INL/CON-10-17941
PREPRINT

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RRFM 2010

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March 2010

SUMMARY OF 'AFIP' FULL SIZED PLATE IRRADIATIONS IN THE ADVANCED TEST REACTOR

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ABSTRACT

Recent testing at the Idaho National Laboratory has included four AFIP (ATR Full Size plate In center flux trap Position) experiments. These experiments included both dispersion plates and monolithic plates fabricated by both hot isostatic pressing and friction bonding utilizing both thermally sprayed inter-layers and zirconium barriers. These plates were tested between 100 and 350 w/cm^2 at low temperatures and high burn-ups. The post irradiation exams performed have indicated good performance under the conditions tested and a summary of the findings and irradiation history are included herein.

1. INTRODUCTION

1.1 Background

Fuel development for the US Reduced Enrichment for Research and Test Reactor (RERTR) program has recently tested several variations of 'full sized' plates in the Advanced Test Reactor (ATR). Both U-Mo dispersion type designs and solid, monolithic U-Mo fuel phase with diffusion barriers between the fuel and the aluminum cladding have been tested.

This recent testing has focused on taking this U-Mo fuel technology developed and successfully demonstrated at a small scale (mini-plates) and scaling up to full sized plates that are seen in prototypic test reactors such as ATR, MITR-II, and MURR. The first results from full sized testing including both non-destructive and destructive examinations are included here.

1.2 Experiment Composition

Each of the three AFIP experiments described herein included two fuelled plates stacked one above the other and welded into an aluminium frame. Each plate was 57cm in length and 6cm in width. The parameters tested in each of the experiments are listed in Table 1. All of the plates were clad in aluminium-6061.

Table 1 Tested Parameters of the AFIP Experiments

	AFIP-1	AFIP-2	AFIP-3
Fuel Type	U-7Mo Dispersion	U-10Mo Monolithic	U-10Mo Monolithic
Fabrication Method	Roll Bonded	Friction Bonded	Hot Isostatic Press
Matrix materials	Plate 1: Al-2Si Plate 2: Al-4043	N/A	N/A
Diffusion Barriers	N/A	Plate 1: Si Plate 2: Zr	Plate 1: Si Plate 2: Zr

1.3 Irradiation Testing History

The three AFIP experiments were irradiated in the centre flux trap of the Advanced Test Reactor. The irradiation schedule for the AFIP tests is shown in Table 2 along with the effective full power days of each irradiation cycle.

Table 2 AFIP Irradiation Schedule

ATR Cycle	AFIP Position A	AFIP Position B	EFPD
141A	AFIP-2	Al Dummy	32.4
142A	AFIP-2	Al Dummy	48.0
142B	AFIP-2	AFIP-1	52.0
143A	Al Dummy	AFIP-1	48.9
143B	AFIP-3	AFIP-1	57.3
144A	AFIP-3	Al Dummy	43.7

The preliminary heat flux and fission density values that were calculated for the AFIP experiments are shown in Figure 1 and Figure 2 respectively. Nodes 1-10 are located axially along the top plate of the experiment while nodes 11-20 are located axially in the lower plate of the experiment.

