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Burnup Estimation with measurements of the Energy Efficiencies from Gamma Scanning

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1. Introduction

Nondestructive tests have been performed on spent nuclear fuel to verify the burnup and cooling time for safeguard purposes. In the gamma scanning test, Cs-137 is used as a monitor nuclide for the burnup[1]. The additional fission products studied are Cs-134 and Eu-154, these isotopes dominate the gamma-ray spectrum of a spent fuel with a cooling time of 10-20 years[2].

Without a geometry correction, the activity ratios of the nuclides, which are fission products, have been introduced. Haddad calculated the cooling time of the fuel with the activity ratio of Nb-95/Zr-95[3]. Iqbal and et al. performed a gamma scanning to obtain the activity ratios of Zr-95/Cs-137 and Cs-134/Cs-137[4].

Energy efficiency of detector must be confirmed on the way of peak analysis. There are two methods to obtain an energy efficiency; one is measurement with reference sources before gamma scanning for fuel sample, the other is measurement with several gamma peaks from a radioisotope in fuel sample without reference sources. So, we tried to compare the two methods in this study.

For a burnup calculation, the ORIGEN-ARP code is available to calculate the atomic ratio instead of the activity ratio as a burnup calculation[5,6].

2. Methods and Results

PWR spent fuel from a nuclear power plant and two irradiated fuel capsules were prepared for a burnup estimation. The former declared burnup was used as a preliminary test. The latter was for a burnup estimation. Two fuel capsules(02F-11K, 03F-05K) containing three fuel rigs each were irradiated in the HANARO research reactor. Then a gamma scanning was carried out.

PWR spent fuel rod with 40,000 MWd/t-U and a cooling time of 17 years was cut into several parts and 10 pellets were taken out and contained in a small CANDU fuel tube. This rod containing 10 pellets was moved to the gamma spectrometry system to carry out a gamma scanning test.

On the other hand, three fuel rigs of each capsule were made for an irradiation and temperature test[7]. Each rig had 5 UO_2 pellets. 02F-11K was irradiated at the OR5 hole in the HANARO research reactor in March, 2003 and 03F-05K in April, 2004. These capsules had a different linear power history for 54 days and 60 days, then cooled down for 20 months and 12 months, respectively. Detection points were determined at 3 points for the rigs and at 1 point for the PWR fuel, respectively. After setting up the detecting points, the gamma scannings were performed for 3 hours at a each point. They were carried out three times at each point to reduce the counting errors of the cesium isotopes.

2.1 Measurement the energy efficiency without reference sources

To calculate the atomic ratio of Cs-134/Cs-137, the basic equation is as follows;

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

Where, C is the gamma counts(cps) at each energy, λ is the decay constant(s^{-1}), N is the atomic amount, P is the decay branch ratio, and ε is the total detector efficiency Here, N. is the radioactivity. Most papers have shown the activity ratio(A_{134}/A_{137}), but we show the function of (N_{134}/N_{137}) via the function of Nε with a different viewpoint as shown in eq.(2).

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

From Eq.(2), the numerator in the left term can be changed to $N_{134}\varepsilon$(662keV) by means of an interpolation of the plot of $N_{134}\varepsilon$ (E_{134}) at 662 keV. So, only ratio (N_{134}/N_{137}) remains.

2.2 Measurement the energy efficiency with reference sources

We carried out a gamma scanning with reference sources, and an energy efficiency(ε) was obtained. So, Eq(1) is simplified. Fig.1 shows each peak point in reference sources and fitting curve. Relative efficiencies of Cs-134 and Cs-137 were obtained by curved line. The results of atomic ratios(N_{134}(604 keV)/ N_{137}(662 keV)) were lower those of ratios(N_{134}(795 keV)/ N_{137}(662 keV)). This difference would come from the peak analysis.

ORIGEN-ARP code was used to calculate the burnups which are related to the atomic ratios obtained from experiments. Fig.2 shows the atomic ratio with the burnup for each capsule following the code calculation.

