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CHANNEL GAP MEASURMENTS IN NUCLEAR PLATE FUEL

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ABSTRACT

The U.S. High-Performance Research Reactors (USHPRR) program is developing new Low Enriched Uranium (LEU) U-Mo Fuel and testing the performance of the plate fuel. The primary fuel design is based on uranium-molybdenum (U-Mo) foil clad in an aluminum alloy that are in the form of mini-plate specimens (1"x 4" plates). The fuel plates will be placed in a capsule in four layers with two plates per layer. The experiment is designed in such a way that the gaps between the U-Mo fuel plates are ultrasonically measured after each irradiation cycle. Irradiation has taken place at the ATR (Advance Test Reactor). Geometry changes in the fuel plates is an important performance indicator.

Keywords: Ultrasonics, nuclear plate fuel, irradiation

NOMENCLATURE

ATR	advanced test reactor
CGP	channel gap probe
HEU	highly enriched uranium
INL	Idaho National Laboratory
LEU	low enriched uranium
M3	Material Management and Minimization
MP	mini-plate irradiation experiment
NNSA	National Nuclear Security Administration
USHPRR	U.S. High-Performance Research Reactors
U-Mo	uranium-molybdenum

1. INTRODUCTION

In December of 2014 the U.S. National Nuclear Security Administration (NNSA) established the Office of Material Management and Minimization (M3) for the purpose of identifying, securing, and removing weapons-usable nuclear materials around the world.[1] M3 has absorbed ongoing U.S. efforts under the former Global Threat Reduction Initiative Convert Program aimed at the conversion of domestic and foreign research reactors from the use of highly enriched uranium to low-enriched uranium (LEU) fuel.

Execution for the development of LEU plate fuel, with its ultimate goal of reactor conversion to LEU, is achieved through testing the new fuel system designs in various reactors. One of the salient fuel performance parameters is fuel swelling. Fuel swelling is characterized by measuring the gaps between the plates ultrasonically.

The fuel plates are contained in fuel capsules holding eight plates each, with 2 plates at 4 levels as shown in Figure 1. Once the capsules with the plates are irradiated, they have to be inspected during the outage in-between irradiation cycles. The capsules need to have visual inspection performed and channel gap widths measured prior to reinsertion. The capsule handling, inspection, and gap measurements are performed submerged in the ATR canal.[2] These inspections are to ensure that the plates have not deformed significantly. Obstruction of the coolant channels and restriction of the coolant are a performance and safety concern. The Channel Gap Probe (CGP) has been developed to measure channel gap widths. CGP serves as an indirect measure of the fuel plate performance and deformation throughout the course of irradiation. The CGP data enables the evaluation of the risk from continuing irradiation prior to reinsertion of the plates in reactor.

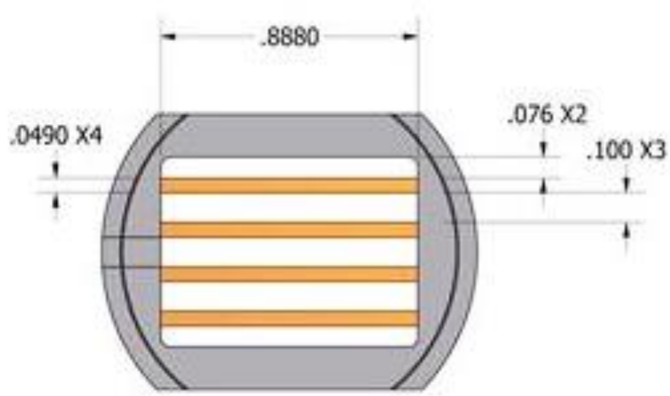

FIGURE 1: GEOMETRY OF THE PLATE FUEL LOADED WITH IN THE CAPSULE.

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2. MATERIALS AND METHODS

The Mini-plate (MP-1) experiment is designed to evaluate performance of LEU monolithic fuel plates manufactured by a commercial fabricator. The fuel plate performance is tested as a function of irradiation conditions that are representative of conditions found in research reactors. The representative irradiation conditions dictate the basis for selecting mini-plate geometries and ATR irradiation conditions for the MP-1 experiment. The dimensions of the aluminum cladded mini-plates are 0.05 × 1 × 4 in.

Fourteen MPs are evenly distributed into four capsules in various locations within the capsules. The remaining 18 slots are filled with aluminum dummy plates. The capsules are stacked on top of each other and inserted into the Large B test position within the ATR[2] via a test-train assembly. The capsules are irradiated and then the test-train is removed from the reactor.

The capsules are removed from the test-train and the channel gaps between the plates are individually measured while submerged. The channel gap widths are measured by inserting a measurement probe between the plates. The probe consists of a wand with leaf springs that have ultrasonic crystals attached to the underside of the springs as shown in Figure 2. The leaf springs slide along the plates and the gap width is determined by the time of flight measurements between the two ultrasonic transducers in pitch-catch mode.

