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COMPLETION OF FEASIBILITY STUDIES ON USING LEU FUEL IN THE MIT REACTOR

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ABSTRACT

Optimization studies on the use of monolithic U-10Mo fuel for the MIT reactor have resulted in a design of a fuel element containing 18 plates with 0.508 mm thick fuel and 0.254 mm finned aluminum cladding. These studies have included neutronic and burnup modeling using MCNP, MCODE and REBUS-PC, thermal-hydraulic studies using RELAP and PLTEMP, as well as testing of various parameters such as the cladding oxide layer buildup on finned plates. Pressure drop relations have also been developed for finned channels for use in thermal-hydraulic calculations. A culmination of these studies have concluded that the use of U-Mo LEU fuel in the MITR is feasible in both a mixed HEU-LEU core and all-LEU core and that LEU core operation at 7 MW will provide the equivalent experiment fluxes as with the HEU core at 6 MW.

1. Introduction

The MIT Reactor (MITR-II), contains a hexagonal core that contains twenty-seven fuel positions in three radial rings (A, B, and C), as shown in Figure 1. The reactor is currently licensed to operate at 5 MW, with an upgrade to 6 MW expected soon. Typically at least three of these positions (two in the A-ring) are filled with either an in-core experimental facility or a solid aluminum dummy element to reduce power peaking. The remaining positions are filled with standard MITR-II fuel elements. Each rhomboid-shaped fuel element contains fifteen aluminumclad fuel plates using HEU (93% enriched) in an aluminide cermet matrix with a fuel thickness of 0.76 mm (0.030 in.) and a length of 61 cm (24 inches). The cladding of each fuel plate has 0.25 mm longitudinal fins to increase heat transfer to the coolant. The fuel has an overall density of 3.7 g/cm^3, with a total loading of 506 g ^{235}U in each element.

The core is light water moderated and cooled and is surrounded by a D_2O reflector. Boron impregnated stainless steel control blades are located at the periphery of the core on each of the sides of the hexagon. In addition, fixed absorbers of boron-stainless steel can be installed in the upper twelve inches of the core in a hexagonal configuration between the inner and second fuel rings as well as in three radial arms extending to the edge of the core.

Several reentrant thimbles are installed inside the D_2O reflector, delivering greater neutron flux to the beam ports outside the core region. Beyond the D_2O reflector, a secondary reflector of graphite exists in which several horizontal and vertical thermal neutron irradiation facilities are present. In addition, the MITR Fission Converter Facility is installed outside the D_2O reflector. This facility contains eleven partially spent MITR fuel elements for delivery of a beam of primarily epithermal neutrons to the medical facility for use in Boron Neutron Capture Therapy (BNCT).

