PIE OF THE 2ND IRRADIATION TEST (KOMO-2) FOR THE ATOMIZED U-MO DISPERSION ROD FUELS AT KAERI

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ABSTRACT

Two U-7wt.%Mo dispersion fuel rods with different fuel particle sizes, two U-7wt.%Mo dispersion fuel rods surface-treated with pre-oxidation and Ni coating, one U-7wt.%Mo dispersion fuel rod with a poison material of Er_2O_3, a U-9wt.%Mo dispersion fuel rod, and a U_3Si dispersion fuel rod were loaded in the KOMO-test (the 2nd irradiation test of U-Mo fuels in HANARO by KAERI). In addition, the monolithic U-Mo ring fuel was loaded to develop higher U-density fuel. The fuel assembly with the above 10 fuel rods was irradiated in HAHARO successfully from January 9, 2003 to January 27, 2004. After cooling them for about 3 months, the PIE has been performed. Most of the fuel particles were interacted with the Al matrix in the central area of the rod-type U-Mo dispersion fuels with a high linear power and a higher burnup than 60 at.%. Some large pores were observed between the particles in the central area of the fuel rods. However the swellings of the fuel meats are not large, at less than 17 %. The fuel of a larger particle-size distribution showed a better stability than the fuel of a smaller particle-size distribution. Any surface treatments were observed to have no improvement on the oxidation layer formation of the cladding surface. U_3Si dispersion fuel used as a reference showed a much lesser interaction with the matrix Al when compared with the U-Mo dispersion fuel. In an examination for the tubular monolithic U-Mo fuel abnormal phenomena such as many bubbles and a large swelling happened due to an unexpected contamination of the silicon from the quartz tube used for a mold during melting & casting process.

1. Introduction

According to the non-proliferation policy under the reduced enrichment for research and test reactors (RERTR) program, low enriched uranium(LEU) fuel such as uranium silicide dispersion fuels are being used in research reactors. Because of a lower enrichment, higher uranium density fuels are required for some high performance research reactors[1,2]. U-Mo alloy with a high uranium density has been considered as one of the most promising candidates for a dispersion fuel due to its good irradiation performance. An international qualification program to replace the uranium silicide dispersion fuel with U-Mo dispersion fuel under the RERTR program is under way[3].

KAERI has carried out a qualification of the U-Mo dispersion rod fuel for the back-end option and a reactor upgrade by applying a higher U-density[4]. The first irradiation test (KOMO-1) in HANARO by KAERI for the U-Mo dispersion rod fuels revealed that the fuels with a U-loading of 6.0 g-U/cc were not acceptable due to a complete interaction between the U-Mo particles and Al matrix. The parameter with the strongest affect was concluded as the fuel temperature.

In the 2nd irradiation test, lower U-density fuels were targeted in order to reduce the temperature. Lower uranium densities in the fuel meats were changed from 6. g-U/cc to 4.5 g-U/cc and 4.0 g-U/cc for fuel meats with the 5.49 mm and 6.35 mm diameters, respectively. One U-Mo monolithic ring with Al cladding was loaded in order to avoid a severe interaction problem. In addition, two different particle sized fuels, two surface treated fuels with pre-oxidation and Ni coating, one fuel rod with a poison material of Er_2O_3, a fuel rod dispersed with U-9wt.%Mo powder, and a U_3Si dispersion fuel rod were loaded.

The fuel assembly consisting of the above 10 fuel rods was irradiated in HAHARO from January 9, 2003 to January 27 up to burnup of 60 at%. The average and the local maximum burnups were estimated as 60.8 at% and 71.2 at%, respectively. The irradiated fuel bundle was cooled in a cooling pool for about three months. Then a PIE was performed in the IMEF (Irradiation Material Examination Facility) facility. In this paper the results obtained from the PIE are reported from the aspect of a qualification of the feasibility of the U-Mo dispersion rod type fuel.

