IRRADIATION TESTING OF HIGH-DENSITY URANIUM ALLOY DISPERSION FUELS

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ABSTRACT

Two irradiation test vehicles have been designed, fabricated, and inserted into the Advanced Test Reactor in Idaho. Irradiation of these experiments began in August 1997. These irradiation tests were designed to obtain irradiation performance information on a variety of potential new, high-density dispersion fuels. Each of the two irradiation vehicles contains 32 "microplates." Each microplate is aluminum clad, having an aluminum matrix phase and containing one of the following compositions as the fuel phase: U-10Mo, U-8Mo, U-6Mo, U-4Mo, U-9Nb-3Zr, U-6Nb-4Zr, U-5Nb-3Zr, U-6Mo-1Pt, U-6Mo-0.6Ru, U-10Mo-0.05Sn, U_2Mo, or U_3Si_2. These experiments will be discharged at peak fuel burnups of approximately 50 and 80 at.% U^{235}. Of particular interest are the extent of reaction of the fuel and matrix phases and the fission gas retention/swelling characteristics of these new fuel alloys. This paper presents the design of the irradiation vehicles and the irradiation conditions.

INTRODUCTION

Since 1978, the development of high density fuels to enable research and test reactors currently employing high-enriched uranium (HEU) fuels to convert to low-enriched uranium (LEU) has been a major component of the U.S. Reduced Enrichment for Research and Test Reactors (RERTR) program. To be successful any fuel conversion must be accomplished with little to no impact on reactor operations and core configuration. Prior development work leading to the qualification of UAlx-Al, U_3O_8-Al and U_3Si_2-Al dispersion fuels has resulted in the conversion of about 20 reactors from HEU to LEU. The uranium silicide dispersion fuel in particular, having a density of 4.8 g-U/cm^3, is viewed as adequate to convert approximately 90% of all research reactors using HEU of U.S. origin. The remaining 10% are awaiting the development of a dispersion fuel of even higher density. The U.S. RERTR program is currently attempting to develop dispersion fuels having densities in the range of 8 to 9 g-U/cm^3 [1].

The focus of the effort to develop high-density dispersion fuels thus far has been g-stabilized uranium alloys in an aluminum matrix. The rationale for interest in this class of dispersion fuels has been presented by Meyer et al. [2]. To gain initial fuel performance data on a sample of such g-stabilized uranium alloy dispersion fuels, an irradiation experiment has been initiated in the Advanced Test Reactor (ATR) located in Idaho. This experiment is scoping in nature, attempting to gain performance data on the following ten (10) different uranium alloy dispersion fuels: U-10Mo, U-8Mo, U-6Mo, U-4Mo, U-9Nb-3Zr, U-6Nb-4Zr, U-5Nb-3Zr, U-6Mo-1Pt, U-6Mo-0.6Ru and U-10Mo-0.05Sn, where alloying additions are expressed in weight percent. Also included in this test are the uranium intermetallic compound U_2Mo, as well as U3Si2 which serves as a control fuel type having known irradiation behavior. All fuels in this test are in an aluminum matrix and aluminum cladding. These twelve (12) fuel types are contained in two irradiation vehicles, designated RERTR-1 and RERTR-2. Both irradiation vehicles contain all fuel types except one, in essentially the same configurations; the U-5Nb-3Zr fuel type is not included in RERTR-2.

The fuels employed in this test were fabricated in plate form. Due to the small size of the fuel plates, they are referred to as "microplates." The external dimensions of the microplates are 3.000-in. in length, 0.875-in. in width, and 0.050-in. in thickness (76 mm x 22 mm x 1.3 mm). The fuel volume fraction within the dispersion region of the microplates is nominally 25%. Detail regarding the design and fabrication of these microplates is reported elsewhere [3]. Full power irradiation of both vehicles began on August 23, 1997.

IRRADIATION TEST VEHICLES

The irradiation vehicles RERTR-1 and RERTR-2 were designed to occupy small I-hole positions located radially outside the ATR core. Though outside the core, these positions are exposed to a relatively high thermal neutron flux, as will be detailed in the subsequent section. These I-hole positions are vertical, 1.5-in. (3.8 cm) diameter holes into which the irradiation vehicle is placed. In this experiment, the irradiation vehicles consist of a flow-through "basket" holding 8 vertically-stacked, flow-through capsules. Each capsule holds four microplates in a configuration such that the long dimension of the microplates is parallel to the coolant flow. Flow-through spacers are included at both the top and bottom of the stack of eight capsules to center the stack about the axial midplane of the 4.0-ft. (1.2 m) high core. Figure

1 is a schematic representation of the irradiation vehicles; Figure 2 shows the microplate configuration within the flow-through capsules.

