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Thermal analysis of KAERI TRISO fuel irradiation at HANARO

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1. Introduction

The TRISO(Tri-structural Isotropic)-coated fuel particle for a VHTR has a diameter of around 1 mm, and is composed of a nuclear fuel kernel and four different outer coating layers. These coating layers consist of a buffer PyC (pyrolytic carbon) layer, an inner PyC layer, a SiC layer, and an outer PyC layer. The fuel kernel is a source of a heat generation by the nuclear fission of fissile uranium. The role of each of the four coating layers is different in view of retaining the generated fission products and other interactions during in-reactor service[1].

KAERI has been developing a TRISO-coated particle fuel technology as a part of the Korean VHTR (Very High Temperature modular gas cooled Reactor) project, which started in 2004, and completed its first irradiation test of TRISO fuels in its research reactor, HANARO for an evaluation and prediction of the irradiation behavior of the fuel. The test was started in August 4, 2013 and finished in March 31, 2014 completing its 5 cycle irradiation of 132.2 EFPD.

In this paper, thermal performance of TRISO fuels was evaluated for its five cycle irradiation at HANARO which had been carried out in the absence of the fuel temperature monitoring. A COMSOL[2] based FE (finite element) model was utilized in this analysis.

2. Methods and Results

2.1 Irradiation test rods and service conditions

Two irradiation test rods were used in the test and they are shown schematically in Figure 1. The rod 1 contains nine fuel compacts, and the rod 2 contains five fuel compacts with eight graphite specimens placed in between as indicated in green color in Figure 1. Fuel compacts have a circular cylindrical shape, 8 mm in diameter and 10 mm in height, normally with a packing fraction of 20%, approximately. The graphite specimens have the same diameter but are half the height of compacts. Test specimens were loaded into a graphite sleeve to secure a gap between the specimens and the metallic cladding. The gap was filled with a mixed gas of He and Ne, which provides a high-temperature environment for the test specimens and protects the metallic cladding from thermal load. General descriptions of the test rods are summarized in Table 1.

KAERI TRISO fuels were irradiated at HANARO for about 8 months and completed its 5 cycle irradiation test, which is equivalent to 132.2 EFPD. The service history of TRISO fuels at HANARO was summarized in Table 2.

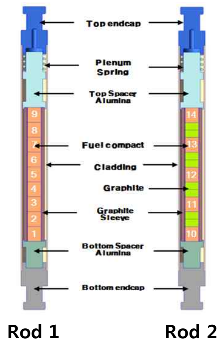

Fig. 1. Schematic configurations of test rods with identification of fuel compacts

Table 1. Descriptions of test rods

Components	Rod 1	Rod 2
Cladding	STS 316L(outer)/Graphite(inner)	
End cap	STS 316L	
Fuel	9 compacts	5 compacts
Graphite Specimen	N/A	VHTR structural graphite
		Matrix graphite,
Spacer	Al_2O_3(top and bottom)	
Spring	STS304	
Gap gas	He 30% + Ne 70%	He 10% + Ne 90%

Table 2. Service history of TRISO fuels at HANARO

Cycle No.	Irradiation period	EFPD
89-1	8. 5. ~ 8. 19, 2013	12.18
89-2	10. 14. ~ 10. 28. 2013	12.88
90	11. 4. ~ 12. 2. 2013	24.72
91	12. 16, 2013 ~ 1. 13, 2014	27.37
92	1. 27. ~ 2. 24, 2014	27.51
93	3. 3. ~ 3. 31, 2014	27.54
Total		132.2

The thermal power and the burn-up of TRISO fuels were evaluated by using WIMS/VENTURE code[3]. Figure 2 presents thermal power of the rod 1 and 2 as a function of effective full power day. The thermal power of the rod 2 is lower than the rod 1 as the rod 2 contains fewer fuels than the rod 1. The thermal power at the start of the first cycle was relatively low because of the lower power operation of the reactor at the beginning of the cycle. Figure 3 shows average fuel burn-ups of the rod 1 and 2 as a function of effective full power day. The average fuel burn-ups of the rod 1 and 2 at the end of the 5th cycle were 36,932 and 35,428 MWD/MTU, respectively.

