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Design of Critical Experiments Targeting Epithermal Cross Sections of Tantalum

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INTRODUCTION

Sandia National Laboratories (SNL) and Oak Ridge National Laboratory (ORNL) are collaborating to develop a capability to test the epithermal/intermediate cross sections of tantalum (Ta) at the SNL critical experiments facility using the Seven Percent Critical Experiment (7uPCX) fuel.

The Sandia Critical Experiments (SCX) Program provides a specialized facility for performing water moderated and reflected critical experiments with UO_2 fuel rod arrays. A history of safe reactor operations and flexibility in reactor core configuration has resulted in the completion of several benchmark critical experiment evaluations that are published in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook [1].

The critical experiments described here are scheduled to be performed at SCX in fiscal year 2023. Currently, fabrication details for the needed new equipment are being finalized for completion of the procurement process. The experiments will then be executed and documented for publication consideration by the ICSBEP.

DESIGN OF THE CRITICAL ASSEMBLY

A set of benchmark experiments with titanium replacement rods has been completed using the 7uPCX and is documented as LEU-COMP-097 [2]. The experiments described here are similar but use tantalum rods and triangular pitched grid plates with a central test region.

The assembly core resides in an elevated assembly tank that is connected to a moderator dump tank located at a lower elevation. The moderator resides in the dump tank when not in operation. To begin operations the moderator is pumped from the dump tank into the assembly tank. The moderator can be released by gravity to the dump tank through two large-diameter pneumatically operated dump valves. The moderator is maintained at a constant temperature by a heater in the dump tank. During operation, the moderator is continually circulated between the dump tank and the assembly tank. The moderator level is maintained by overflow into a standpipe.

The fuel rods are supported by an upper and lower 2.54 cm thick aluminum grid plate. The grid plates are located in the assembly tank to provide a 16.51 cm thick water reflector below the lower grid plate. The diameter of the tank provides a radial water reflector around the assembly that is at least 15.24 cm thick. The assembly tank standpipe is set to provide a 15.24 cm thick upper reflector when the assembly tank is full.

A set of new grid plates will be fabricated for the experiments with fuel rod holes on a 0.86 cm triangular pitch and a dry central test region. The grid plates are sized to support up to 2046 fuel rods. The design arranges the grid plates into two regions: a close-packed region, and a driver region. The close-packed region has a fuel rod in every location, which results in a high fuel-to-moderator ratio and a hardened neutron energy spectrum. The driver region has every other rod removed from every other row to increase the reactivity of the assembly, allowing criticality to be achieved for all the proposed configurations. The grid plates are designed to have a central test region with 37 locations to hold tantalum rods. The test region is composed of two concentric hexagonal structures. The outer portion is an aluminum can that serves as a holder for the inner test region. The inner test region is interchangeable, allowing it to be operated with and without a cadmium thermal flux filter. Figure 1 shows a cross sectional view of assembly core with triangular pitched grid plates and central test region. An expanded view is included to show the central test region and cadmium filter.

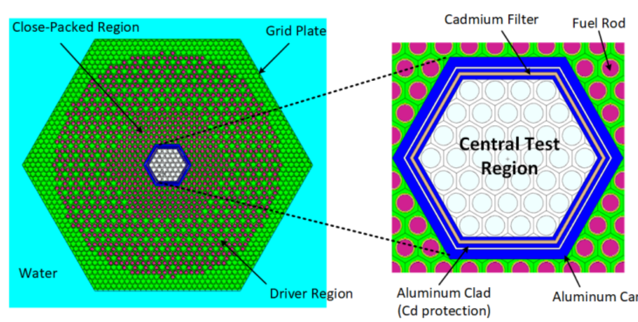

Fig. 1. Cross sectional view of the assembly core.

The fuel rods are clad in 3003 aluminum tubes with a nominal outer diameter of 0.635 cm. UO_2 fuel pellets enriched to 6.90 percent with a nominal diameter of 0.53 cm are stacked to an average height of 48.78 cm within the cladding. A spring is present above the fuel pellets to maintain vertical alignment.

The assembly has three identical fuel-followed control/safety elements, two operated as safety elements and one as a control element. During the experiments, all are held at their most reactive position with the absorber (B_4C) above the surface of the water, such that the absorber does not affect the system. The fuel followers are designed to be nearly identical to a fuel rod in the assembly. Polyethylene separates the absorber from the fuel followers. When fully raised the fuel followers are in the core, the polyethylene-filled sections are above the upper grid plate and the absorber sections are above the level of the moderator.

During approach-to-critical experiments, the assembly is driven by a small stainless-steel-clad ^{252}Cf source that is designed to be placed in a fuel rod location in the assembly grid structure. The behavior of the neutron population in the assembly is monitored by several fission chambers located outside the fuel array either in dry wells or outside the assembly tank. Two of the detectors inside the tank are in dry wells surrounded by polyethylene and provide signals to the assembly plant protect system (PPS). Figure 2 provides an overall schematic of the critical assembly. Additional details of the critical assembly design can be found in [2].

