Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, October 21-22, 2010

Irradiation Test of Annular UO_2 Pellet in the HANARO

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1. Introduction

In-reactor behavior of the annular UO_2 fuel could be different from the conventional solid UO_2 fuel because it is expected to be operated at low temperature and the geometrical shape of the two kinds of fuel rods is not identical. Since the annular pellet temperature of the annular fuel rod is lower than the solid fuel by several hundred degrees[1], densification and swelling – although they are generally known as athermal phenomena – could be affected by low temperature. In contract with the solid fuel having only one gap, annular fuel has both inner and outer radial gaps which can accommodate the change in pellet volume. A number of cracks and crack pattern created in annular pellet could be different from those in the conventional solid pellet because temperature profile and hence thermal stress distribution in the two pellets would not be the same [2]. Therefore, in order to investigate the in-reactor behavior of the annular UO_2 pellet, the irradiation test was carried out in the HANARO and post irradiation test is being carried out in the KAERI's PIE facility.

2. Irradiation test of annular UO_2 pellet in the HANARO

A non-instrumented test rig was developed and used for the irradiation test of annular pellet in the OR-4 hole of the HANARO [3]. The test rig contained two test capsules at upper and lower region. Each test capsule was composed of 3 test fuel rods with a triangular lattice. The claddings of the fuel rods were made of SUS316L. Each fuel rod had 6 fuel pellets and annular pellets with different densities of 89.7, 92.4, 96.0, 98.0%TD were introduced to observe how the densification of the annular pellet varies as a function of its density. Figure 1 shows the arrangement of the test fuel rods in the test rig.

Neutronic calculation for the 6 test rods was performed using MCNP and HELLIOS codes. Figure 2 shows the axial power profile of the test fuel rods. The calculation of HELLIOS showed that the average burn-ups of the upper and the lower test rod were 12,500 MWD/MTU and 10,000 MWD/MTU, respectively, at a target irradiation time of 115 EFFD. The pellet temperature of the test rods was calculated by DUO-THERM [1] which was developed for the thermal analysis of the annular fuel rod. The inner and outer pellet surface temperature and the maximum pellet temperature for the lower rod 3 are presented in Fig.3. The maximum pellet temperature is about 980^{o}C at BOL.

3. Post irradiation examination of annular UO_2 pellet

3.1 Non-destructive test

Non-destructive test for the test fuel rods transported to the KAERI's PIE facility was carried out. Since one of the concerns regarding annular fuel pellet is whether geometrical shape of annular pellet would be maintained during irradiation, gamma scanning along the axial direction with an axial step of 2mm was performed to investigate if there was any axial movement of the annular pellets and if there was any change in pellet shape. Gamma activity at each step was measured for 60 seconds. Figure 4 represents the axial gamma scanning results for the upper rod 3 and the lower rod 1, respectively. Since pellet interfaces can be clearly identified by a small dip in the gamma counts, it can be concluded that the geometrical integrity of the annular pellet was maintained during the irradiation test.

3.2 Destructive test

The gamma scanning results were used to determine the cutting location of specimens for destructive test by OM and SEM. Figure 5 shows the macroscopic cross-section of the lower rod 1 and lower rod 3, both of which have a high initial pellet density of 98% TD. The linear powers for the two rods at BOL were about 80 and 105 kW/m, respectively. Two features are observed in the crack pattern for the annular pellets with high density. Some numbers of radial cracks passing through the entire thickness of the annular pellet were clearly developed: 7 radial cracks in the lower rod 1, and, although not so clearly developed as in the lower rod 1, 9 radial cracks in the lower rod 3. This would mean that one through-width crack was generated per 10~15 kW/m of linear power.

Furthermore, there are many radial cracks extending over about half a width of the annular pellet. Another interesting feature regarding crack pattern is that, especially in the lower rod 3, we can observe some circumferential cracks connected to each other at crack interfaces, covering more than half of the circumference. These two features have an important implication from a viewpoint of both the inner and outer gap sizes, and hence in terms of the heat split of the annular fuel rod.

At present, the optical microscopy (OM) observation was finished and the analysis of the OM results and the scanning election microscopy (SEM) observation are being carried out to analyze the pellet density, grain size, and dimensional change.