2. KOMO-2 Test Procedures

Centrifugally atomized U-7wt.%Mo, U-9wt.%Mo, and U_3Si powder were used for the fabrication of the rod-type U-Mo dispersion fuel meats. As shown in Table 1, a standard fuel rod containing U-7wt.%Mo dispersion fuel meat with 4.0 g-U/cc and 6.35 mm in diameter and a reduced fuel rod containing U-7wt.%Mo dispersion fuel meat with 4.5 g-U/cc and 5.49 mm in diameter were prepared. Two U-7wt.%Mo dispersion fuel rods with a small and large U-Mo particle size were loaded to evaluate the U-Mo size effect. Two U-7wt.%Mo dispersion fuel rods with pre-oxidation and Ni coating were included to investigate the influence of surface treatments. A U-7wt.%Mo dispersion fuel rod with burnable poison of Er_2O_3, a U-9wt.%Mo dispersion fuel rod, and a U_3Si dispersion fuel rod were loaded. In addition, a monolithic U-Mo tubular fuel of $^{OD}6.2\times{}^{t}0.7\times{}^{L}3.25$ was loaded to develop a higher U-density fuel. Linear power and B.O.L. temperature were calculated as shown in Table 1.

Table 1. Design of rod-type U-Mo dispersion fuel for KOMO-2 test.

Rod no.	Characteristics	U density (gU/cc)	Meat Diameter (mm)	Meat Lentgh (mm)	Linear Power (kW/m)	BOL Temp. (□)
494-L2	4.0 gU/cc U-7Mo	4.0	6.35	310	104.37	183.8
494-BP2	Erbia	4.5	5.51	210	92.57	180.2
492-LS1	U_3Si	4.0	6.37	210	112.09	201.2
494-SP1	Small grain	4.0	6.35	110	98.47	175.7
494-LP1	Large grain	4.0	6.35	110	97.95	175.0
494-Ni1	Ni coated	4.0	6.35	310	107.84	188.6
494-H2	4.5 gU/cc U-7Mo	4.5	5.49	360	102.99	189.4
489-T1	Tube	16.3	$^{t}0.68$	3.25	150.32	302.9
494-Ni2(P)	Pre-oxidation	4.0	6.35	310	108.3	188.8
491-H2	4.5 gU/cc U-9Mo	4.5	5.49	360	102.99	195.9

The irradiation test bundle was loaded at the OR5 hole of HANARO on Jan. 9, 2003 and was discharged on Mar. 7, 2003 for a visual inspection. After being loaded again on Jun. 5, 2003, the irradiation test bundle was discharged finally on Jan. 27, 2004. Fig. 1 shows the variation of the linear power of each rod with respect to an increasing burnup. Average burnup was calculated as 60.8 at.%U-235 and the maximum local burnup was 71.2 at.% of U-235 .

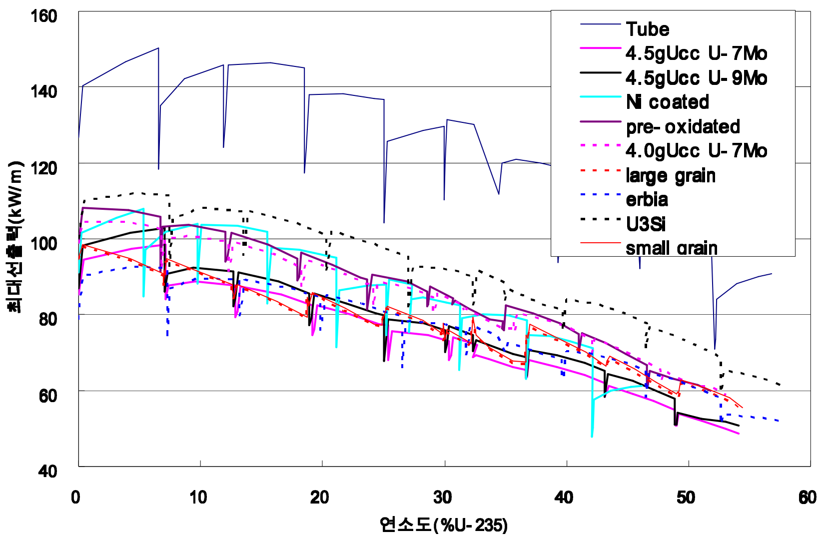


Fig. 1. Variation of the linear power with respect to burnup of fuel rods in KOMO-2 test.