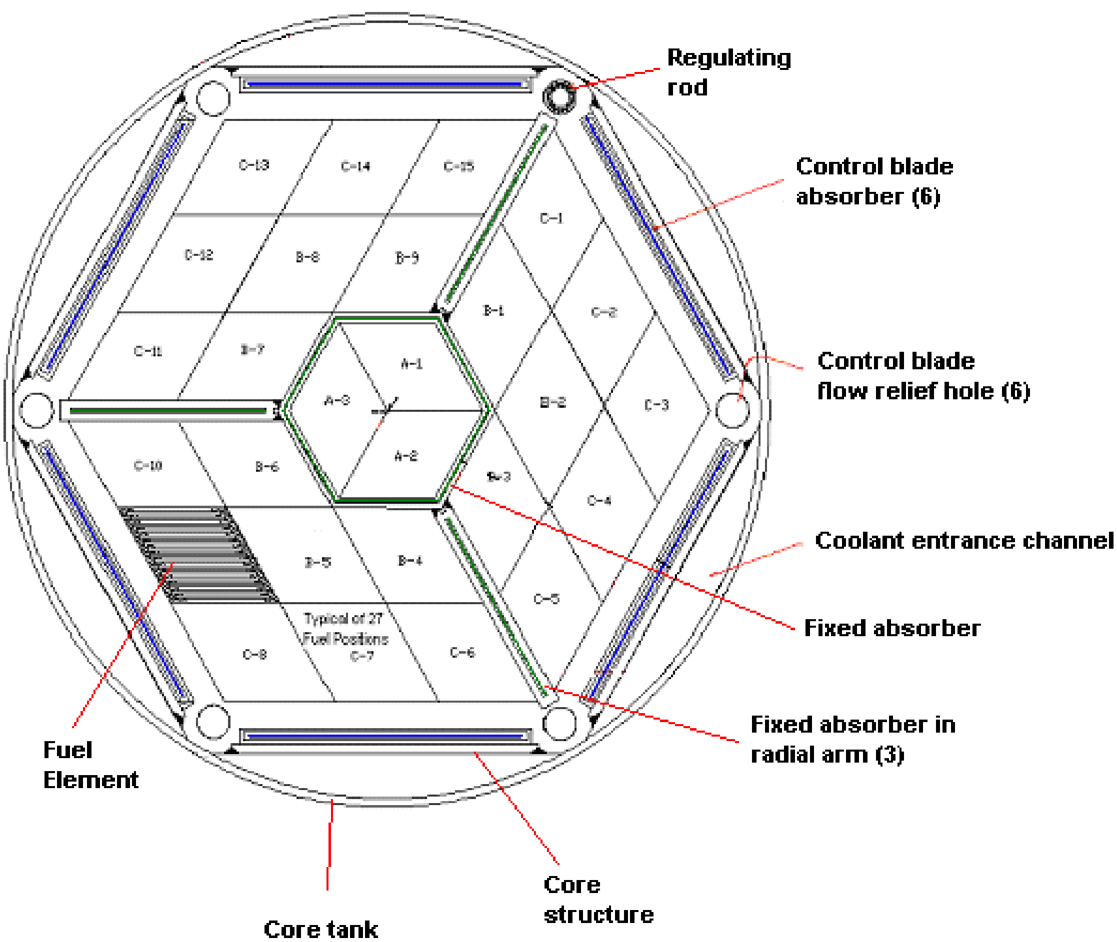

Figure 1. Layout of the MIT Reactor core.

2. LEU Optimization studies

Initial LEU conversion optimization studies [1] found that replacing HEU fuel (93% enriched U-Al_x fuel) with LEU fuel (19.75% enriched U-7Mo) of the same number and dimension of fuel plates resulted in a significant reduction of the neutron flux available to experiments. It was also found that reducing the thickness of the cladding and increasing the number of plates in an LEU fuel element resulted in a flux and reactivity increase, as well as increasing the thermal-hydraulic safety margins over the unchanged geometry LEU case. Although several U-Mo alloys have shown promise in irradiation tests, a fuel with 10% Mo (U-10Mo) shows the best irradiation behavior and has been downselected for use. This fuel has a density of 17.02 g/cm^3.

Further neutronic and thermal-hydraulic optimization has resulted in an LEU fuel design using 18 plates of U-10Mo with a fuel thickness of 0.020” (0.508 mm), and an aluminum cladding thickness of 0.25 mm (0.010”, including any interlayers), plus 0.25 mm fins machined onto the cladding surface. [2]. Although 0.25 mm cladding with U-Mo fuel is currently under testing and has not yet been qualified for use, discussions with fuel developers at the U.S. High Performance Reactor Working Group (USHPWG) meetings indicate that such a cladding thickness appears to be feasible for use.

This optimization has shown the LEU fluxes in MITR experimental facilities to be less than the HEU case by 7% to 40%, depending on the facility and neutron energies of interest. Thus, the LEU core, as designed will require an operating power of 7 MW to keep most experimental fluxes at 6 MW HEU levels. However, because of the increased fuel density, LEU operation at 7 MW will not give the equivalent HEU gamma flux to in-core experiments that rely on gamma heating to maintain high temperatures. Future experiment designs will need to be designed to take this into account.

3. Neutronic evaluations

Several programs have been used to model the MITR for neutronic evaluations in conversion studies. The Monte Carlo neutronics code MCNP has been used for analysis and optimization in LEU conversion studies at the MITR. This model is also being used in the MCNP-ORIGEN coupling code MCODE to model fuel burnup for both LEU and HEU fuels. An upgrade of MCODE has been made to include a graphical user interface in a version called MCODE-FM. [3] This model has also been modified to include a criticality search to more accurately model burnup through the critical movement of control blades. [4]

A model of the MITR developed at ANL using the REBUS-DIF-3D diffusion theory program is also being used for burnup studies. [5] This model has twelve axial layers (six in the fuel region) in a triangular-Z mesh, and has been modified to include the ability to position control blades to the nearest axial mesh point and to place aluminum dummies anywhere in the core. 1-D models have also been developed for the WIMS-ANL code for cross-section generation. Recent improvements in the WIMS MITR model includes the use of the Supercell option as well as representing the MITR fuel plates in four different models, depending on the location in the core, as well as number of adjacent solid aluminum dummies.