4. Summary

In order to investigate the in-reactor behavior of the annular UO_2 fuel rod, the irradiation test was carried out in the HANARO. The test rig and capsule were developed and the neutronic and thermal hydraulic analyses were performed. The annular UO_2 pellets were irradiated up to 12,500 MWD/MTU. The PIE was performed for the irradiated annular fuel rods at the KAERI's PIE facility. The gamma scanning showed that the geometrical shape of the annular pellets was maintained during the irradiation. The optical microscopy and the scanning election microscopy observation are being carried out.

REFERENCES

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[2] Y.S. Yang, D.H. Kim, S.K. Kim, J.G. Bang, and G.W. Song, "Thermal Behavior of Annular Fuel Pellet under Generalized Plane Strain Condition," Transactions of the Korean Nuclear Society Autumn Meeting, Pyeong Chang, Korea, Oct. 25-26, 2007.

[3] Y.S. Yang, D.H. Kim, J.G. Bang, H.K. Kim, K.S. Kim, and G.W. Song, "Irradiation Test of Dual-Cooled Annular Fuel Pellets," Proceedings of TOP Fuel 2009, Paris, France, Sep. 6-10, 2009.

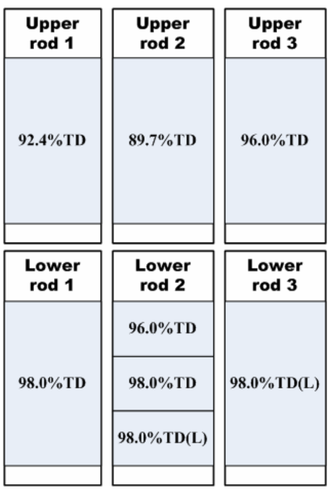

Fig. 1. Arrangement of test fuel rods.

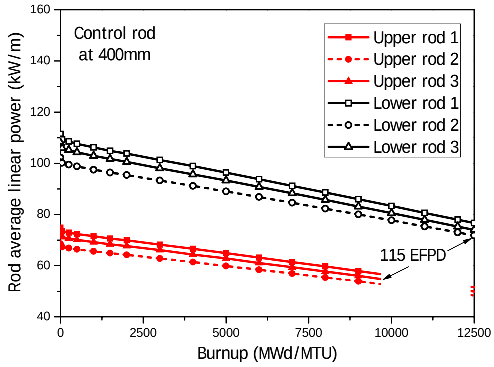

Fig. 2. Calculated power history of the test fuel rods.

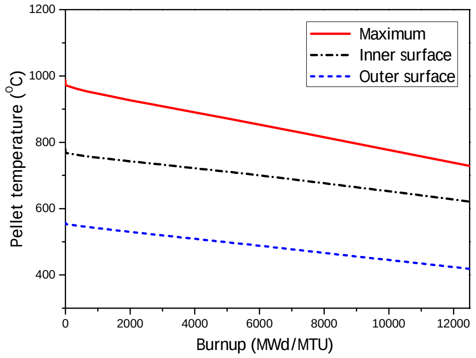

Fig. 3. Temperature of pellet during irradiation.

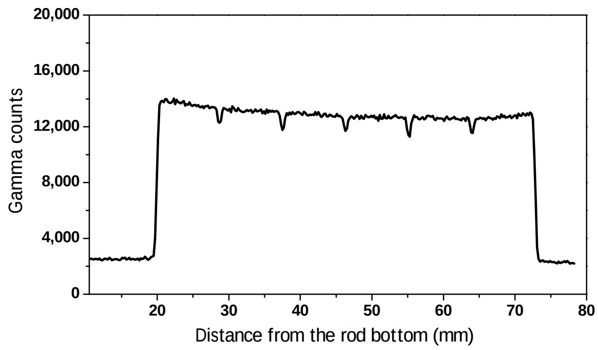

Fig. 4. Axial gamma scanning result for the upper rod 3.

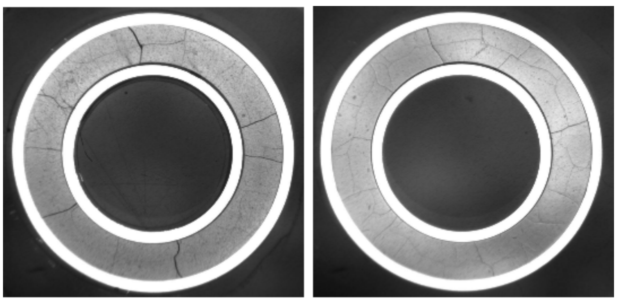

Fig. 5. Macroscopic cross-section for the annular pellets with 98%TD.