Re-irradiation of a high Burnup UO_2 specimen at HANARO

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1. Introduction

To support the PIA(Post irradiation Annealing) test, which has been performed in the PIEF hot cell, a re-irradiation test of a high burnup UO_2 specimen was undertaken at the research reactor HANARO. Small size specimen was inserted into the newly developed irradiation capsule and transferred to HANARO. After a short irradiation (~1 or 2 days), the capsule was returned to the PIEF hot cell and cut for the PIA test. For the high burnup UO_2 re-irradiation, a new irradiation capsule was developed. To guarantee the test safety, thermal safety analyses were performed

2. Post-Irradiation Annealing Test

To investigate the fission gas behavior in a high burnup fuel, a post-irradiation annealing test has been performed [1]. The escaped rare radioactive gases (Kr-85 and Xe-133) from the furnace pass through a beta chamber where the gas release is measured. After the beta counting, gases pass into the cold trap, in front of a HPGe(High Purity Ge) gamma detector. A very sensitive HPGe is used to obtain a cumulative value of the release gases.

In the PIA test, it is important to distinguish the fission gas inventories (grain matrix or grain boundary). Due to its short half-life, Xe-133 almost never remained in both inventories but a short and low-temperature irradiation can create Xe-133 in grain matrix only. So, an Xe-133 detection can be assumed as a starting point of an intra-granular gas release.

3. Specimen preparation and characteristics

For the sample preparation, the highest burnup commercial fuel rod segment is used which was irradiated in Ulchin Unit 2 for three cycles [2]. The segment maximum burnup was around 65MWd/kgU. By using the ORIGEN-S code [3], a remaining fission product analysis was performed. Figure 1 shows the power history for the ORIGEN-S calculation.

According to the radial positions, the high burnup fuel shows different structures and characteristics (rim effect). So, the specimen preparation was handled carefully for the exact fission gas release analysis. Figure 2 shows the specimen shape to distinguish the center, intermediate and rim region. Each sample was about 150mg .

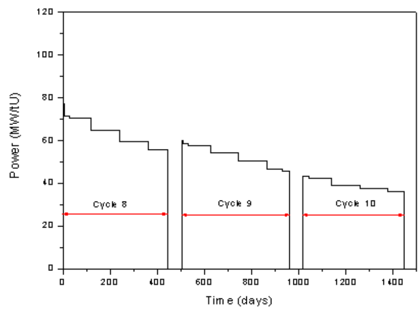

Figure 1. Power history for the ORIGEN-S calculation

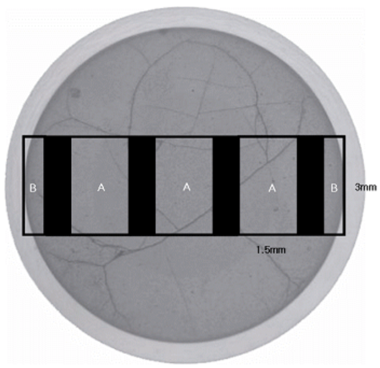

Figure 2. Re-irradiation specimen cutting plan

4. Re-irradiation capsule

The newly developed re-irradiation capsule consists of an inner and outer capsule. Inner capsule was manufactured from SUS 304 and SUS 314L tube. After the specimen insertion, a mechanical sealing using the SWAGELOK is adapted due to a welding difficulty in a hot cell environment (fig 3a). Outer capsule, which was slightly modified from the radioactive isotope production capsule, was used to instrument the inner capsule to the irradiation test rig. Around the outer capsule, through the 10mm diameter hole, coolant can flow and contact with inner capsule and remove the heat which is generated during a irradiation (fig 3b).

5. Safety analysis

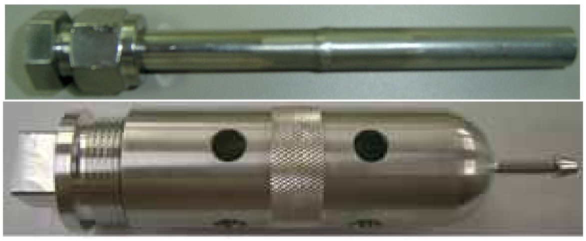

Figure 3. (a) inner capsule, (b) outer capsule

As mentioned in chapter 2, a short and low-temperature irradiation condition is required to meet the experimental purpose. So, instead of the core center region, the HANARO reflector region was determined as the re-irradiation capsule insertion position. Using the HANARO MCNP model and neutronic code HELLIOS, the thermal neutron flux (1.16×10^{14} n/cm^2-sec) and the fission density (2.32×10^{13} fissions/sec/cc) were calculated. Xe-133 production was estimated by the ORIGEN-S code to determine the optimum irradiation time and cooling time. A one day irradiation and one day cooling condition were set as an optimum experimental condition (fig 4).

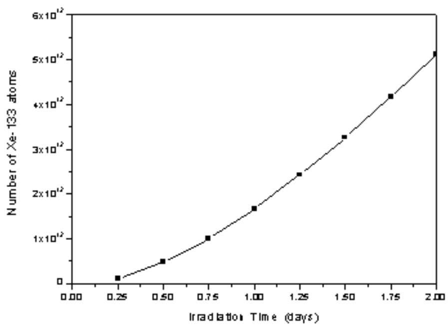

Figure 4. Xe-133 concentration with the irradiation time

The HANARO reflector region is cooled by a natural circulation water of at a atmospheric pressure. So, the irradiation capsule outer surface temperature must be kept lower than the coolant boiling point. For the safety analysis, the maximum temperature of the inner capsule's outer surface (contact point with coolant) was calculated. Heat generation rate was derived from the fission density and all the dimensions were set as a designed value. If there is no available data, a conservative assumption was used to guarantee the safety margin.

By using the commercial thermal hydraulic code, CFD-ACE [4], the temperature distribution was calculated under a natural convection water condition. For the maximum temperature calculation, it was assumed that the specimen contacted with the capsule inner surface. Fig 4 shows that the maximum capsule outer surface temperature isn't exceed 77℃.

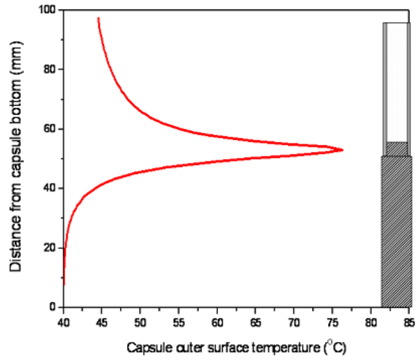

Figure 4. Outer capsule maximum temperature

4. Conclusion

For the re-irradiation test of a high burnup UO_2 fuel specimen in HANARO, a new test capsule was designed and manufactured. By using the detailed HANARO operational conditions and specimens' characteristics, the optimum irradiation and cooling time was decided and the safety analysis results show that the conservative maximum capsule conditions' can't exceed the HANARO temperature limit.

6 References

[1] D. H. Kim et al., "Development of Post-Irradiation Annealing Apparatus", Proc. KNS, May, 2004

[2] C.B. Lee et al., "Post-Irradiation Examination of high Burnup UO2 fuel", Int. Mtg. on LWR Fuel Performance, ANS, September, 2004

[3] Hermann, etc., "ORIGEN-S: SCALE system module to calculate fuel depletion, actinide transmutation, fission product buildup and decay, and associated radiation source term", NUREG/CR-0200, Rev 6.

[4] CFD-ACE, Version 2003, CFD Research Corporation, Huntsville, Alabama.