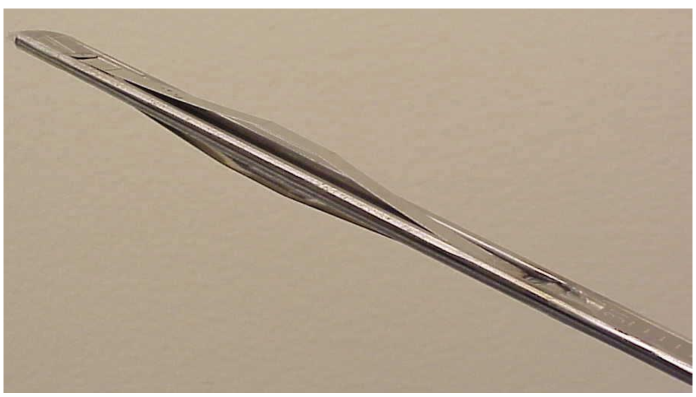

FIGURE 2: THE MEASUREMENT PROBE CONSISTS OF A WAND WITH TWO LEAF SPRINGS THAT HAVE ULTRASONIC TRANSDUCERS ATTACHED.

The measurement probe has a thermocouple built into the wand just above the start of the leaf springs. The thermocouple is used to correct for changes in the speed of sound for water due to temperature variations. To ensure that the calibration of the probe is valid, the probe is inserted into a gauge block that has three gaps, 0.062, 0.086, 0.116 in.

The actual measurement and calibration check processes are as follows. The wand is inserted into the gauge block and then into a desired channel within a capsule. The leaf springs are inserted past the end of the channel. The actual channel measurements and calibration checks are made when the wand is withdrawn. The calibration is checked as part of each measurement.

Prior to irradiation, each capsule's channels were measured to provide a baseline line contour along the center line of each channel. The baseline channel contour will be compared with the irradiated channel contour to determine any changes in geometry and to measure swelling.

3. RESULTS AND DISCUSSION

A representative channel gap measurement is shown in Figure 3. The data displayed shows the channel gaps between the lower and upper set of plates as well as the three gauge block gaps. The lower plate gap is from ≈1 to 5" and the upper plate gap is from ≈ 5.5 to 9.5". There are usually transitions at the plate edges as shown in Figure 3 where the probe geometry changes significantly. The probe geometry change causes significant distortion in the measurement and the data within the transition zones are not reliable. The transition zones in Figure 3 are at ≈ 1, 5.5, and 9.5".

The gap between the lower plates shows a significant amount of curvature while the upper gap remains constant. The curvature is due to the assembly of the plates within the capsule. Figure 3 shows the importance of the base line measurements as ideally the channel gaps should be constant. The gauge block gaps used for the calibration check and probe calibration are at 16, 19 and 23 inches are also shown in this figure.

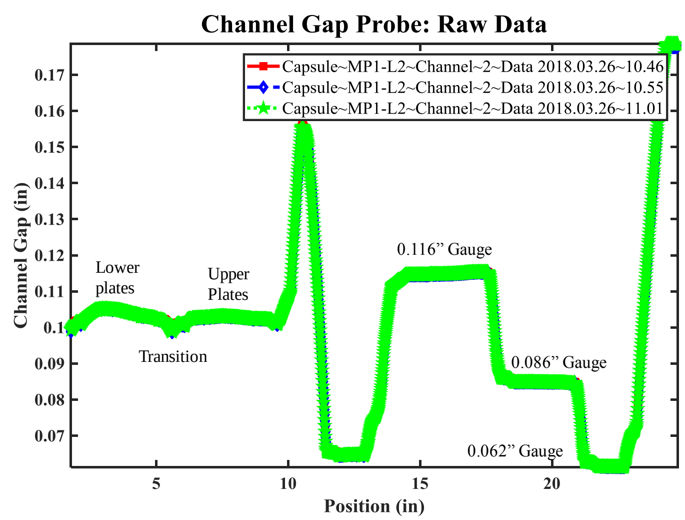

FIGURE 3: RAW BASELINE DATA OBTAINED FROM CHANNEL 2 IN MP-1 CAPSULE 2.

The baseline data is subtracted from the corresponding irradiated channel to determine the geometry changes in the plates. The difference between two channels for a single irradiation cycle is shown in Figure 4. The location of the lower plates are given on the graph by the blue background and the tan background indicates the upper plate gap. The data suggest that the maximum geometry change of the plates was small (0.002") when the transition regions are discounted. The measurement resolution is less than 0.001" as determined from the scatter in the line plot.