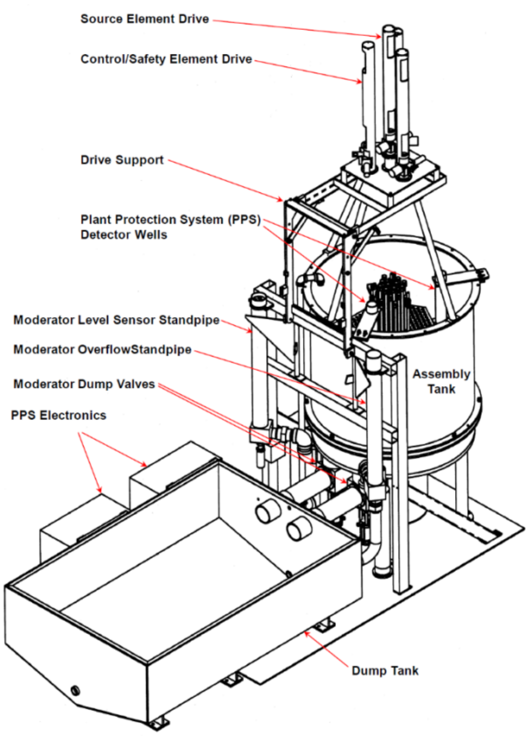

Fig. 2. Schematic of the critical assembly.

EXPERIMENT METHOD

The focus of these critical experiments is to measure the effects of tantalum on the critical array size. The critical array size will be determined by an approach-to-critical experiment with the number of fuel rods in the array as a free parameter. The array will be fully-reflected and water-moderated. The triangular-pitched arrays will be loaded from the center toward the outside while maintaining a roughly cylindrical cross section of the array. The close-packed region will remain constant with fuel rod adjustments made to the driver region.

Approach-to-critical experiments will be performed by taking count rate measurements for specific fuel arrays. The measured count rates are inverted. A linear fit to the inverse count rate as a function of number of fuel rods in the array will be used to extrapolate to zero inverse count rate to estimate the critical configuration of the experiment.

ANTICIPATED CRITICAL CONFIGURATIONS

Critical configurations were developed for central test regions loaded with up to 37 Ta rods for both unfiltered and Cd filtered configurations. Addition configurations with Ta rods located within the driver and close-packed region were also evaluated.

The critical configuration producing the highest Ta material reactivity worth, while also isolating the absorption reaction rates of Ta to the epithermal energy range is shown in Figure 3. This configuration has 37 Ta rods in the central test region and includes the Cd filter. Using the MCNP 6.2 code [3] with the ENDF/B-VII.1 cross section library the assembly is calculated to be nearly critical at a loading of 1236 fuel rods. The incremental fuel rod worth near critical is calculated to be about 0.024 \$. The Ta rods have a reactivity worth of $\Delta\rho \approx -0.0175$.

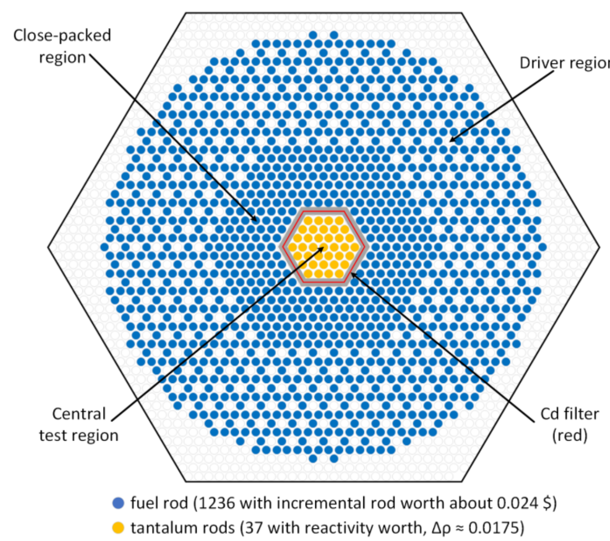

Fig. 3. Critical configuration maximizing both Ta reactivity worth and epithermal energy range absorption rates.

Figure 4 shows the average neutron flux in the Ta rods as a function of energy. Critical configurations with Ta rods located in the driver region, the central test region without Cd filter, and the central test region with Cd filter are presented for comparison. As indicated, the thermal peak is noticeably diminished when the Ta rods are moved from the driver region to the central test region, and nearly undetectable when the Cd filter is included.

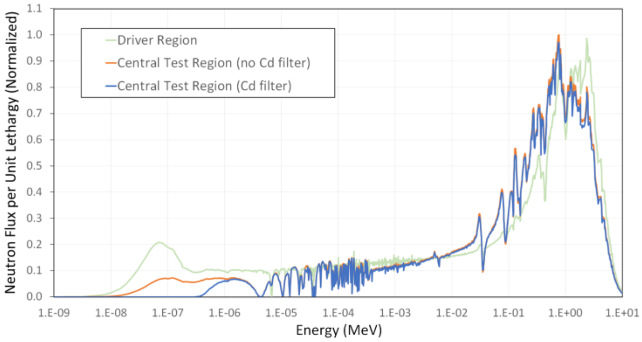

Fig. 4. Neutron spectra in the Ta rods.

