Burnup Calculation Based on Non-Destructive Test in Hot-Cell

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1. Introduction

The burnup is important factor for nuclear fuel as aspects of the safety and long lasting operation. All behaviors of fuel in reactor change with burnup. So, exact burnup must be confirmed with accuracy to study the fuel performance. Gamma scanning test has been performed as non-destructive test[1]. In this test, long lived isotopes such as Cs-137($T_{1/2}$ = 30 years) which are fission product are good burnup monitor. Without dependence of geometry, atomic ratio of the isotopes have been used[2]. Especially, atomic ratio of Cs-134 to Cs-137 is good linear behavior with burnup. In this days, ORIGEN-2 code is available to calculate the atomic ratio for burnup calculation[3].

In this study, gamma scanning test for irradiated UO_2 fuel was performed to obtain gamma peaks of Cs-134 and Cs-137 and ORIGEN-2 code were used to compare the atomic ratio. Three fuel rods contained in the capsule(02F-11K) were irradiated and several pellets were detected by gamma detector.

2. Experimental

The capsule, 02F-11K, with 3 fuel rods was irradiated in HANARO research reactor for 54 days and moved to Hot-Cell.

After being cooled down, it was dismantled to withdraw the fuel rods. Gamma scanning test for all rods were performed with geometry as shown in Fig. 1. To measure temperature, center of 3 pellets were drilled for thermocouple. The slit dimension of collimator is 40 mm(W) x 2 mm(H) x 250 mm(D) and made by tungsten. The detecting distance was 160 cm due to 100 cm of wall thickness. Three pellets at top, middle and bottom positions were selected for detection as points in figure.

After set up the detecting points, gamma scanning tests at each point in all rods were performed three times repeatedly to reduce the gamma peak errors of cesium isotopes. Detecting time was set up by 3 hours. To consider the energy efficiency of detector, Cs-134 with 7 gamma energies is available alternatively. But in this study, 5 energies of it were too small to be applied due to low branch ratios.

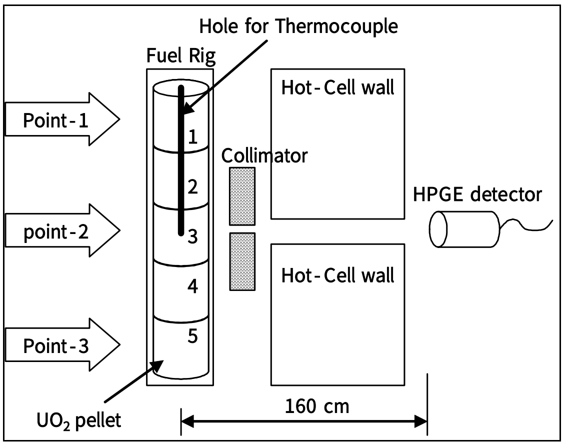

Figure. 1 Geometry of gamma scanning test.

3. Results and Discussion

To calculate the atomic ratio of Cs-134 to Cs-137, the basic equation is as follows[4];

$$C(E_i) = \lambda N P(E_i)\varepsilon(E_i) \qquad (1)$$

Where, C is gamma counts at each energy, λ is decay constant, N is atomic amount, P is decay branch ratio. ε is energy efficiency of detector. So, λN is radioactivity in this paper.

Eq.(1) is applied to atomic ratio of Cs-134 to Cs-137 and simplified.

$$\frac{C_{134}/(\lambda_{134}P_{134})}{C_{137}/(\lambda_{137}P_{137})} = \frac{N_{134}\varepsilon(E_{134})}{N_{137}\varepsilon(662keV)} \qquad (2)$$

From Eq.(2), the numerator in right term can be changed to N_{134} ε(662keV) by means of the energy interpolation of plot of $N_{134}\varepsilon(E_{134})$ at gamma energies. But two energy peaks of Cs-134 at 605 keV and 796 keV were available due to low peaks of others, so value of $N_{134}\varepsilon$ at 662 keV was obtained. Finally, Eq.(3) is shown as follows;

$$\frac{N_{134}\varepsilon(662keV)}{N_{137}\varepsilon(662keV)} = \frac{N_{134}}{N_{137}} = R_{exp} \qquad (3)$$

Where, R_{exp} is experimental ratio from gamma scanning test.

To compare with R_{exp}, ORIGEN-2 code was used. The ratio follows linear behavior and exact burnup of fuel can be obtained. Table 2 shows experimental ratio and burnup at each pellet in rods. 3.2 ~ 3.4 GWd/MTU of burnup are predicted except rod #3 which is assumed that it was placed near control rod in reactor under irradiation.

Table 1 Atomic ratios of Cs-134 to Cs-137 and burnup at each rod

Position		Point-1	Point-2	Point-3
Rod #1	R_{exp}	0.0055	0.0051	0.0051
	GWd/MTU	3.47	3.23	3.23
Rod #2	R_{exp}	0.0055	0.0051	0.0051
	GWd/MTU	3.27	3.23	3.23
Rod #3	R_{exp}	0.0044	0.0042	0.0042
	GWd/MTU	2.81	2.7	2.7

Before the capsule was irradiated, the reactor core calculation code(HANAFMS) was used to estimate linear power and burnup for the safe irradiation condition[5]. This code is the application program with the WIMS/VENTURE and MCNP for all irradiation holes in HANARO reactor. The value of burnup from the reactor core calculation code was 5 GWd/MTU, which is higher than the values in this study.

Difference of burnups would be improper library of ORIGEN-2 code under assumption that data of reactor core calculation code was correct. Neutron cross section data in the code we used in this study was natural fueled CANDU library. That probably makes an error due to absence of library of HANARO reactor. Then, selection of libraries in the code is very important. It would be related to neutron spectrum at the region of the loaded fuel under irradiation. As shown in Fig.2, it shows neutron flux with energy in three types of reactors. It is assumed that the neutron spectrum of HANARO research reactor is softer than that of CANDU and PWR reactors based on the libraries in the ORIGEN-2 code.

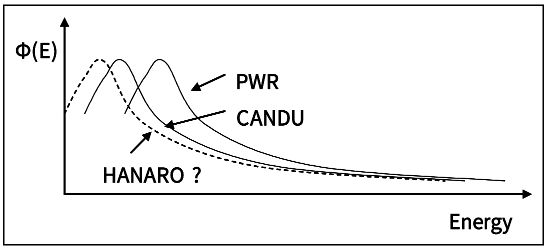

Figure. 2 The behaviors of neutron spectrum at each reactor type.

But it is hardly to say that which one is correct burnup between two methods without chemical analysis. We need more verification and have to compare the results among code calculation, gamma scanning and chemical analysis.

4. Conclusion

Fuel capsule(02F-11K) contained 3 UO_2 fuel rods was irradiated in HANARO research reactor for 54 days. Gamma scanning test was performed to obtain Cs-134 and Cs-137 peaks for burnup calculation. The atomic ratio of Cs-134 to Cs-137 from the test was compared that from ORIGEN-2 code calculation. 3.2~3.4 GWd/MTU of burnup was obtained and the other result had lower burnup due to the effect of control rod in reactor.

References

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