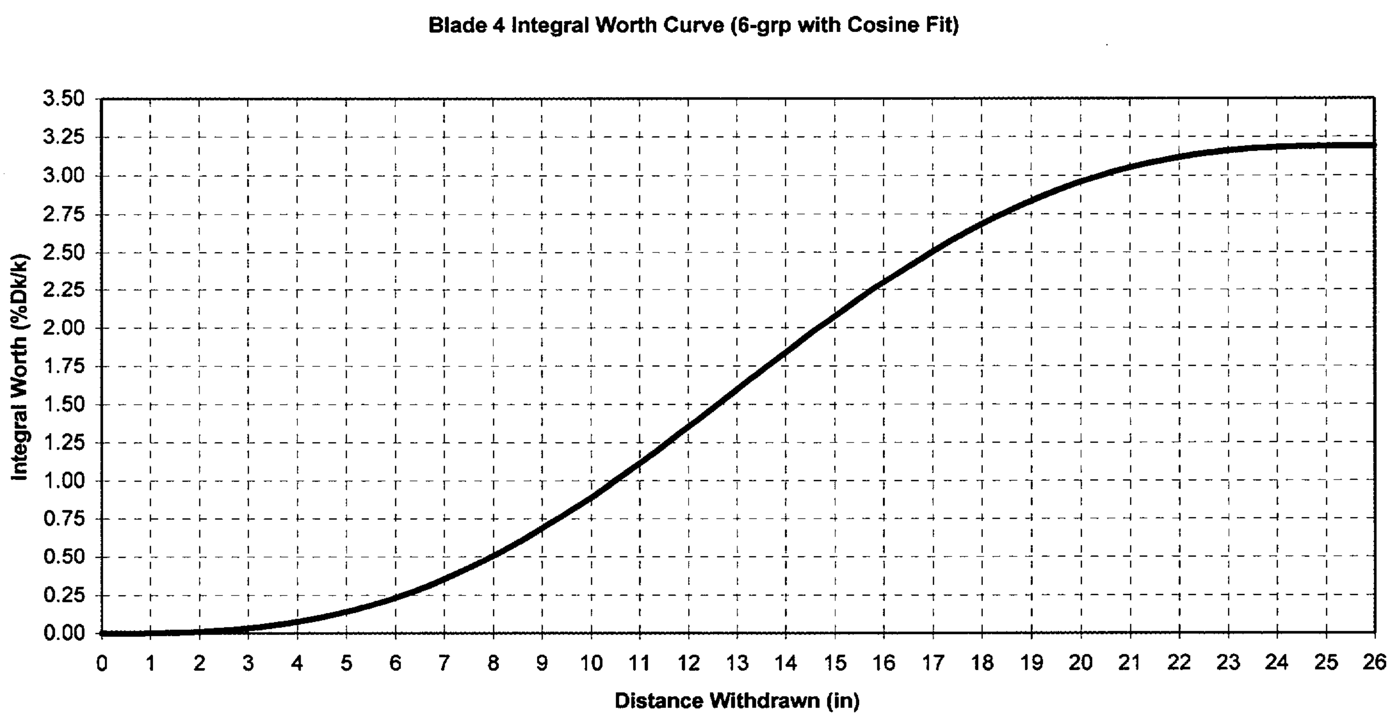


Fig. 9: Blade 4 Integral Worth Curve

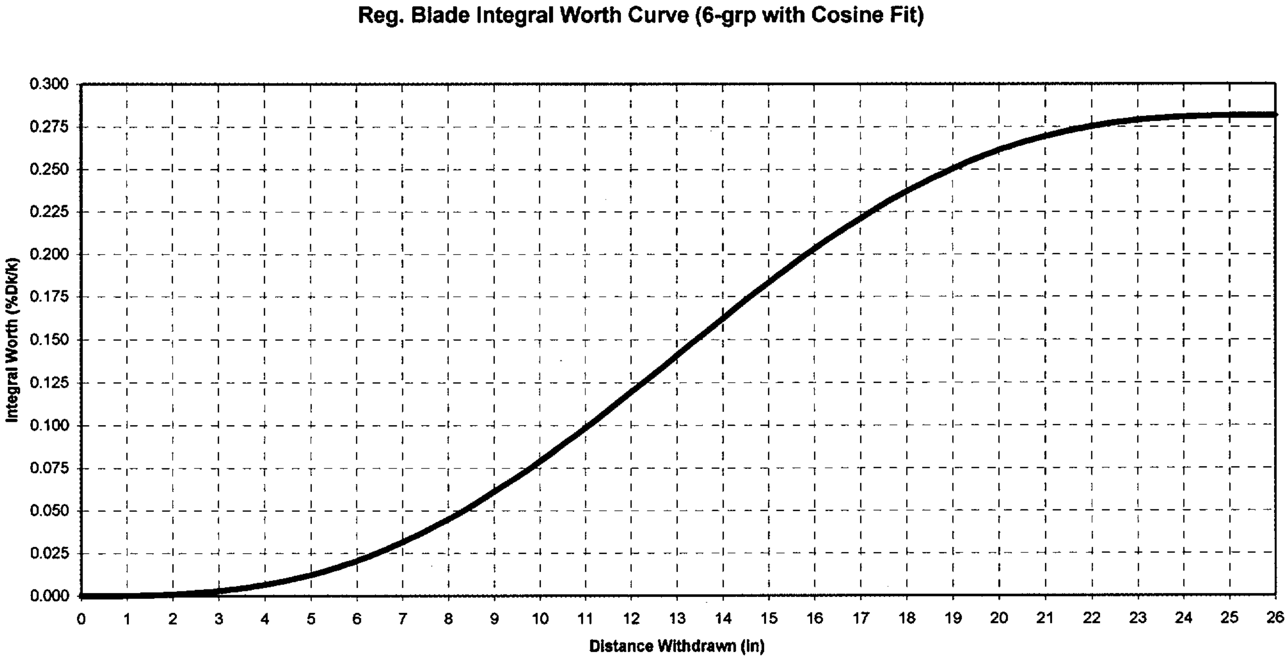
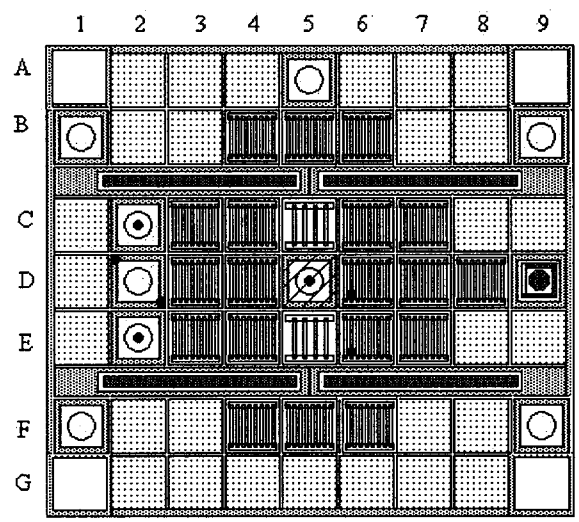


Fig. 10: Regulating Rod Integral Worth Curve

Low Power Flux Mapping

A combination of gold foils and copper wires were used to perform flux mapping in selected locations of the core (Fig. 4). Gold foils were used to provide an absolute determination of neutron fluence-rate, while copper wires provided a relative flux distribution at the chosen locations. Gold foils and comparison copper wires were installed into