The flow-through capsules are designated "A" through "H" in RERTR-1 and "Z" through "S" in RERTR-2. Each capsule holds four fueled microplates for a total of 32 microplates in each irradiation vehicle. Table 1 shows the configuration of the fuel types within each irradiation vehicle and within each capsule.

IRRADIATION TEST CONDITIONS

The two irradiation vehicles RERTR-1 and RERTR-2 are currently undergoing irradiation in ATR capsule positions I-22 and I-23, respectively. These test positions are located in the control drum region of the ATR and are cooled by the primary reactor coolant. The nominal primary coolant inlet temperature and pressure are 52¡C and 2.5 MPa, respectively. Thermal hydraulic calculations indicate that the mean coolant flow velocity within the experiments is 915 cm/sec, and that the total flow rate through each I-hole position will be 2,570 cm3-H2O/sec. At the maximum allowable ATR power of 60 MW/lobe, each experimental vehicle will generate approximately 35 kW of thermal power, resulting in a bulk coolant temperature rise of less than 5¡C through the experiments. A conservative hot-channel analysis predicts a maximum coolant temperature rise of 7¡C. Table 2 shows the calculated microplate thermal fluxes, powers, heat fluxes and temperatures for the RERTR-1 experiment at full power and beginning-of-life (BOL); conditions for RERTR-2 are virtually identical. Normally, however, the ATR operates at lobe powers of 25 to 30 MW. Thus, the microplate operating temperatures of these experiments are expected to remain low. Maximum thermal neutron fluxes experienced by all of the microplates will be in the range of 2.0 to 3.0x1014 n/cm2-sec at BOL for full power operation.

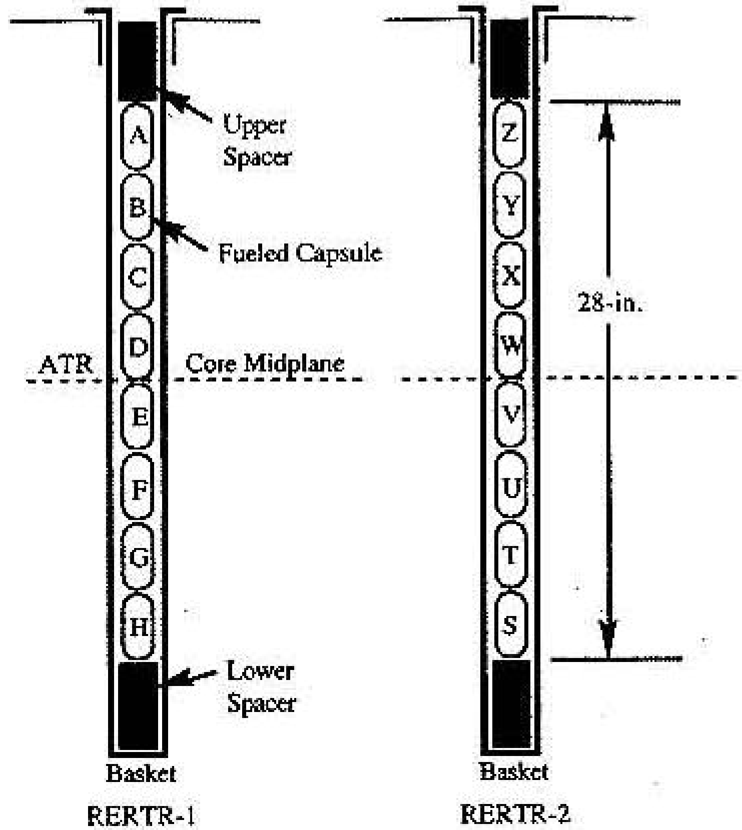

Figure 1. Schematic Diagram of Irradiation Vehicles (not to scale)