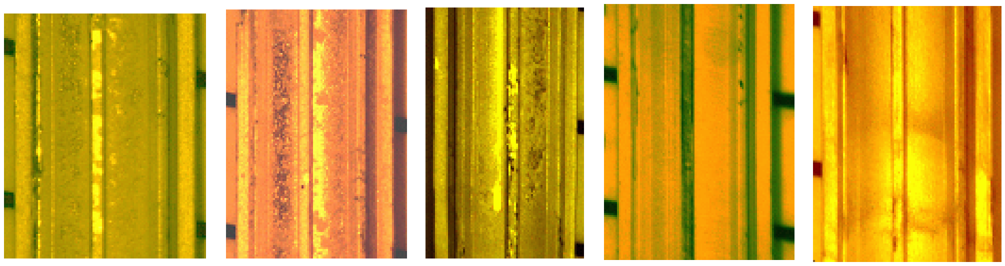
Table 2. Local maximum linear power and the centerline temperature of the U-Mo dispersion fuel rods in KOMO-2 test.

Rod No.	Max. Linear Power (kW/m)			Central Temp. (□)			Burnup (at%U-235)		
	Bottom	middle	top	bottom	middle	top	bottom	Middle	top
494-L2	76.4	99.0	100.5	145.5	176.5	178.5	50	62	68
494-BP2		77.7	85.5		157.8	169.6		62	70
492-LS1		91.8	112.0		172.3	201.2		62	70
494-SP1			94.2			169.9			62
494-LP1			95.0			171.0			62
494-Ni	107.8	92.3	46.5	188.5	167.3	104.6	65	62	40
494-H2	62.0	84.0	98.3	134.2	167.3	188.9	50	62	68
489-T1		150.3			343.8			64	
491-H2		81.8	102.8		164.0	195.6		62	68
494-Ni2(P)		95.5	104.0		171.7	183.3		62	68

3. Results and Discussion

Table 2 shows the maximum linear power, central temperature (BOL) and burnup for each sample of the irradiated fuel rods. Central temperature was calculated using the maximum linear power and the initial conductivity of the fuel meat. But the central temperature will be higher because the reaction layer formation and swelling degrades the thermal conductivity of the fuel meat.

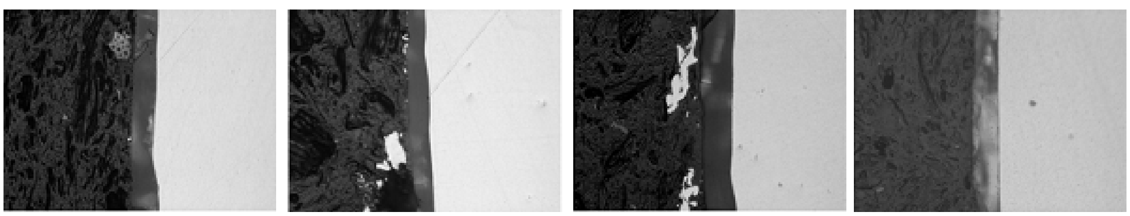
The irradiation bundle was disassembled in the IMEF and a visual inspection of each rod was carried out as shown in Fig. 2. Cladding surface damage was observed at the maximum linear power area in the 4 g-U/cc U-7Mo dispersion fuel rod (494-L2) and U_3Si dispersion fuel rod (492-LS1). While the Ni coated fuel rod (494-Ni1) showed a separation of the coated layers and cladding, the pre-oxidation treated fuel rod (494-Ni2(P)) showed sound a surface appearance. Surface of the tubular U-Mo monolithic fuel rod also showed a sound appearance.



(a) 494-L2 (b) 492-LS1 (c) 494-Ni1 (d) 494-Ni2(P) (e) 489-T1

Fig. 2. Post-irradiation appearance of the fuel rods observed at the area of local maximum linear power.

Oxide layers at the surface of the fuel rod cladding were observed using an optical microscopy as shown in Fig. 3. Measured thickness of the oxide layer shows a linear correlation with linear power as shown in Fig. 4. Surface treatment was not effective in reducing the oxidation of the cladding surface during the irradiation test because the pre-oxidation treated fuel rod (494-Ni2(P)) and Ni coated fuel rod (494-Ni1) showed a thicker oxide layer formation.



(a)494-L2 (b)494-Ni2(P) (c)494-Ni1 (d) 492-LS1

Fig. 3. Cross-sectional view of the irradiated fuel rods near the oxidation layer.

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