Comparisons between the REBUS-ANL model and the MCNP/MCODE models have shown favorable results for HEU fuel in axial and radial power peaking, reactivity worth and in burnup reactivity [6].

Further development of both neutronic models has resulted in the ability to model fuel movements, including the flipping of fuel end-to-end, to produce an "equilibrium" core for HEU and LEU comparative studies. Results of a comparison between the models are shown in Figure 2.

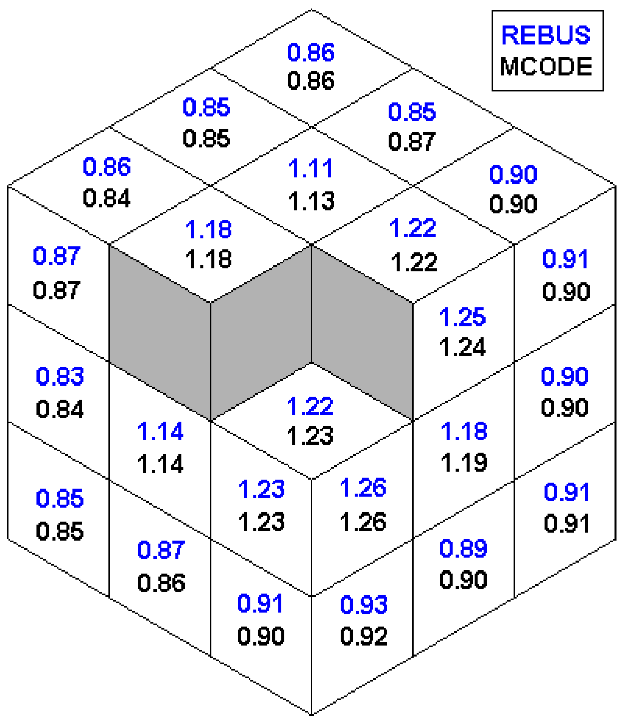

Figure 2. Comparison of REBUS and MCODE models of an "equilibrium" HEU core.

Burnup reactivities of the HEU and LEU fuels have also been compared using the updated models. Figure 3 shows a comparison of K_{eff} in a 24 element configuration with all control blades out using the updated MCODE and REBUS models. The models begin with all new HEU (UAlx) or LEU (monolithic U-10Mo) fuel, undergoing 500 days of operation at 5 MW. The REBUS and MCODE models compare favorably, particularly initially. A difference of about 0.2% $\Delta K/K$ is due to a higher water density being used in the MCODE model. As burnup progresses, the REBUS model tends toward a lower Keff. This is primarily due to differences in the MCNP fission product cross-section libraries, with MCODE using the ENDFB-VII library while REBUS uses ENDFB-VI with some lumped fission product modeling.

In the MCODE model, the LEU core initially has a slightly lower K_{eff} than the HEU case, but the burnup slope is considerably flatter due to lower thermal neutron flux in the fuel region, causing the two curves to intersect after about 470 days of operation. This is consistent with previous models indicating that the monolithic LEU fuel will have a longer fuel cycle than the current HEU core.

