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Irradiation Test of U-Zr SFR Fuels in Hanaro

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1. Introduction

Metallic fuel technologies for a SFR are under development in KAERI [1]. The validation of the U-Zr fuel technologies plans to begin in 2010 by performing a fuel irradiation test.

The irradiation tests will be carried out in a fast neutron spectrum facility in the long run. In the sense of cost and time, however, it seems to be most reasonable to employ the Hanaro research reactor for the irradiation tests, since fuel in-pile behavior depends mainly on temperature as well as burnup. It is not difficult to find similar approaches to use thermal research reactors for fast reactor fuel tests [2-4].

The Hanaro tests consist of two stages; the 1st test with maximum burnup of 3 at%, and the 2nd test with maximum burnup of 6 at%. The former is expected to identify the Ce-bearing fuel performance, and the characteristics of Cr and Zr as barriers to eliminate the eutectic melting of fuel with cladding.

In this work, we have designed an irradiation capsule for U-Zr in Hanaro. Irradiation conditions for the fuel test were drawn, and the irradiation capsule was designed. Also a preliminary fuel performance was analyzed.

2. Capsule Design

U-Zr fuel irradiation under steady state condition is scheduled to be done in one of Hanaro's OR holes. The irradiation conditions are summarized as follows;

- Linear power: 306 W/cm
- Burnup at EOL: ~ 3 at%
- Expected duration: ~150 EFPD.

A schematic diagram of the capsule is shown in Figure 1. There are two test sections; each section accommodates six rodlets. The fuel rods in the lower section are expected to experience linear power 35% higher than in the upper section. The chemical composition of the fuel rods is U-10Zr, and U-10Zr-6Ce, of which U-235 enrichment is 19.75%. The fuel slug has dimensions with a diameter of ~4 mm and a height of 60 mm. A ferritic-martensitic stainless steel is used for the fuel cladding. Fuel slug and cladding is sodium-bonded. The fuel rod is contained in the sealing tube for safety in case of the sodium leakage from the cladding. In addition, the temperature on the outer cladding surface is raised higher than 500 °C by introducing the He gap between the cladding and the sealing tube. Linear power of the fuel rod is acquired by surrounding the capsule blocks by a thermal neutron absorber like Hf and borated aluminum plate.

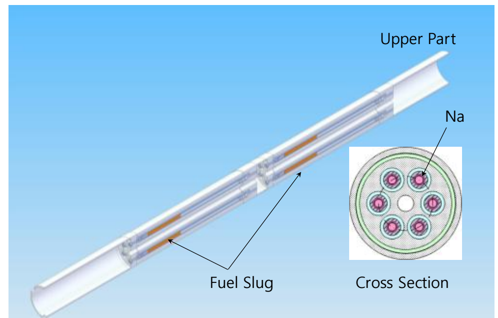


Figure 1. Three-dimensional model for the U-Zr irradiation capsule.

3. Performance Analysis of Fuel Rod

Design criteria for the SFR fuel rod [5] are tentatively given as follows;

- The centerline temperature of the fuel is less than its melting temperature.
- The temperature at the inner surface of the cladding is less than the eutectic melting temperature of the fuel.
- The cladding hoop strain is limited by 3%.
- The cumulative damage fraction (CDF) of the cladding is limited by 0.001.

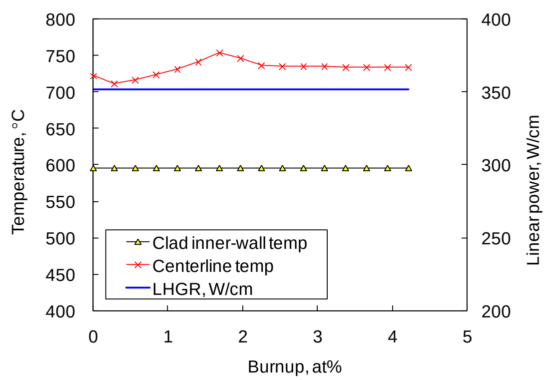
Thermal conductivities of the fuel and the cladding are one of the most important factors in determining the distribution of the temperature in the fuel rod. The thermal conductivity for U-10Zr was reported by Billone [6]. The effect of Ce on the fuel thermal conductivity was estimated to be less than 5% [7]. It is assumed that the fission gas release for the Ce-bearing fuel follows the same behavior as in the U-10Zr.

Fuel performance analysis for the 1st Hanaro test was performed by using MACSIS code [1]. The temperature at the outer cladding surface is assumed to be 550 °C which is calculated by considering a heat transfer through the gap between the cladding and the sealing tube. The linear power of the fuel rod is taken conservatively in the analysis.

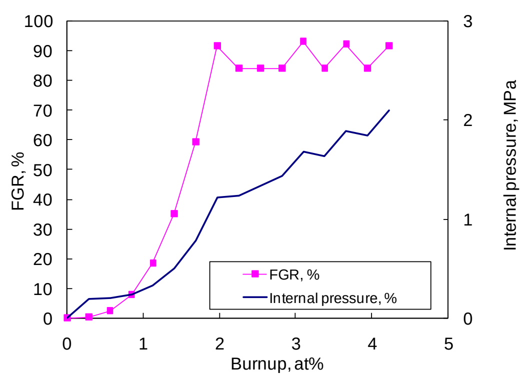
Figure 2 (a) is the variation of the fuel rod with the fuel burnup. The centerline temperature of the fuel is less than 750 °C. It increases due to the fuel thermal conductivity degraded by the porosities formed by the fission gas, then falls slightly by the infiltration of sodium into the fuel slug, and saturates at 730 °C after the thermal conductivity is recovered. The temperature at the inner cladding surface is not higher than 600 °C.

Figure 2 (b) shows the behavior of fission gas release along with the burnup. It is estimated that the fission gas is released up to 90% around burnup of 1~2 at%. The internal pressure of the cladding also exhibits a relatively enhanced increase at the early stage, and it increases steadily up to 2.2 MPa at the end of the irradiation. The resultant hoop stress of the cladding is estimated to be 13 MPa which is far less than the yield strength. The cladding hoop strain and the CDF are negligible compared with the design criteria.

Therefore it is concluded that the integrity of the fuel rods is guaranteed during the 1st U-Zr Hanaro irradiation test.



(a)



(b)

Figure 2. Fuel rod behavior during the 1st U-Zr Hanaro irradiation test; (a) temperature, (b) fission gas release.

4. Summary

The validation of the U-Zr fuel technologies is to begin in 2010 by performing a fuel irradiation test with Hanaro. The 1st Hanaro irradiation test with a maximum burnup of 3 at% is expected to identify the Ce-bearing fuel performance, and the characteristics of Cr and Zr as barriers for the fuel eutectic melting. An irradiation capsule was designed. A preliminary analysis for the fuel performance shows that the integrity of the fuel rods is guaranteed during the 1st U-Zr Hanaro irradiation test.

Acknowledgements

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