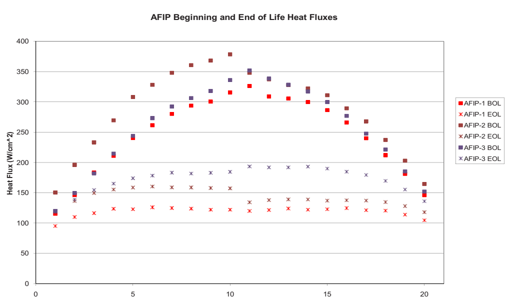

Figure 1 Heat fluxes for beginning and end of life of AFIP experiments

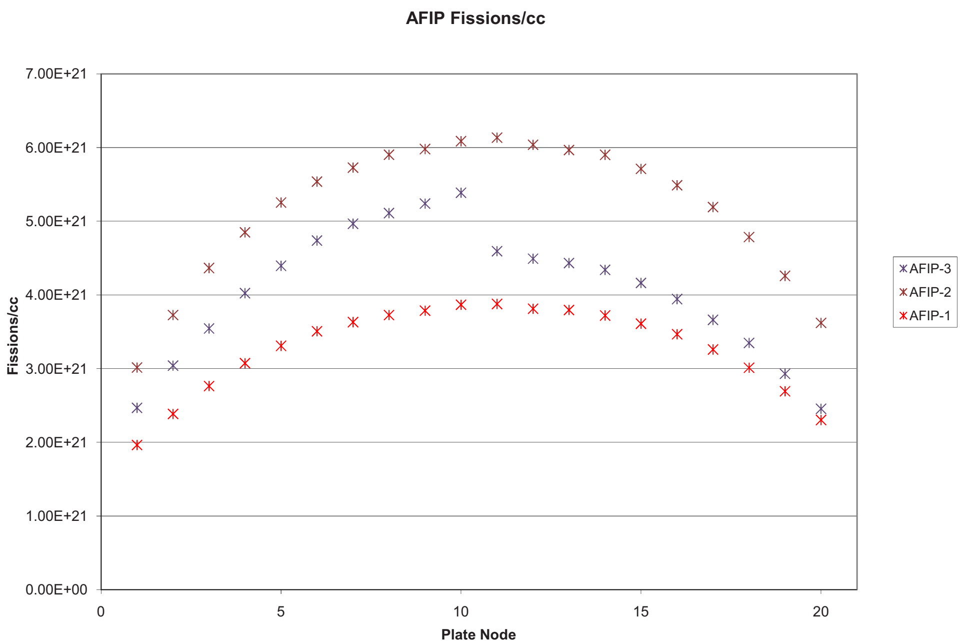

Figure 2 Fission Densities of AFIP Tests

2. POST IRRADIATION EXAMINATION RESULTS

2.1 Non-Destructive Examinations

Thickness measurements taken on all six AFIP plates indicate uniform and acceptable swelling behavior. These values also indicate that there was no delamination between the fuel foils and the cladding in the monolithic fuel system. Pre and post irradiation plate thickness values and fuel meat thicknesses are used to calculate average fuel using equation 1. This calculation assumes all swelling of the plate is due to fuel swelling which is accurate with aluminum cladding assuming there is not fuel/clad delaminations.

$$Fuel\ Swelling = \frac{T_{PostIrradiation} - T_{PreIrradiation}}{T_{Fuel\ Thickness}} \qquad (1)$$

Swelling values are calculated in 3.2mm increments over the fuel zone, corresponding with the collected thickness values. The plate average fuel swelling for each plate as well as peak fuel swelling values and average fission density are shown in Table 3.

Table 3 Swelling values from the AFIP experiment

Plate ID	Plate Ave Fuel Swelling	Peak Fuel Swelling	Plave Ave Fission Density
1TT	16.9%	31.5%	3.20E+21
1B5	16.3%	27.2%	3.35E+21
2TT*	36.5%	67.1%	5.04E+21
2BZ	31.8%	52.9%	5.31E+21
3TT	20.9%	36.2%	4.29E+21
3BZ	17.3%	28.2%	3.84E+21

* Only the high burnup half of plate could be measured due to damage during handling

Eddy current testing is performed to measure oxide formation or corrosion on the surface of the plates during irradiation. Measurement values were all less than 10 µm in thickness and indicate very little oxide growth or corrosion during irradiation. This indicates the pre-irradiation autoclaving process is adequate for the powers tested in this experiment.

2.2 Destructive Examinations

Destructive examinations were conducted on all six plates. Two full cross-sections from each plate were sectioned, one from the high power end and one from the low power end. Each sample was mounted and polished in preparation for metallographic examination. Each section was examined for bond integrity, inter-diffusion between the fuel and cladding/matrix, fission gas behavior, and verification of fuel swelling calculations. A typical cross section is shown in Figure 3.

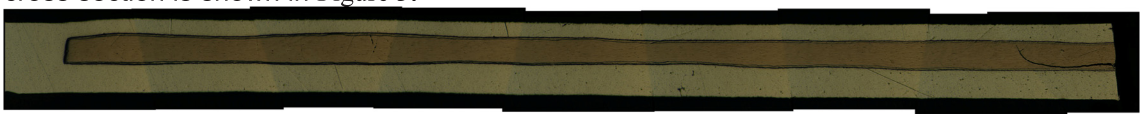

Figure 3 Cross sectional image of an AFIP-3 plate (3BZ)

2.2.1 AFIP-1

AFIP-1 consisted of two dispersion fuel plates, one with Al-2%Si matrix (1TT) and one with Al-4043 matrix (1B5). A prototypic image from both of the plates is shown in Figure 4. Areas of fuel, matrix, interaction layer, and porosity can be seen throughout the image. Both compositions had considerable fuel/matrix interactions but the porosity was limited in both cases.

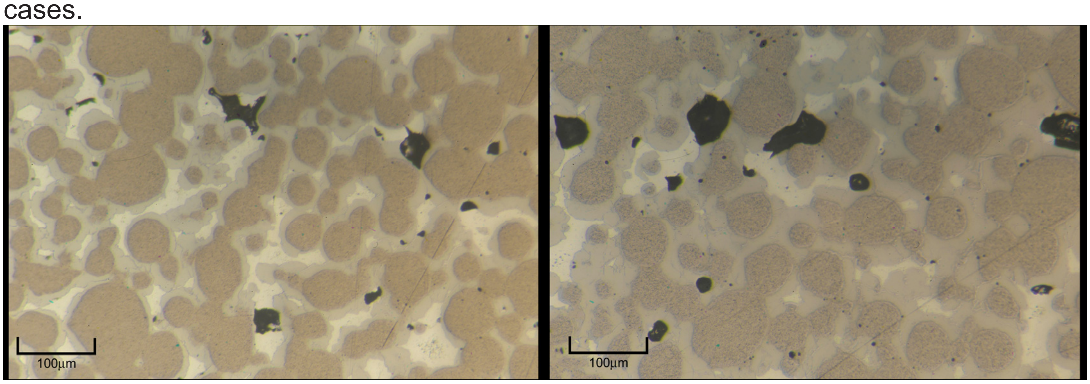

Figure 4 Images from 1TT (left) and 1B5 (right)