By a measurement of the energy efficiency without reference sources, the atomic ratio for the PWR spent fuel rod was $5.84x10^{-4}$ and the related burnup from ORIGEN-ARP was 39,500 MWd/t-U. It had a good agreement with the declared burnup of 40,000 MWd/t-U. In this case, the code library was correctly applied to the PWR spent fuel. Table.1 shows the atomic ratios and burnups for each capsule.

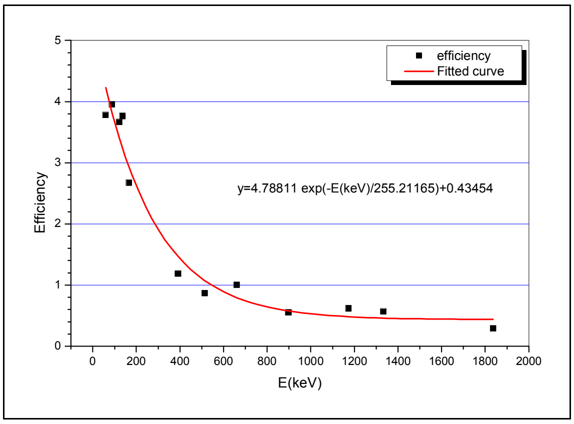

Figure 1. The plot of energy efficiency with reference sources.

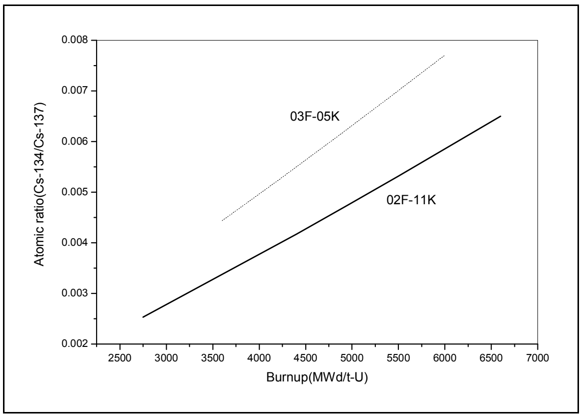

Figure 2. The plot of the atomic ratio with the burnup by ORIGEN-ARP.

Table 1. The atomic ratios of Cs-134/Cs-137 and burnups at each rig

Position			Point-1	Point-2	Point-3
02F-11K	Rod #1	R_{exp}	0.0055	0.0051	0.0050
		Bu	5.66	5.3	5.25
	Rod #2	R_{exp}	0.0055	0.0051	0.0050
		Bu	5.66	5.3	5.25
	Rod #3	R_{exp}	0.0044	0.0042	0.0042
		Bu	4.62	4.4	4.4
03F-05K	Rod #1	R_{exp}	0.0060	0.0053	0.0050
		Bu	4.7	4.2	4.0
	Rod #2	R_{exp}	0.0073	0.0065	0.0060
		Bu	5.75	5.15	4.79
	Rod #3	R_{exp}	0.0071	0.0061	0.0059
		Bu	5.58	4.9	4.7

All of the rigs show that the burnup decreased vertically from the top to the bottom due to the neutron flux shape. Particularly, one of three rigs in each capsule had a lower burnup. But Data from the measurement with reference sources were lower values than Data from the measurement without reference sources.

3. Conclusion

Fuel capsules(02F-11K, 03F-05K) containing three 3 UO_2 fuel rigs were irradiated with a different linear power history in the HANARO research reactor for 54 days and 60 days, respectively. Gamma scannings were performed to obtain the Cs-134 and Cs-137 peaks for the atomic ratio of Cs-134/CS-137. The energy efficiencies were obtained by two methods; measurement of reference sources and Cs-134 in a fuel sample. But the results showed a difference due to a peak analysis. Burnup was obtained by the ORIGEN-ARP code with the given atomic ratio from the gamma scanning. With an energy efficiency from Cs-134, a preliminary test for the PWR spent fuel declared burnup was carried out to compare it with the data of ORIGEN-ARP before a capsule test. It had a good agreement by following the PWR library. In the capsules, the burnups were 5.1 GWd/MTU for the 02F-11K and 4.8 GWd/MTU for the 03F-05K as a mean value. But these results were higher than those from the efficiency calculation with reference sources. The peak analysis was needed to solve the efficiency difference.

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