Modeling and Reference Core Calculations for the LEU-Fueled UMass-Lowell Research Reactor

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Introduction

The University of Massachusetts at Lowell currently owns and operates a 1 MW research reactor that is loaded with high-enriched plate-type fuel elements. In response to proliferation concerns, a series of studies[1-2] was initiated in the late 1980s to convert the UMass-Lowell Research Reactor (UMLRR) to use a standard low-enriched uranium fuel plate design containing less than 20 w/o enriched U235. The initial LEU core design studies were completed in 1993 with the submission and approval of a supplement to the FSAR for conversion to LEU fuel.[3] A top view of the LEU core layout as proposed in the FSAR Supplement is sketched in the top part of Fig. 1. The key changes relative to the existing HEU core include a smaller 20-element fueled region, a central flux trap, more water/radiation baskets, and the movement of the regulating blade from the D9 position to the D8 grid location. This configuration can achieve similar or better overall performance characteristics relative to the HEU core in terms of the irradiation facility fluences and ease of operation.

After a six years hiatus, the Department of Energy has recently funded final fabrication of the LEU fuel elements and the physical conversion is now planned for Fall 1999. To support the conversion, a major effort is currently underway at the University to update our local modeling and calculational support capabilities, to revive and improve upon the old LEU computational models, and to readdress the proposed movement of the regulating blade. In particular, we would like to avoid the proposed regulating blade position change if possible, since this design modification requires a physical 3 inch offset in the regulating rod drive shaft, which requires the installation and mechanical testing of a new shaft. This latter consideration has prompted additional design calculations and the development of a new reference LEU core configuration that keeps the desired small core footprint while retaining the regulating blade in the D9 location. The purpose of this paper is to briefly overview the calculations and results of this design study.

Models and Methods

The earlier LEU design studies[2-3] used a variety of 2-group 2-D VENTURE[4] models as the basis for most of the physics computations that guided the design analysis. These deterministic diffusion theory calculations were used to determine the initial excess reactivity, various integral blade worths, and the expected power and flux distributions within the system, with special focus on the relative fluences in the experimental facilities.

The current study also used a series of 2-group 2-D VENTURE models as the primary basis for comparing the relative performance of different configurations. However, unlike the previous work, full 3-D VENTURE and MCNP[5] models have also been developed to completely characterize the new facility. These models are quite detailed and they were developed with future flexibility in mind. The 3-D VENTURE model has a 130x121x65 mesh grid in the three coordinate directions, with nearly 950 homogeneous zones in the full 3-D configuration to allow for control movement, for fuel burnup studies, and for flexibility in the placement of irradiation samples. The MCNP model is even more complex geometrically, with explicit modeling of each fuel plate, control element, regulating blade, etc., and full continuous energy and angular representations of the velocity variable are used. The deterministic VENTURE models allow the generation of flux and power distributions throughout the system, and MCNP allows detailed characterizations of each experimental facility. The overlap in capability in the two techniques is also very useful for validation of the individual models.

The 3-D models have only been used thus far to validate the 2-D analyses, giving us greater confidence in the final proposed LEU core configuration. However, these 3-D models represent significant new capability, and they will be used extensively during the startup tests in Fall 1999, for following the core evolution over several years of operation, and to evaluate the radiation environment in the various experimental facilities as needed for each reactor user.

The New LEU Core Layout

The original LEU core design study suggested moving the regulating blade to grid location D8 because the computed D9 regulating blade worth in the compact 20-element LEU core was too low. With the goal of eliminating this proposed change, a series of 2-D XY VENTURE calculations was made to identify a new configuration that gave a suitable D9 regulating blade worth, yet retained a relatively small core footprint with its associated high flux level. The availability of two partial fuel elements and the ability to rotate the regulating blade into either a low-worth or high-worth orientation were used to achieve this goal. The partial elements have the same geometry as a full fuel assembly, but only contain half the U235 loading. The regulating blade has a rectangular shape, with only three of the four sides having boral plates as the neutron absorbing material. Thus, the remaining aluminum plate can be oriented towards or away from the core to give a low-worth or high-worth configuration, as needed.

The best LEU core layout studied contains 19 full fuel elements, 2 partial elements, and the regulating blade in grid location D9 in its high-worth orientation. This final configuration is sketched in the bottom part of Fig. 1, and selected reactivity results for the original and new LEU core designs are given in Table I. These results include data from the 2-D and 3-D VENTURE calculations and from the 3-D MCNP models. A bias is observed in the 2-D versus 3-D excess reactivity due to the transverse buckling approximation that is required in the 2-D models. The difference observed between the VENTURE and MCNP regulating blade worth is also expected. This is due primarily to the spatial homogenization required when modeling the small regulating blade elements in VENTURE. Based on the volume fractions used, the VENTURE regulating blade worth prediction is expected to be high by as much as 20-25%. In general, however, the results thus far show good consistency within expectations, and within the MCNP statistical uncertainty. Also, since the initial core excess reactivity and blade worth distribution of the new LEU core configuration are within desired limits, this new core layout is expected to be the startup core for the LEU-fueled UMLRR. Startup testing in Fall 1999 will hopefully confirm this expectation and also allow further benchmarking of the new 3-D VENTURE and MCNP models.

Table I Selected reactivity data for the original and new LEU core configurations.