sample bayonets and then lowered into in-core radiation baskets. Copper flux wires were placed in between the fuel plates of un-irradiated fuel elements. The irradiations were then performed at an indicated power level of 100 watts for 30 minutes.

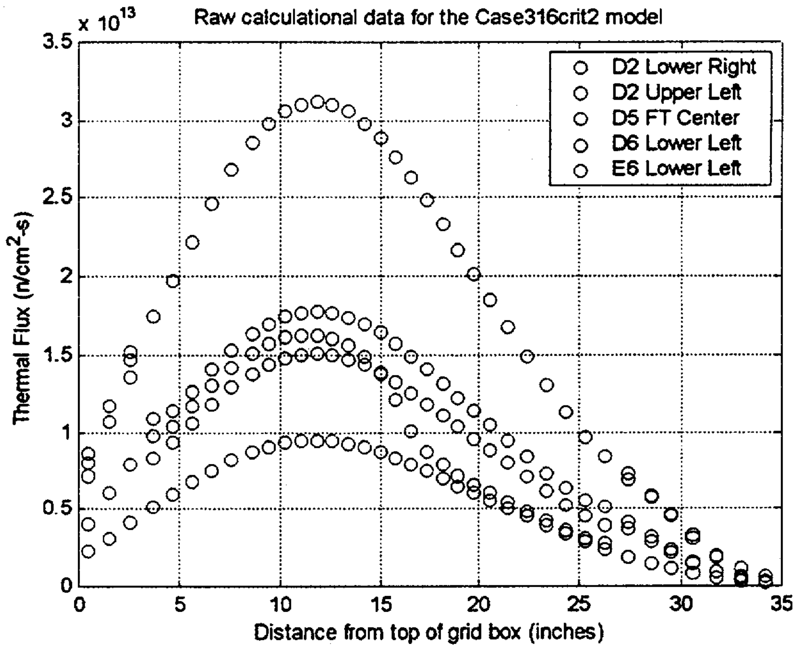
After irradiation, the wires and foils were removed and counted on a gamma spectrometer. An inter-calibration between the gold foils and copper provided an absolute flux distribution at the wire locations. The flux distributions were then compared to computational models for consistency.



