The Activity Calculation Considering Operation History Compared with Measurement for Reactor Vessel Material of the Decommissioning Plant

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1. Introduction

Reliable evaluation of radioactivity inventory for the plant components and residual materials is very important for decontamination and decommissioning. This can make it possible to define optimum dismantling approaches and waste management strategies, and to estimate project costs accurately.

To calculate radioactivity of a structure, various information such as interest nuclide, cross-section, decay constant, irradiation time, neutron flux level and so on are required. Among them, irradiation time and neutron flux level are very changeable due to the plant overhaul, emergence reactor trip and fuel loading pattern. Therefore, considering these variables as realistically as possible could prevent overestimation and establish decommissioning plan reasonably.

In this paper, a method considering own operation history of the nuclear power plant would be introduced in order to calculate neutron induced activation. The method was applied to the activity calculation of reactor vessel (RV) which is the major structure for decommissioning. The result of calculation will be compared with measurement.

2. Methods and Results

In this section, a method considering operation history to get calculated activity is described. And the calculation (C), measurement (M) of activity and comparison of C/M are presented.

2.1 Neutron Activation Calculation Considering Operation History

The neutron activation phenomenon is well known and the activity of the product nuclide when product nuclide is produced at the constant rate of R (atoms/sec) due to the neutron irradiation can be written as,[1]

$$A = R(1 - e^{-\lambda t}) \qquad (1)$$

where A is activity (Bq) of the product nuclide and λ is decay constant (sec^{-1}) of the product nuclide. In Eq. (1) production rate R can be written as,

$$R = N_0 \int \sigma(E)\phi(E)\, dE \qquad (2)$$

where N_0 is the number of target nuclide irradiated by neutron flux $\phi(E)$, and $\sigma(E)$ is microscopic cross section for the interested activation reaction.

Eq. (2) can be written as a summation form by discretizing the integral term to use multi group cross-section and neutron spectrum. Also assuming that the irradiation time is period i, specific energy group is j and total energy group is n, the total activity right after i^{th} period becomes,

$$A_i = A_{i-1}e^{-\lambda t} + N_0 \sum_{j=1}^{n} \sigma_j \phi_j^i \,(1 - e^{-\lambda t}) \qquad (3)$$

By defining that period i is a month we can calculate the activity considering operation history as a month.

In addition, by multiplying the ratio monthly power to full power for each month to the second term of Eq. (3), we can consider non-full power period as well as zero power period affecting the decrease in radioactivity.

2.2 Radioactivity Calculation of Reactor Vessel Material

In order to calculate radioactivity, various parameters are required. RAPTOR-M3G[2] code was used for 3D transport calculation and BUGLE-96[3] library was applied to generate 47 group-wise cycle specific neutron spectrum for every fuel cycle. This make it possible to consider changeable flux level of each fuel cycle. Also plant specific monthly averaged core power level was reviewed as shown Fig. 1.

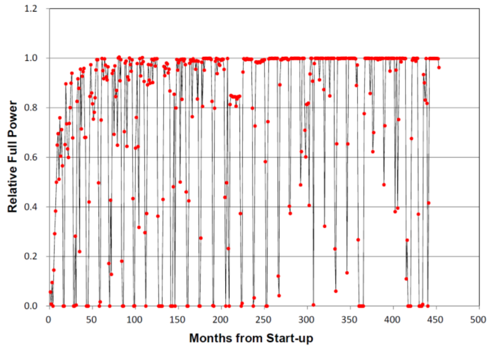

Fig. 1. Monthly averaged power level change

The object to be calculated is a specimen in 6th surveillance capsule. This 6th surveillance capsule was irradiated during 453 months from cycle 1 to cycle 30 and there is a history that the irradiation location had been changed.

The specimen was made of same material as the reactor vessel. Therefore, all other variables are same except for the location that has higher flux than reactor vessel. Reaction of interest, composition of target material, half-life of product and etc are reviewed. Table 1 shows the radiological characteristics of reaction of interest. In this paper, Fe-54(n,p)Mn-54 reaction was selected because iron is dominant atom in reactor vessel material.

Table 1: Radiological Characteristics of iron in RV

Target nuclide	**Reaction of Interest**	**Target Atomic Mass**	**Target Atom Fraction**
Iron	$^{54}Fe(n,p)^{54}Mn$	55.845 g/mol	0.0585
	Density	**Composition in RV ***	**Product Half-Life**
	7.86 g/cm^3	96.38 %	312.1 day

* The composition was taken from WCAP-8586 [4]

Fig. 2 shows the radioactivity calculation result. Note that the 6th surveillance capsule had been stored and decayed in the spent fuel pool without irradiation from cycle 22 to cycle 27.

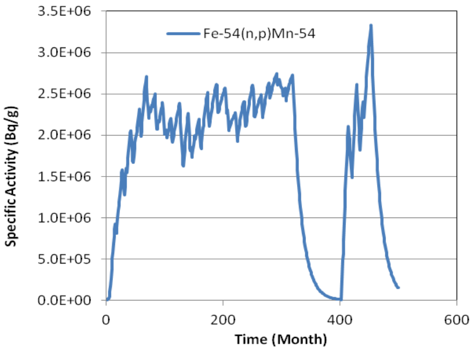

Fig. 2 ^{54}Mn activity trend in RV material in 6th capsule

As shown Fig. 2 the specific activities of the product nuclides are increasing during the irradiation period, and then decreasing during the overhaul(zero power) period. After irradiation, decay time was also reflected because the measurement was performed 3.8 years later. Finally, the ^{54}Mn specific activity of RV material from calculation is 1.52E+05 Bq/g.

2.3 Radioactivity Measurement and Comparison

There are many specimens in surveillance capsule to monitor reactor vessel integrity against irradiation embrittlement. In the view of activation process, these specimen material will be expected to show the similar tendency with the reactor vessel material since those are same material. Therefore, these measured activity data could be used to verify the calculated activity and the method considering operation history.

The selected specimens were cut into measurable shape and measured for ^{54}Mn activity with HPGe gamma spectrometer detector. Total 4 specimens were selected and measured.

Table 2 shows the comparisons between calculated and measured specific activity of ^{54}Mn. The % error is derived from (C-M)/M*100, where C and M denote calculated and measured specific activity respectively.

Table 2. Comparison between calculated and measured activity of ^{54}Mn in reactor vessel material

Material	**Reaction**	**Spec. Activity (Bq/g)**		**% error**
		C	**M**	
Reactor Vessel	$^{54}Fe(n,p)^{54}Mn$	1.52E+05	1.48E+05	2.70
			1.49E+05	2.01
			1.48E+05	2.70
			1.47E+05	3.40
			1.48E+07 (avg.)	2.70

In Table 2, the measured values obtained from four different specimens are very consistent. And It is found that there are very good agreement between calculation and measurement.

3. Conclusions

It is very important to evaluate the radioactivity distribution for decommissioning. The precise evaluation of the radioactivity distribution can make it possible to reduce the radioactive waste and to establish decommissioning plan properly.

We have described the method for radioactivity calculation considering operation history. The radioactivity calculation results presented in this paper clearly reflect the relations between increases by irradiation and decreases by decay according to operation history. The measured specific activities of ^{54}Mn for reactor vessel material are very consistent that means the measurement procedure was good. It is also found that there are very good agreement between calculation and measurement of ^{54}Mn specific activity.

Therefore, the method considering operation history could calculate radioactivity of some material accurately and lead to prevent overestimation of radioactive waste and dose rate in planning decommissioning. In the future, we will apply the method to various interest nuclides having different operation history.

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