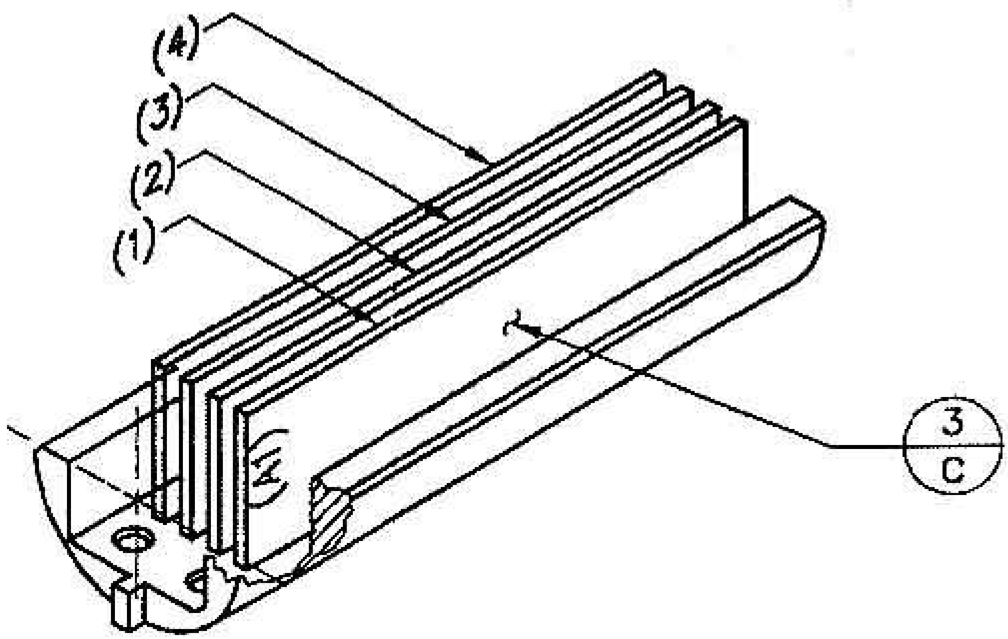

Figure 2. Flow-Through Capsule Holding 4 Microplates

Table 1. Microplate Configuration within RERTR-1 and RERTR-2[+]

Capsule Designation	Microplate Designation (RERTR-1 / RERTR-2)	Fuel Phase Composition[+] (RERTR-1 / RERTR-2)
A or Z	A-1 / Z-1 A-2 / Z-2 A-3 / Z-3 A-4 / Z-4	U_3Si_2 / U_3Si_2 U_2Mo / U_2Mo U-6Nb-4Zr / U-6Nb-4Zr U-5Nb-3Zr / U-6Mo-1Pt
B or Y	B-1 / Y-1 B-2 / Y-2 B-3 / Y-3 B-4 / Y-4	U-6Mo / U-6Mo U-6Mo-1Pt / U-6Mo-1Pt U-10Mo / U-10Mo U-6Mo-0.6Ru / U-6Mo-0.6Ru
C or X	C-1 / X-1 C-2 / X-2 C-3 / X-3 C-4 / X-4	U_3Si_2 / U3Si2 U_3Si_2[a] / U_3Si_2[a] U-4Mo / U-10Mo-0.05Sn U-10Mo / U-6Mo-0.6Ru
D or W	D-1 / W-1 D-2 / W-2 D-3 / W-3 D-4 / W-4	U-10Mo / U-10Mo U-10Mo-0.05Sn / U-10Mo-0.05Sn U-9Nb-3Zr / U-9Nb-3Zr U-8Mo / U-8Mo
E or V	E-1 / V-1 E-2 / V-2 E-3 / V-3 E-4 / V-4	U-6Mo / U-6Mo U-6Mo-1Pt / U-6Mo-1Pt U-9Nb-3Zr / U-9Nb-3Zr U-8Mo / U-8Mo
F or U	F-1 / U-1 F-2 / U-2 F-3 / U-3 F-4 / U-4	U-10Mo / U-10Mo U-10Mo-0.05Sn / U-10Mo-0.05Sn U-10Mo[a] / U-10Mo[a] U-6Mo-0.6Ru / U-6Mo-0.6Ru
G or T	G-1 / T-1 G-2 / T-2 G-3 / T-3 G-4 / T-4	U-6Nb-4Zr / U-6Nb-4Zr U-5Nb-3Zr / U-6Mo U_2Mo / U_2Mo U-10Mo / U-8Mo
H or S	H-1 / S-1 H-2 / S-2 H-3 / S-3 H-4 / S-4	U-4Mo / U-4Mo U_3Si_2[a] / U_3Si_2[a] U-10Mo[a] / U-10Mo[a] U-10Mo / U-10Mo

[+]Alloy compositions given in wt.%. [a]Atomized alloy powder.

The experimental vehicle RERTR-1 is scheduled to undergo two reactor cycles totaling 91 days of irradiation (38 effective full power days), being discharged from the reactor following a shutdown scheduled for November 30, 1997. The peak fuel burnup at this time is expected to be ~50 at.%. RERTR-2 will undergo five reactor cycles totaling 231 days of irradiation (96 effective full power days). Discharge of RERTR-2 is anticipated to occur following reactor shutdown in May of 1998 at a peak fuel burnup of ~80 at.%.

Table 2. Calculated Steady-State Fuel Conditions at 60MW Lobe Power for RERTR-1 at Beginning-of-Life.