Parameter	2-D VENTURE	3-D VENTURE	3-D MCNP**
Original LEU core configuration (in top part of Fig. 1)			
Excess reactivity (%)	3.79	4.13	4.10
*Blade 1 worth (%Δk/k)	3.02	3.00	3.05
Regulating blade worth (%Δk/k)	0.58	0.58	0.49
New LEU core layout (in bottom half of Fig. 1)			
Excess reactivity (%)	3.21	3.64	3.36
*Blade 1 worth (%Δk/k)	2.69	2.68	2.71
Regulating blade worth (%Δk/k)	0.47	0.49	0.36

* Control Blade 1 refers to the lower left control element in the diagrams in Fig. 1.
** The MCNP statistical uncertainty in all the calculated k_{eff} values is about 0.05%.

References

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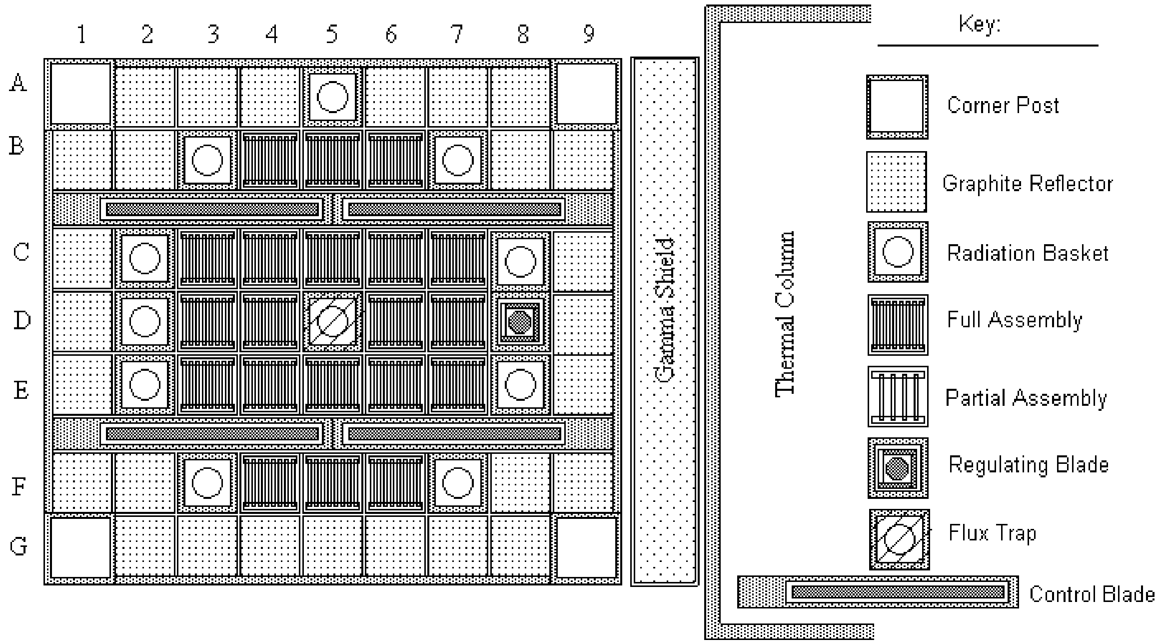

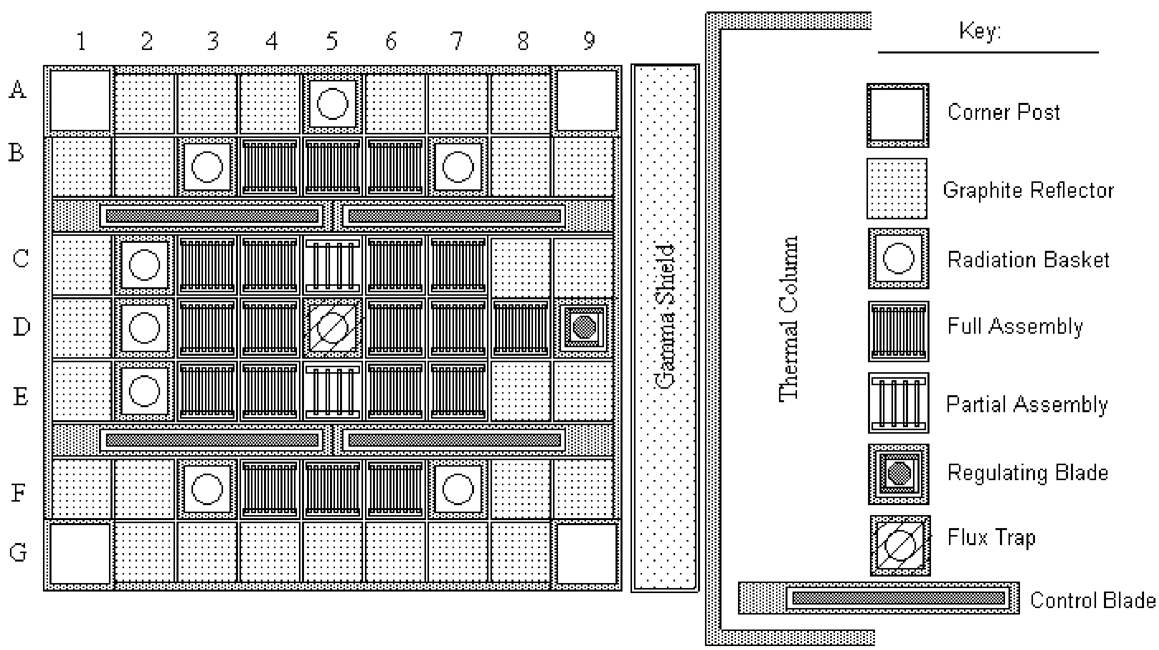

Fig. 1 Original (top) and new (bottom) reference LEU core configurations.