(Gold Foils and Copper Wire, Copper Wires)

Fig. 11: Flux Wire Mapping Diagram

Analysis of the flux mapping data showed very good agreement with VENTURE model predictions for the core-center regions (rows 5 and 6) and good agreement with the experimental regions (row 2). For the in-core regions, the copper flux wires were placed to provide neutron data along the length of the 24-inch fuel plates, while the computational data extends several inches above and below this region. The computational data and experimental data are presented in the following figures. The good agreement of the data provides confidence in the VENTURE computational data used in the thermal-hydraulic safety analyses.



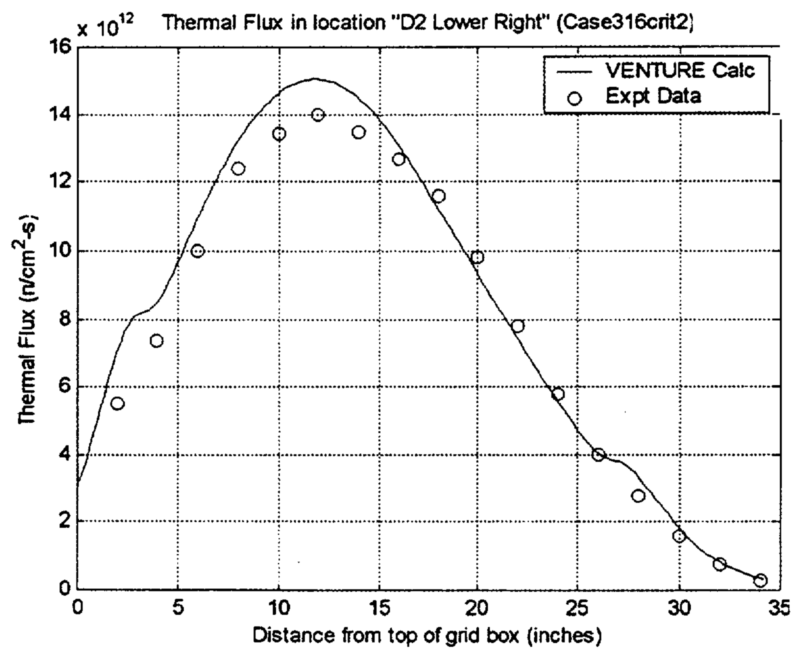
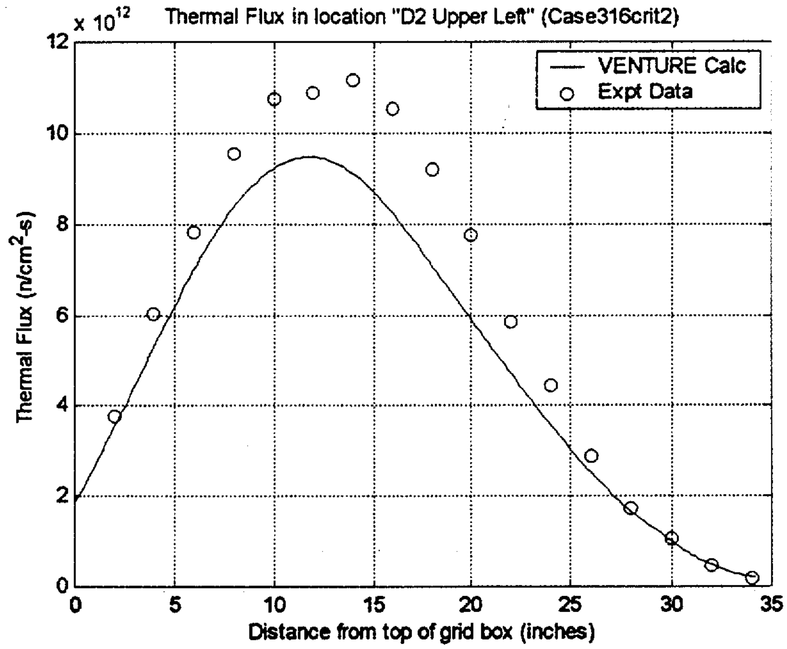