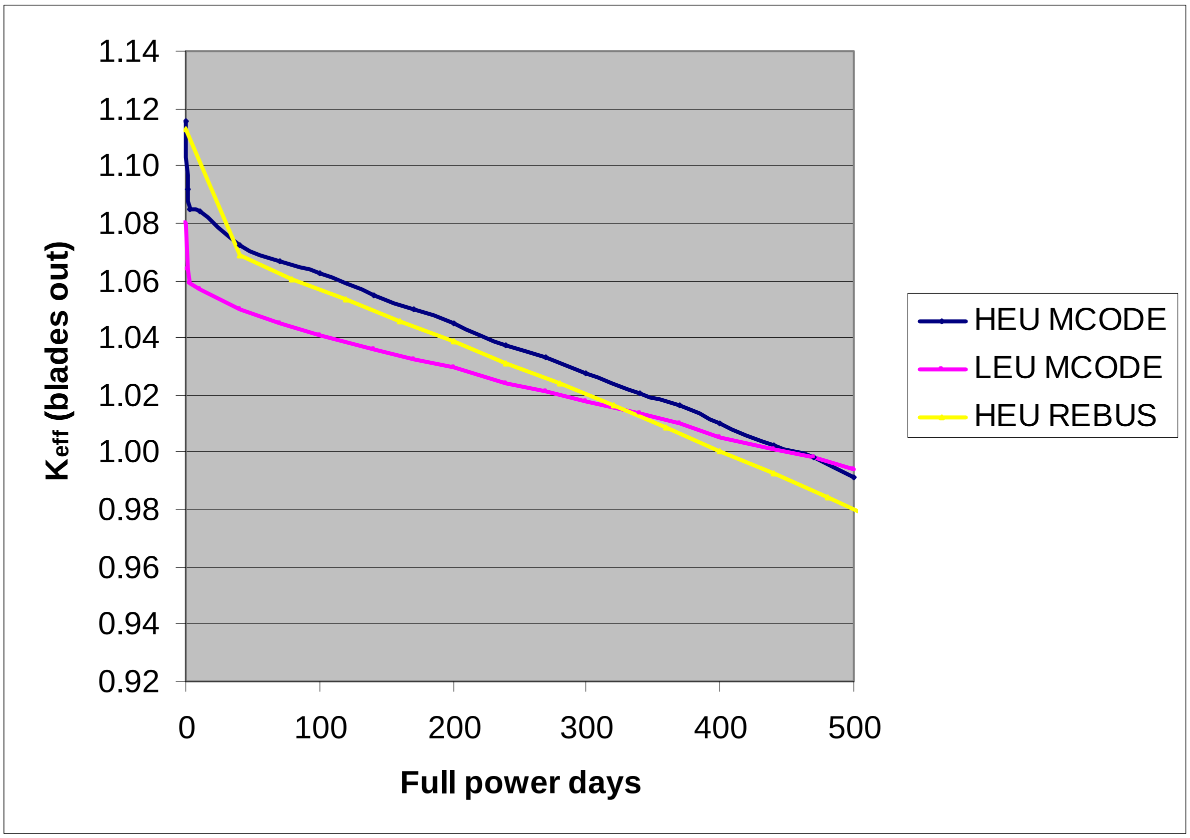

Figure 3. Blades out K_{eff} MCODE and REBUS rundown comparison

4. Thermal-hydraulic evaluations

The MIT in-house multi-channel thermal-hydraulics code, MULCH-II, developed specifically for the MITR, has been validated against PLTEMP for steady-state analysis as well as against both RELAP5 and actual temperature measurements for the loss of primary flow (LOF) transient. MULCH-II was also used in the optimization studies to determine the Limiting Safety System Settings (LSSSs) based on the onset of nucleate boiling in the hot channel.[7] A maximum power peaking factor of 1.76 was calculated for the LEU core from MCNP calculations. This peaking factor, when input into MULCH and assuming the engineering hot channel factors remain the same as those of HEU core, showed that the LSSS power would be about 8.5 MW, which would allow LEU operation at levels of 7 MW without significant modification to the existing primary coolant system. [2]

Another significant effort towards improving thermal-hydraulic modeling was in determination of a new friction factor correlation for finned channels. This was done with an experimental flow loop with finned rectangular coolant channels ranging from HEU to LEU geometries. The new correlation for turbulent flow regime, similar to the Blasius correlation but with a larger coefficient to account for the increased surface roughness of the fins, will improve the accuracy of future thermal-hydraulic evaluations. [8]

5. Evaluation of a Transitional LEU/HEU core

Because MIT will likely be either the first or one of the first worldwide users of monolithic U-Mo fuel, MIT plans to introduce LEU fuel into the existing HEU core with a gradual conversion to all LEU fuel. In this manner, the LEU fuel can be evaluated within a known envelope and the fuel can be replaced with existing HEU fuel should problems occur.

Neutronic and thermal-hydraulic evaluations of various stages of a transition core have been made [9], taking into account both power peaking and flow distribution among the HEU and LEU fuel elements. The steady-state thermal hydraulics study concludes that the most limiting case is that of only a few HEU elements with the remaining core being 18-plate LEU elements. The most limiting hot channel is predicted to locate in an HEU element. In the case of a 3HEU/21LEU core, the core with the lowest margin to the onset of nucleate boiling, the reactor power may be limited to 4.9 to 5.8 MW, depending on power peaking and the location and orientation of the hot channel.