2.2.2 AFIP-2

AFIP-2 consisted of two friction bonded, monolithic fuel plates. One had a thermally sprayed silicon diffusion barrier and the other had a zirconium diffusion barrier. Both plates appear to have performed very well with no delaminations occurring during either irradiation or subsequent sectioning. The silicon thermal spray layer can be seen as large precipitate rich regions on the fuel/clad interface and the zirconium barrier is clearly seen between the fuel and cladding.

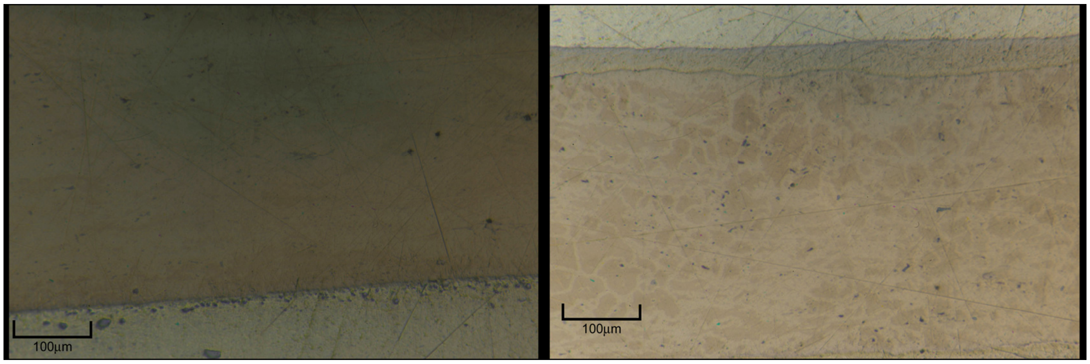

Figure 5 Images from 2TT (left) and 2BZ (right)

2.2.3 AFIP-3

AFIP-3 consisted of two monolithic plates fabricated by hot isostatic pressing (HIP). One had a thermally sprayed silicon diffusion barrier and the other had a zirconium diffusion barrier. Both plates appear to have performed very well with no delaminations occurring during either irradiation or subsequent sectioning. The two plates in this experiment appeared to have behaved very similarly to the plates in AFIP-2 indicating that there appears to be no significant performance difference between the two fabrication methods for the conditions tested.

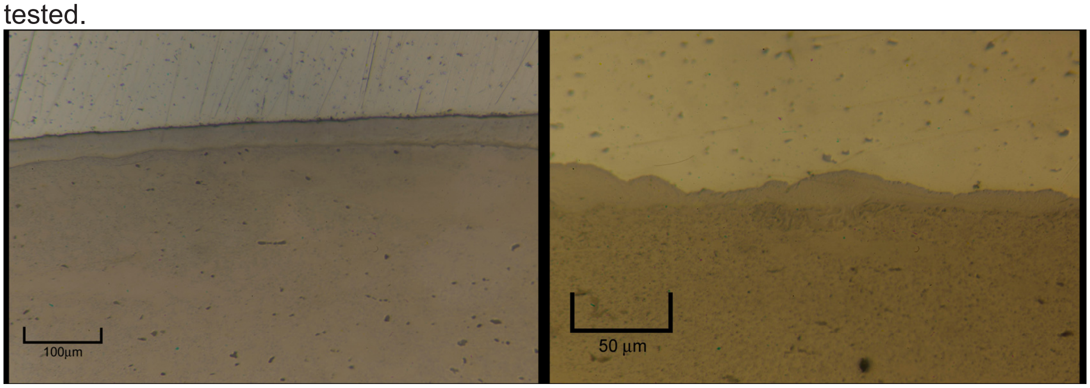

Figure 6 Images from 3BZ (left) and 3TT (right)

3. Summary

All of the plates that were irradiated in the first three AFIP experiments appear to have behaved acceptably. Swelling values are low for the fission densities that were achieved. The fuel/clad bonding in the monolithic system was maintained in all cases. No excessive reactions or porosity was seen along the boundary in the areas examined. Interactions between the fuel and matrix material in the dispersion plates was thick and some porosity was beginning to form, however, the overall swelling of those plates was satisfactory.