Tantalum is a neutron absorber used as a structural material in nuclear applications. Ta is nearly isotopically pure, with 99.99 wt% of natural Ta being composed of ^{181}Ta. The total and absorption cross sections for ^{181}Ta are plotted in Figure 5.

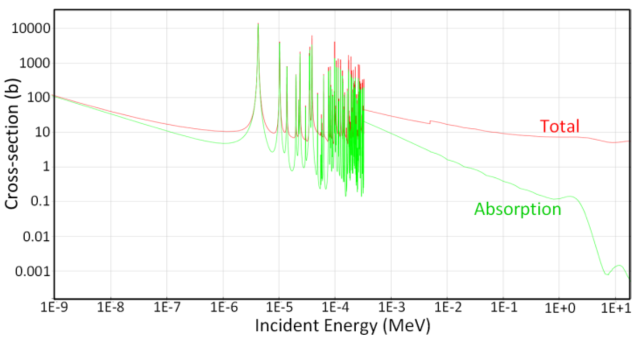

Fig. 5. Energy-dependent cross sections for ^{181}Ta.

Figure 6 shows the Ta energy-dependent absorption reaction rates and neutron spectra for the critical configurations with 37 Ta rods in the central test region for the cases with and without Cd filter. As expected, the Cd filter greatly reduces the absorption reaction rate in the thermal energy range. Table I provides the Ta absorption rates within the three listed energy groups as a percentage of the total abortions.

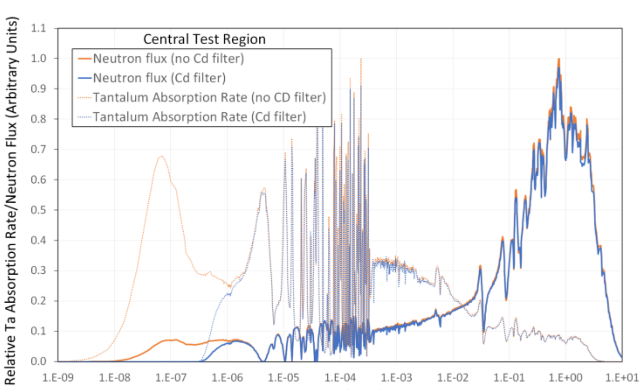

Fig. 6. Energy-dependent reaction rates and neutron spectra.

Table I. Three group absorption rates for Ta.

Tantalum Rod Location	< 0.5 eV	0.5 eV – 10 keV	> 10 keV
Central Test Region (Cd filter)	0.3 %	91.8 %	8.0 %
Central Test Region (no Cd filter)	28.7 %	65.8 %	5.5 %
Driver Region	45.4 %	52.4 %	2.2 %

As part of the analysis to ensure the set of experiments are within the safety envelope prescribed for operations at SCX, the fission density peaking was evaluated. Figure 7 shows the peak to average fission density as a function of fuel rod position for the critical configuration with 37 Ta rods and the Cd filter. The fission density peak is in the rods around the periphery of the core and is considerably depressed near the center. In addition to safety considerations, the fission density analysis provides insight into the neutronic behavior of the assembly.

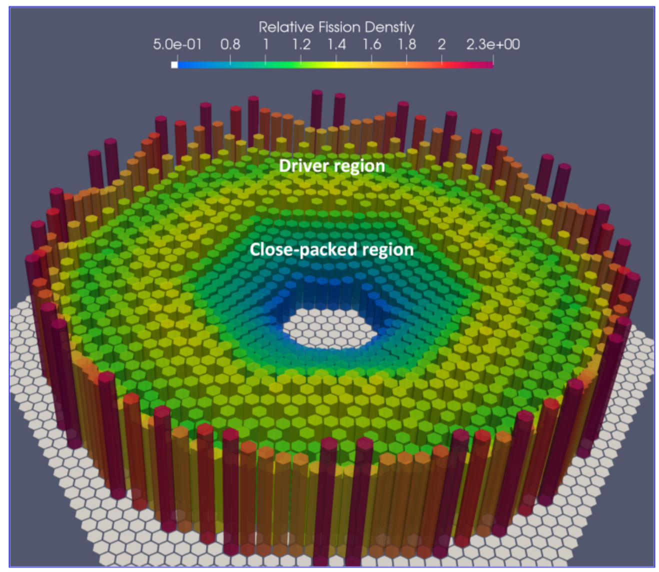

Fig. 7. Relative fission density in the critical assembly.

CONCLUSION

The set of experiments reported here were designed to use the 7uPCX fuel to measure the effects of tantalum material on the critical array size. The calculational results provide confidence that the critical experiments will produce significant material reactivity worths while targeting Ta absorption reaction rates in the epithermal/intermediate energy range.

ACKNOWLEDGEMENTS

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