Figure 12: Combined Computational Flux Data

And

Figure 13: Flux Data for Core location D2 – Lower Right



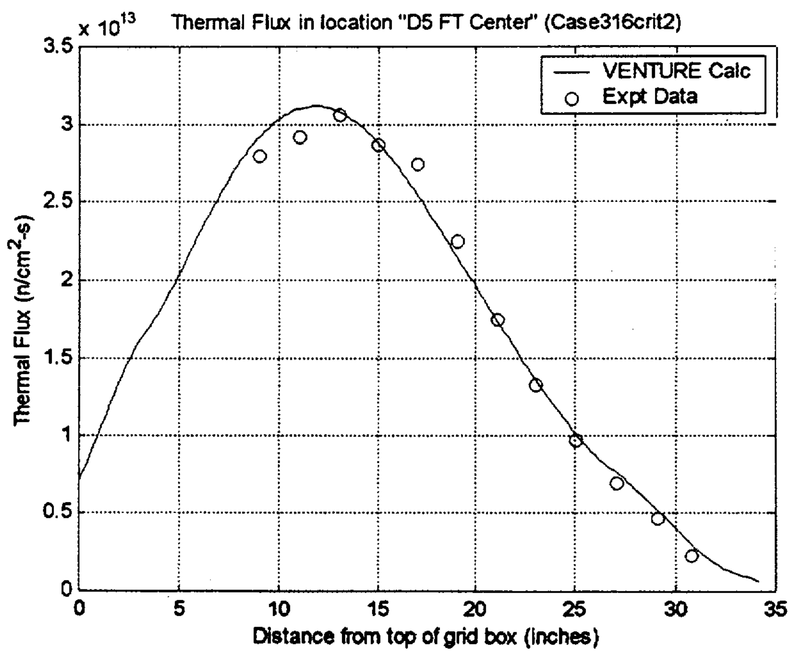
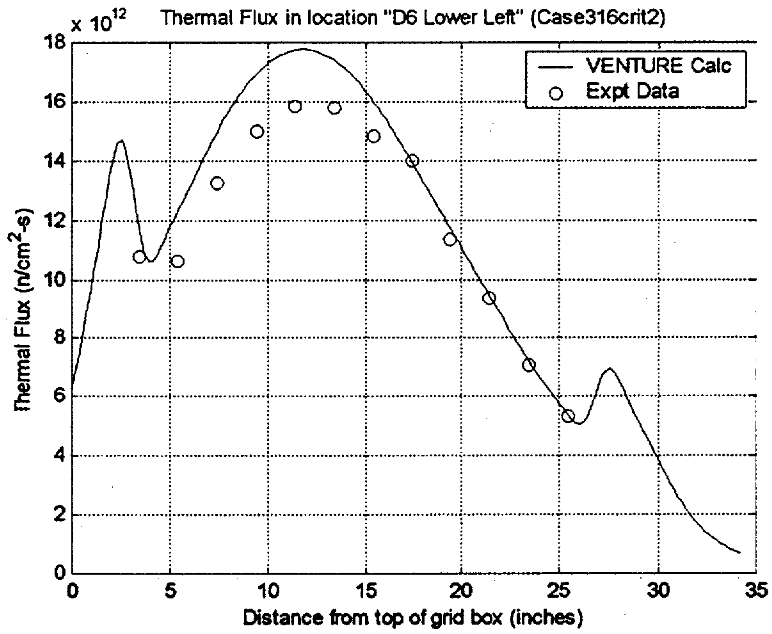
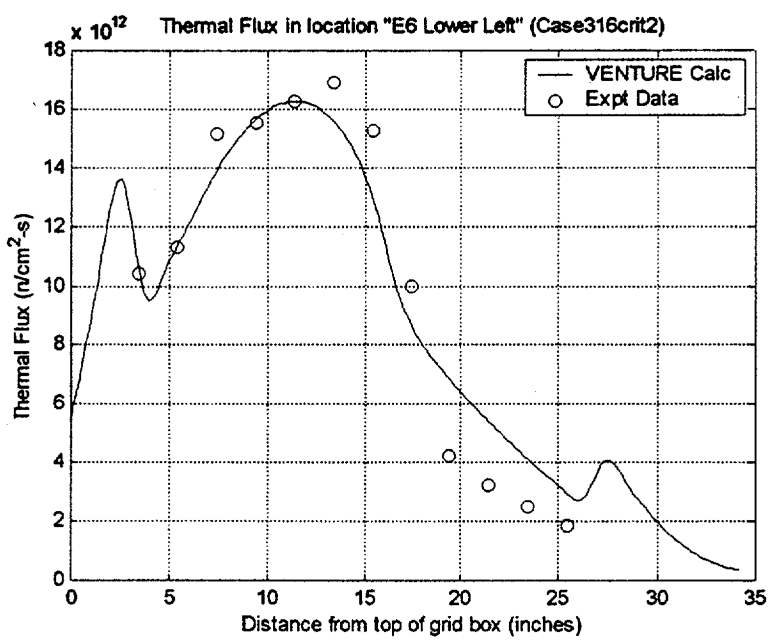