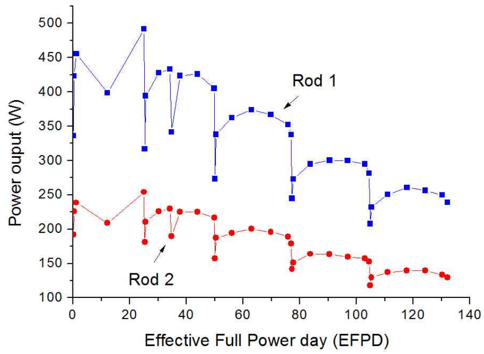

Fig. 2. Thermal power of the rod 1 and 2 vs. EFPD

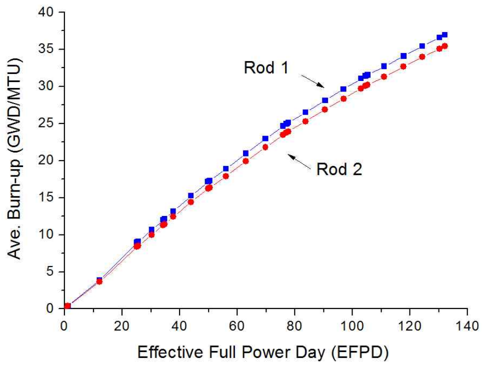

Fig. 3. Ave. fuel burn-up of the rod 1 and 2 vs. EFPD

2.2 Thermal analysis of TRISO fuels

The FE(finite element) model[4] developed for the safety analysis of the TRISO fuel irradiation at HANARO was utilized in this analysis. Figure 4 presents the change of the peak temperatures in the rod 1 and 2 as a function of EFPD. 38 times of calculations were carried out to obtain the temperature distributions of fuel compacts in the rod 1 and 2 at 19 EFPD points. At all EFPD points, compacts #5 and #12 showed maximum temperatures in the rod 1 and 2, respectively. A maximum peak temperature of 1,083^{0}C was obtained in the rod 1 at 25.06 EFPD and the peak temperatures decreased as the cycle progresses. The peak temperature at the end of the 5th cycle was 663 ^{0}C.

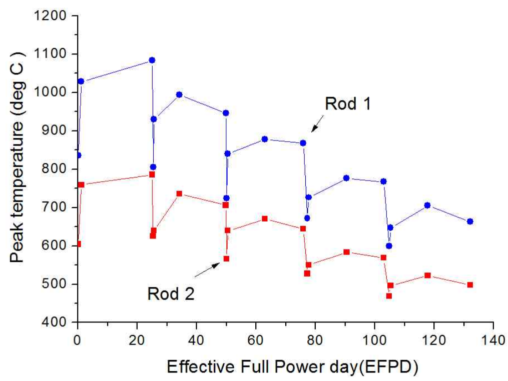

Fig. 4. Peak temperatures vs. EFPD in the rod 1 and 2

In the rod 2, a maximum peak temperature of 785^{0}C was obtained at 25.06 EFPD and the peak temperature at the end of the last cycle was 497 ^{0}C.

Figure 5 shows the temperatures of test specimens along the centerline of the rod 1 and 2 at their maximum powers, which are 491.6W and 254W for the rod 1 and 2, respectively. The highest temperatures of 1083 ^{0}C and 786 ^{0}C were obtained in the fuel #5 and #12 in the rod 1 and 2, respectively.

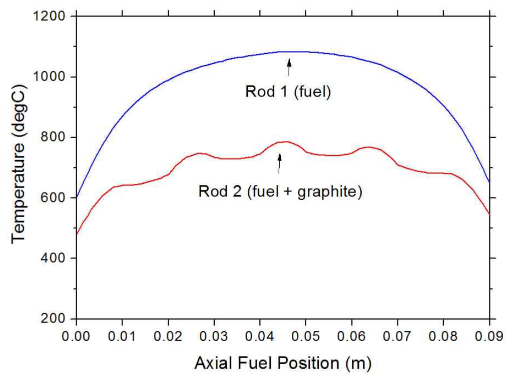

Fig. 5. Axial temperature profiles of the test specimens in steady state

Figure 6 shows the temperature profiles across the lateral cross sections of rod 1 and 2 in the middle of fuel or fuel/graphite strings at their maximum powers. These sections cut across the axial center of the fuel #5 and #12 in the rod 1 and 2. The temperatures change slightly in the fuel and the graphite sleeve and drop mostly in the gaps. The temperatures at the surfaces of the external claddings of the rod 1 and 2 are less than 42 ^{0}C.

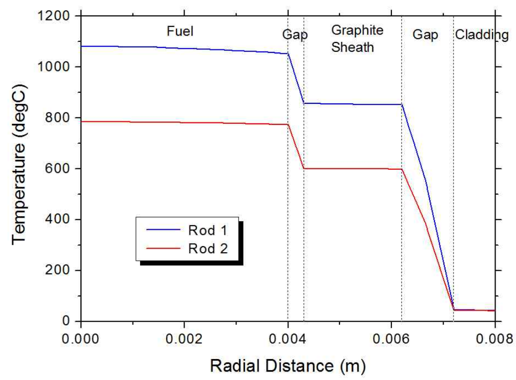

Fig. 6. Temperature profiles across the cross-sections of the test rods in steady state

3. Summary

Thermal performance of TRISO fuels was evaluated for its five cycle irradiation at HANARO which had been carried out in the absence of the fuel temperature monitoring. A maximum peak temperature of 1,083^{0}C was obtained in the rod 1 at 25.06 EFPD and the temperatures decreased as the cycle progresses. The peak temperature at the end of cycles was 663 ^{0}C. In the rod 2, a maximum peak temperature of 785 ^{0}C was obtained at 25.06 EFPD and the peak temperature at the end of the last cycle was 497 ^{0}C.

Acknowledgement

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