6. Fuel Lifetime

Preliminary results presented at the HPRWG meetings have indicated that, based on the irradiation performance of U-10Mo fuel, no significant swelling or other material degradation occurs up to the equivalent of 100% LEU burnup. This would imply that, unlike HEU fuel, there would be no fuel performance-based burnup limit for U-10Mo LEU fuel. However, because of the finned cladding surface of MITR fuel, there have been some concerns expressed as to the distribution of oxide buildup across the fuel surface with increasing burnup, perhaps degrading the heat transfer effectiveness of the fins. To attempt to quantify this, an eddy current probe was manufactured and used to measure the level of oxide buildup on spent MITR-II fuel elements. Preliminary results of measurements on five different fuel elements, show in Figure 3 the axial distribution of oxide on several MITR spent fuel plates. The maximum oxide thickness of about 72 μm is within the expectation of values predicted by oxide buildup correlations. However, it should be noted that the eddy current probe is only able to measure the oxide thickness at the tip of the fins. Thus, it will be necessary to do a detailed, perhaps destructive, test on an MITR-II fuel element. Such tests are being planned to be performed at the Idaho National Laboratory.

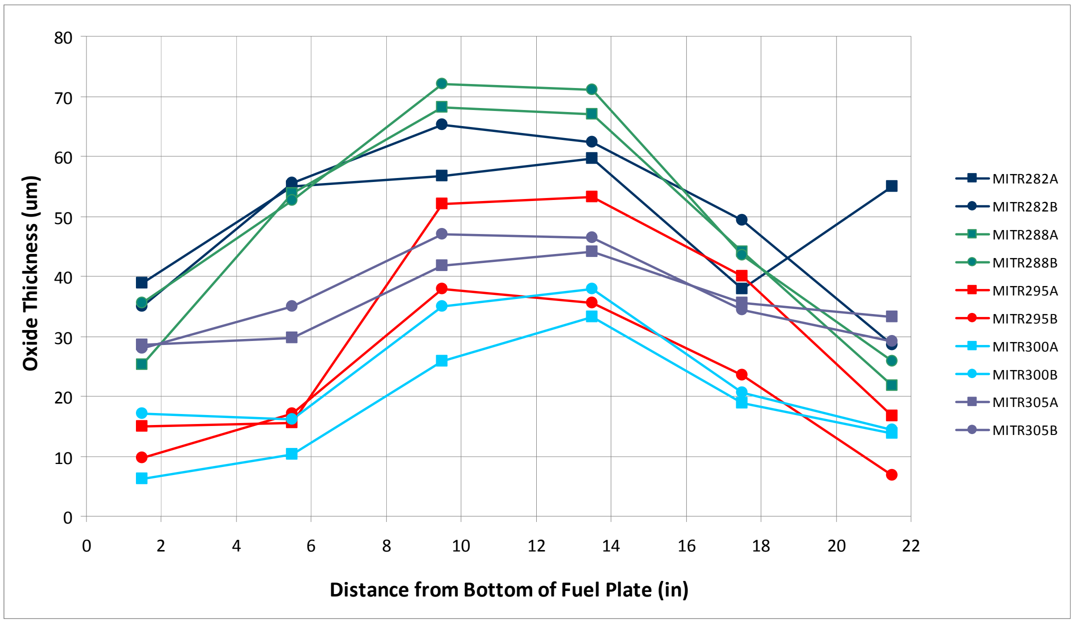

Figure 3. Measurement of oxide thickness on selected MITR-II fuel plates

Summary

Modeling and evaluation of proposed monolithic U-10Mo LEU fuel show that use of this fuel, provided that it can be manufactured with the assumed specifications, can be used in the MIT Reactor. However, in order to provide the 6 MW HEU equivalent neutron fluxes to experiments, an LEU MITR would need to be operated at or near 7 MW. Thermal-hydraulic evaluations show that, as long as the power peaking factor can be maintained at or below 1.76, operation of an LEU-fueled MITR at 7 MW would maintain sufficient margins to the onset of nucleate boiling.

Acknowledgements

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