Methodologies to determine the Pu content of spent fuel assemblies for input nuclear material accountancy of pyroprocessing

Tae-Hoon Lee, Tae-Je Kwon*, Hee-Sung Shin, Young-Soo Kim, and Ho-Dong Kim
Korea Atomic Energy Research Institute, 1045 Daeduk-daero, Yuseong, Daejeon 305-353, South Korea
*KEPCO Nuclear Fuel, 1047 Daeduk-daero, Yuseong, Daejeon, 305-353, South Korea
typhoon@kaeri.re.kr

1. Introduction

A member state support program (MSSP) for the development of the IAEA safeguards approach for an engineering-scale pyroprocessing facility, which is designated as the Reference Engineering-scale Pyroprocessing Facility (REPF), has been carried out by Korea Atomic Energy Research Institute (KAERI) since 2008 [1]. The nuclear material accountancy of the REPF is based on the "Cm balance" technique. The Pu content of processing materials of pyroprocessing can be determined by measuring the Cm mass of the materials and multiplying it by the Cm ratio. The spent fuel assembly is de-cladded, and the irradiated UO2 material of the assembly is homogeneously mixed in the homogenization process in order to obtain a representative sample of the spent fuel assembly for determining the mass of Pu, U and Cm elements, as well as the Cm ratio of the campaign. The shipper-receiver difference (SRD) between the nuclear power plant and HPC of REPF is determined at this point. We found that the error for the Pu mass and Cm ratio determined from the homogenized uranium oxide powder is the most critical for the determination of the material unaccounted for (MUF) throughout the whole processes. This paper presents two approaches to determine the Pu mass of spent fuel assemblies using non-destructive assay and burnup simulation code.

2. Methods

2.1 True amounts of elements of a spent fuel assembly

The true amounts of all the isotopes and gamma/neutron emission from a spent fuel assembly are the total amounts of each isotope in all the fuel rods, fully reflecting the axially-varying burnup along the fuel rods, and the resulting axial variability of the amount of each element.

2.2 Average burnup method

The average burnup method calculates all of the isotopes at the average burnup of a spent fuel assembly, rather than calculating the "true" average isotopes with the same average burnup. This section summarizes the plutonium mass "errors" for all 225 cases of average burnup, initial enrichment, and cooling time, and illustrates the individual isotopic comparisons and resulting plutonium mass errors for one reference case. Fig. 1 shows the errors in the Pu mass determined by the average burnup simulation for many different cases of spent fuel assemblies. The error in the Pu mass ranges from 0.94% to 2.33% for a total of 225 different spent fuel assemblies of various BU, IE, and CT.

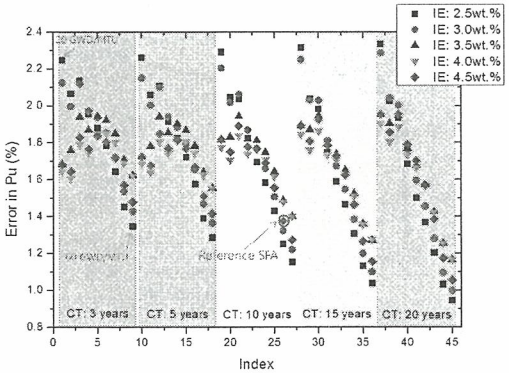

Fig. 1. Errors in the Pu mass determined by the average burnup simulation for many different cases of spent fuel assemblies.

2.3 Neutron emission vs. Pu method

The measured rate of neutron emissions (principally from ^{244}Cm) per initial MtU can be

used to calculate the plutonium mass in grams per initial MtU [2]. The basic relationship between neutron emission rate and plutonium mass is given by

$$M_{Pu} = \alpha N^{\beta} \quad (1)$$

where M_{Pu} is the Pu mass of the spent fuel assembly, and N is the total neutron emission rate of the assembly. The coefficients, α and β, are obtained by fitting the curve shown in Fig. 2. We can see that the curve, which was fitted with one fixed β coefficient for all 225 cases, does not fit well for many cases such as 3.5-wt.% and 4.0-wt.% IE. Anyway, if the coefficient β is fixed to a single value for all cases, which is 0.1018, the coefficient α is a function of IE and CT as given by

$$\alpha = \alpha + (\alpha_1 + \alpha_2 CT) IE \quad (2)$$

where α_0, α_1, and α_2 are coefficients obtained from the curve fitting with the fixed β. The values of these coefficients are 1143.83, -11.73, and -0.059, respectively. Fig. 3 shows the error in the Pu mass between the true values and calculated values obtained by using the fitting equation for all 225 spent fuel cases of different BU, IE, and CT. Their error in the Pu mass ranges from -4.67% to 7.99% for all cases.

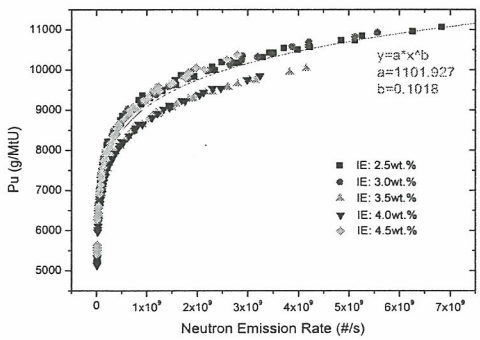

Fig. 2. Pu mass vs. neutron emission curve for 225 cases of different BU, IE, and CT of spent fuel assemblies.

3. Conclusions

This study shows two different non-destructive approaches to determine the Pu mass of spent fuel assemblies, and the analysis results on the errors in their Pu mass. For both methods, the Cm mass of the assembly is obtained based on the neutron measurement results. The Cm ratio of the assembly is determined from the Cm mass and the Pu mass obtained by using either of the two methods. In a comparison of two methods, the second method is simpler than the first and may not need a homogeneously-mixed sample of the spent fuel assembly. On the other hand, the second approach shows larger error in the estimated Pu mass than the first one for many different spent fuel cases of various burnup, initial enrichment, and cooling times.

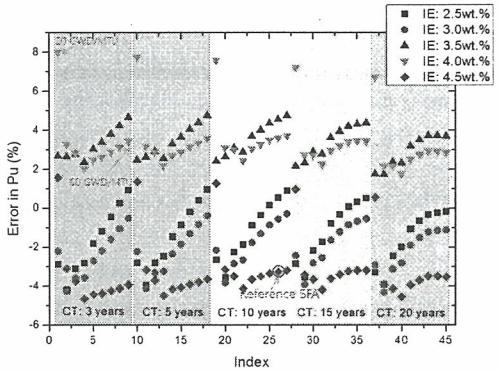

Fig. 3. Error in Pu between true and calculated values from the fitting equation for all 225 spent fuel cases of different BU, IE, and CT.

4. Acknowledgements

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5. References

[1] The IAEA Member State Support Program by ROK, "Support for Development of a Safeguards Approach for a Pyroprocessing Plant," Task No. C 176.

[2] Alain Lebrun, Gilles Bignan, Herve Recroix, and Bernard Mitterrand, "On-line spent fuels plutonium evaluation for safeguards at the head-end of a large scale reprocessing plant using nondestructive assay," Annual Meeting of INMM (1998).