Micro-plate	Thermal Flux (n/cm^2sec)	Power (W)	Heat Flux (W/cm2)	Cladding Surface Temp. (°C)	Fuel-Clad Interface Temp.(°C)	Fuel Central Temp.(°C)
A-1	$2.2x10^{14}$	713.2	93.8	72.6	75.1	76.4
A-2	$2.1x10^{14}$	894.7	92.5	77.8	80.9	82.6
A-3	$2.0x10^{14}$	793.5	82.0	74.9	77.7	79.1
A-4	$2.2x10^{14}$	900.8	93.1	78.0	81.1	82.7
B-1	$2.6x10^{14}$	1062.7	139.8	82.7	86.4	88.2
B-2	$2.6x10^{14}$	1129.2	116.7	84.6	88.5	90.5
B-3	$2.5x10^{14}$	1068.4	110.4	82.8	86.6	88.4
B-4	$2.5x10^{14}$	1062.6	109.8	82.7	86.4	88.2
C-1	$2.9x10^{14}$	946.8	124.6	79.3	82.6	84.4
C-2	$2.9x10^{14}$	967.2	99.9	79.9	83.3	85.1
C-3	$2.9x10^{14}$	1247.8	128.9	88.0	92.4	94.5
C-4	$2.6x10^{14}$	1125.3	116.3	84.5	88.4	90.4
D-1	$3.0x10^{14}$	1245.4	163.9	87.9	92.3	94.5
D-2	$2.9x10^{14}$	1181.2	122.1	86.1	90.2	92.3
D-3	$2.9x10^{14}$	1110.1	114.7	84.0	87.9	89.8
D-4	$3.0x10^{14}$	1221.3	126.2	87.2	91.5	93.6
E-1	$3.0x10^{14}$	1290.5	169.8	89.2	93.7	96.0
E-2	$2.9x10^{14}$	1212.4	125.3	87.0	91.2	93.3
E-3	$3.1x10^{14}$	1229.9	127.1	87.5	91.8	93.9
E-4	$3.0x10^{14}$	1256.1	129.8	88.3	92.6	94.8
F-1	$3.1x10^{14}$	1250.5	164.5	88.1	92.5	94.6
F-2	$3.1x10^{14}$	1263.1	130.5	88.5	92.9	95.1
F-3	$2.9x10^{14}$	1169.5	120.9	85.8	89.8	91.9
F-4	$3.0x10^{14}$	1253.4	129.5	88.2	92.5	94.7
G-1	$2.8x10^{14}$	1122.3	147.7	84.4	88.3	90.3
G-2	$2.8x10^{14}$	1144.9	118.3	85.0	89.0	91.0
G-3	$2.6x10^{14}$	1098.0	113.5	83.7	87.5	89.4
G-4	$2.8x10^{14}$	1224.9	126.6	87.4	91.6	93.8
H-1	$2.4x10^{14}$	978.4	128.7	80.2	83.7	85.5
H-2	$2.5x10^{14}$	746.4	77.1	73.5	76.1	77.5
H-3	$2.3x10^{14}$	953.6	98.5	79.5	82.9	84.5
H-4	$2.6x10^{14}$	1085.6	112.2	83.3	87.1	89.0

POSTIRRADIATION EXAMINATION

Following discharge of the experimental vehicles, the baskets will be stored in the ATR canal for a 30- to 60-day cooling period. The baskets will then be dismantled in the ATR canal. The eight capsules containing the microplates will be loaded into a GE-100 cask for transport to the Alpha-Gamma Hot Cell Facility (AGHCF) at Argonne National Laboratory (ANL) in Chicago. Postirradiation examinations to be conducted at the AGHCF include microplate dimensional characterization, gamma-ray spectroscopy, swelling measurements and metallography. Samples for burnup measurements will be taken and sent to ANL-West in Idaho for analysis.

CONCLUSION

Two virtually identical dispersion fuel experiments are currently undergoing irradiation in the Advanced Test Reactor in Idaho. Ten high-density, aluminum-clad, metallic uranium alloy microplate dispersion fuels are to be irradiated to burnups of approximately 50 and 80 at.%. Additionally, U2Mo-Al and U3Si2-Al dispersion fuels are included in each experiment. The postirradiation examination of these experimental fuels will provide the first glimpse of the irradiation performance of high-density uranium alloy dispersion fuels. It is currently these alloys that hold the promise of a potential new dispersion fuel having a density approaching 9 g-U/cm3. The first data from the 50 at.% burnup fuels is expected to be available during the spring of 1998; data from the 80 at.% burnup fuels will follow during that fall. A subsequent, more refined irradiation experiment focusing on those fuel types that appear most promising from the RERTR-1 and RERTR-2 experiments is envisioned and will be finalized as soon as the initial data from the postirradiation examinations has been analyzed.

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