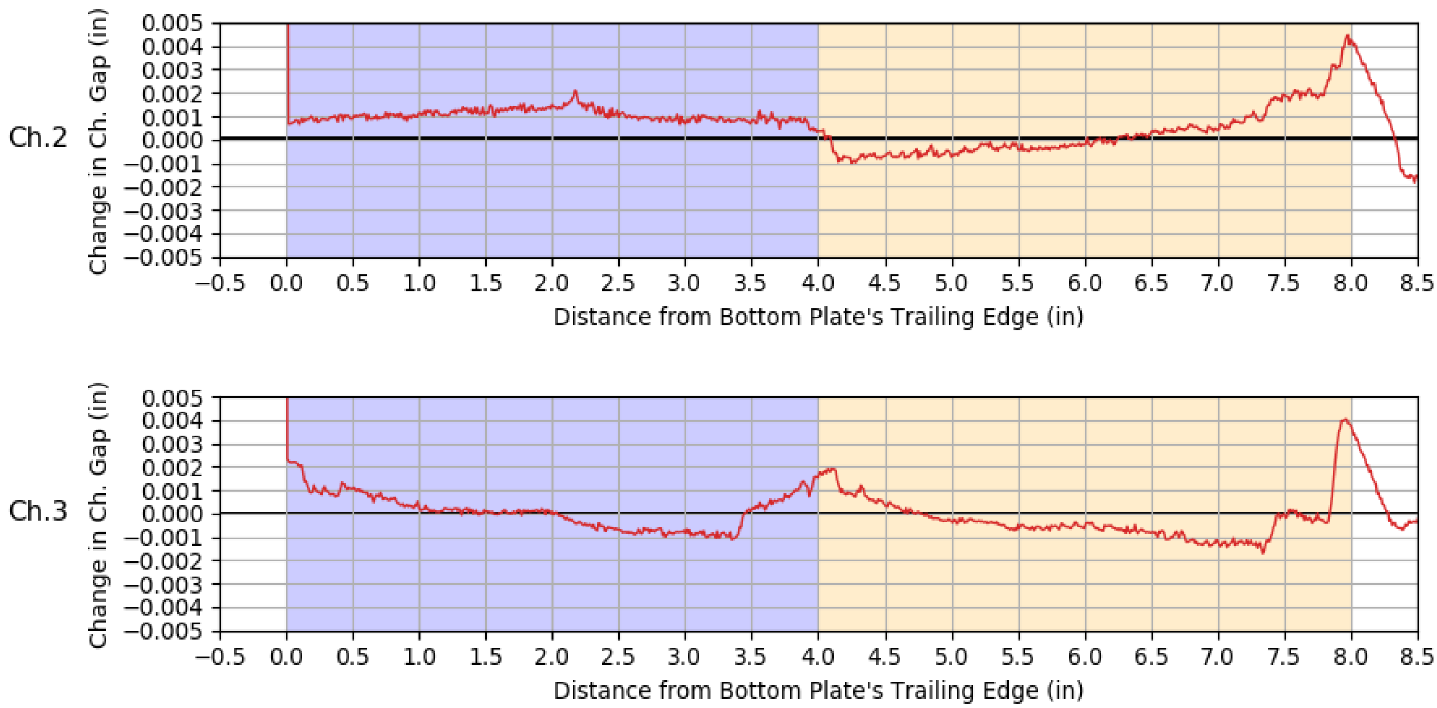

FIGURE 4: THE RESULTING CHANGE IN CHANNEL WIDTH AFTER 1 IRRADIATION CYCLE FOR CHANNELS 2 & 3 IN CAPSULE 1 IS DISPLAYED.

It also should be noted that in some capsules the fuel plates are able to move and were not fixed. These small movements can affect the difference measurements. The sharp changes in gap difference at 2.2” in channel 2 and at 3.5” in channel 3 could be due to plate movement between baseline and irradiation measurements. The capsules see a significant amount of handling during assembling for irradiation and during disassembly for measurements.

4. CONCLUSION

The performance of newly developed plate fuel is being characterized. The plate fuel is assembled in four layers within a capsule and then irradiated within the ATR. The structural performance of the fuel is characterized by channel gap measurements that are made between the fuel plate layers. Important fuel performance parameters are fuel swelling and plate deformation. CGP data enables the evaluation of the risk from continuing irradiation of the fuel plates prior to reinsertion of the plates into the reactor.

Channel gap data has been successfully obtained for one irradiation cycle. The difference between the baseline contour and irradiated plates within a capsule has been shown to be minimal (<0.002”). The resolution of the change in channel gap width is shown to be less than 0.001”. The first irradiation cycle had little effect on the geometry of the plate fuel. The final paper will present the channel gap measurements for multiple irradiation cycles. It is anticipated that the higher irradiation levels will cause measurable geometry changes.

ACKNOWLEDGEMENTS

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[2] FY 2009 Advanced Test Reactor National Scientific User Facility Users’ Guide, https://nsuf.inl.gov/Home/DownloadUserGuide/652