Figure 14: Flux Data for Core Position D2 – Upper Left
And
Figure 15: Flux Data for Flux Trap





<u>Figure 16: Flux Data for Core Position D6 – Lower Left</u>
and
<u>Figure 17: Flux Data for Core Position E6 – Lower Left</u>

Power Calibration

Reactor power level is monitored by three neutron detector-based measuring channels. Two channels provide a linear power measurement. The third channel provides both a logarithmic power and a change-rate (period) measurement.

Calorimetric measurement is the primary method by which the reactor power measuring channels are calibrated. Two parameters are measured for the calorimetric: the primary coolant flow-rate and the coolant temperature change across the core. From these data, the heat addition rate in watts is calculated to determine the true reactor thermal power level. The reactor power measuring channels are then matched to the true power level by vertical positioning of the neutron detectors adjacent to the reactor.

The new LEU core has a smaller geometry than the previously used HEU core. As a result, the neutron fluence at the location of the reactor power detectors was expected to decrease. Prior to the LEU fuel loading, these detectors were moved to their lowest position (closest to the reactor core) to maximize the neutron fluence detected.

A secondary method of power measurement is the use of an ionization chamber to measure N-16 gamma emission produced by the neutron bombardment of oxygen-16 in the primary coolant. The production of N-16 is unaffected by changes to core geometry.

On August 22, the reactor was slowly and carefully brought to an indicated power level of 50% of 1MW. The indicated power levels were checked against the calorimetric calculation and the N-16 measurement. At this level, the indicated measurements were within a reasonable accuracy and the power level was slowly increased. Measurements were recorded at 70%, 93%, and 97% of 1MW based on the calorimetric method. With one exception, all the power measuring channels were either consistent with or conservative to the calorimetric. One linear channel was under-responding by approximately 5% with the reactor at 0.97 MW. The reactor was shutdown to allow electronic adjustments to the under-responding channel.

A subsequent power calibration was performed on September 5. With the reactor at 0.98 MW based on the calorimetric method, each reactor power measuring channel indicated 100% of 1MW.

Temperature Coefficient Measurement

The temperature coefficient was measured by heating the primary coolant water with the reactor at 1 MW power for several hours. Afterwards, the reactor was shutdown for 3 days to allow xenon-135 to decay. The reactor was then brought critical at a low power level. Under forced circulation, the primary water was cooled using the secondary cooling system and data for critical regulating rod height versus primary coolant temperature were recorded. These data are presented in Figure 18. A regression analysis of the data indicates a temperature coefficient of approximately -3.0 E–5 $\Delta k/k\text{-}C^{o}$. The

FSAR predicted sum values for coolant temperature and coolant density is -1.09 E–4 Δk/k-C°. Technical Specifications require a negative temperature coefficient above 70°F. The measured data indicate this is clearly met. The discrepancy between the predicted and measured values may have arisen from the narrow temperature range (80° F to 72° F) used, and the difficulty of achieving an exactly critical reactor for each measurement. Nonetheless, the measured result is considered satisfactory.

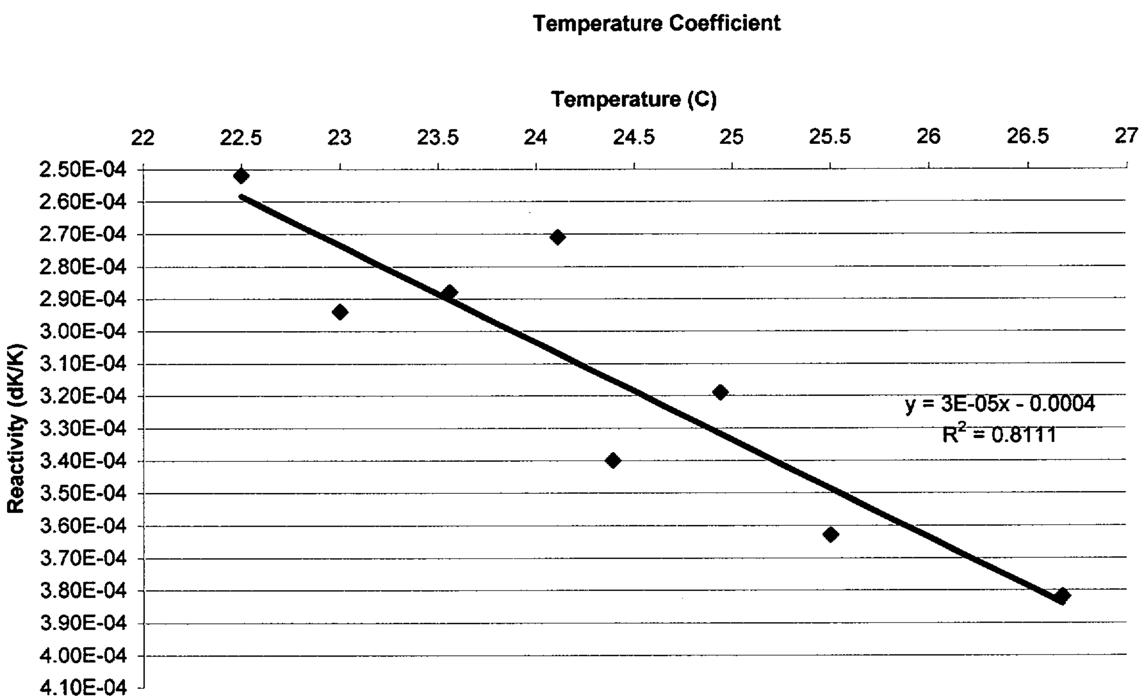


Fig. 18: Temperature Versus Reactivity

Radiological Monitoring

Radiological testing of the primary coolant water was performed immediately after the extended 1 MW operation. Gamma spectrum analysis of samples taken immediately after reactor shutdown indicated several short lived isotopes of aluminum. The same samples were analyzed again three days later to allow short-lived isotopes to decay. Neither sample indicated the presence of fission products or long-lived isotopes.

The presence of relatively high concentrations of aluminum was most likely the result of aluminum remnants from the machining and milling of fuel components during manufacture. The aluminum contaminants will be completely removed in time by the water filtration and conditioning system.

As expected, area radiation monitoring data compared for the HEU and LEU-fueled cores show no increase in radiation levels.

Void Coefficient Measurement

There is no UMLRR license technical specification for a negative void coefficient. However, this measurement was made as a verification of the fuel design. The void coefficient was verified as negative by measuring the reactivity difference of a voided (air-filled) sample bayonet versus a flooded sample bayonet placed in the core position D-2 radiation basket, adjacent to fuel. The reactivity effect measured by this method was negative 0.010% Δk/k.

Conclusions

The conversion of the UMLRR for HEU to LEU is complete. A thorough testing of the reactor core and measurement of key parameters has yielded sufficient data showing the new reactor core will operate well within the bounds set forth in the Final Safety Analysis Report and the reactor license Technical Specifications. The reactor has operated routinely for several months, on a usual schedule of one shift, three to four times per week. The operations and reactor behavior have been normal with no unexpected occurrences or problems.

The new LEU core will provide operational capability for several years before new fuel will be required. The smaller reactor core and core center flux trap provide a greatly increased neutron flux for in-core experiments. The reactor core and experimental facilities have been thoroughly characterized using various computational methods, including the two-dimensional DORT code, MCNP code, and the two and three-dimensional VENTURE codes. These models have been benchmarked with experimental methods.

The computational data and LEU conversion improvements will enhance the experimental work and research opportunities at the UMLRR. With the conversion and test program now complete, routine operations of the reactor have commenced.