A Study on Isotopic Scaling Factor Effect with Different Power Histories for Radioactive Waste Storage Drum

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1. Introduction

Scaling factor has been widely used to quantify difficultly measuring (DTM) radioactive isotopes by using the key (KEY) isotopes which are relatively easily measured such as Co-60, Cs-137, and Ce-144.[1][2] Still there are lots of uncertainties in scaling factors due to different packaging conditions and chemical waste treatments. Above all, assumed power irradiations of fission products result in significant uncertainties. A nuclear plant cycle-wise power irradiation is difficult because of lack of data, long computing time, and burden of treatment of huge number of isotopes. Thus, a uniform power irradiation during a cycle is generally used to quantify spent fuel isotopic inventories.

In this study, we tested various power histories such as uniform and cycle-dependent power densities to estimate the effect of scaling factors during three cycles. The simulations are carried out by ORIGEN-S code.[3] After each cycle including cooling time, isotopic inventories are rearranged with a new fresh fuel loading. Thus, cycle-wise calculations are carried out. The assumed cycle-dependent power histories are based on a typical Westinghouse type PWR.

In order to apply radioactive waste drum, main isotopes are taken into consideration including activation products(Co-58, Co-60, Fe-55, Nb-94, Ni-59, Ni-63), fission products(H-3, C-14, I-129, Ce-144, Sr-90, Tc-99, Cs-137), and actinides which emit alpha particles. After obtaining isotopic scaling factors, some quantification analysis and sensitivities are also done.

2. Simulation Conditions

For the application of the reactor dependent scaling factor, a typical fuel assembly library in the ORIGEN-S code is used such as Westinghous14X14. The uranium enrichment fixed as 3.2 wt%U-235 for simplicity. Four different power histories are given as Table I. Case II is increasing power history event and Case III for decreasing power history one. And Case IV enlarges power density with decreasing history. The assuming irradiation times of three cycles are given as 410 days and the estimated burnup after three cycles are 43,640 MWD/MTU. And 30-day and 10-year of cooling time are considered.

One metric ton uranium is loaded and 30 kg Stainless Steel is added for the structural material. The element compositions are given as 20.64 kg of Fe, 5.7 kg of Cr, and 2.67 kg of Ni.

Table I: Cycle Dependent Power History Condition

	Power Density (MW/MTU)		
	Cycle1	Cycle2	Cycle3
Case I (Uniform Power)	35.48	35.48	35.48
Case II (Increasing Power)	35.37	35.52	35.55
Case III (Decreasing Power)	35.55	35.52	35.37
Case IV (Decreasing Power)	30.48	35.48	40.48

3. Simulation Results

The total number of target isotopes is 12 and a group of alpha emission isotopes including about 35 actinide isotopes described in the IAEA guide.[5] From the results of ORIGEN-S, the activities of 47 isotopes are evaluated and compared the scaling factors based on Co-60 and Cs-137 after three cycles. Table II and III show the scaling factors based on Co-60. Cases I, II, and III provide similar results, which means that there are no significant effect on different power histories. In the case of large change in power histories (Case IV), slight discrepancies are found but it is below than 1% .

Table II: Scaling Factor Based on Co-60 After 30 Days Cooling

	Case I	Case II	Case III	Case IV
C-14	1.83E-04	1.83E-04	1.83E-04	1.82E-04
Ce-144	1.24E+04	1.24E+04	1.24E+04	1.33E+04
Co-58	1.80E+01	1.80E+01	1.79E+01	1.86E+01
Co-60	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Cs-137	1.42E+03	1.42E+03	1.42E+03	1.41E+03
Fe-55	1.26E+02	1.26E+02	1.26E+02	1.28E+02
H-3	7.80E+00	7.80E+00	7.80E+00	7.76E+00
I-129	3.75E-04	3.75E-04	3.75E-04	3.72E-04
Nb-94	1.89E-06	1.89E-06	1.89E-06	1.88E-06
Ni-59	1.58E-02	1.58E-02	1.58E-02	1.57E-02
Ni-63	2.13E+00	2.13E+00	2.13E+00	2.11E+00

Sr-90	9.29E+02	9.30E+02	9.29E+02	9.26E+02
Tc-99	1.74E-01	1.74E-01	1.74E-01	1.73E-01
tot-alpha	2.55E+03	2.55E+03	2.55E+03	2.54E+03

Table III: Scaling Factor Based on Co-60 After 10 Years Cooling

	Case I	Case II	Case III	Case IV
C-14	6.79E-04	6.79E-04	6.79E-04	6.76E-04
Ce-144	6.43E+00	6.44E+00	6.42E+00	6.92E+00
Co-58	2.16E-14	2.16E-14	2.16E-14	2.24E-14
Co-60	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Cs-137	4.18E+03	4.18E+03	4.19E+03	4.17E+03
Fe-55	3.71E+01	3.71E+01	3.70E+01	3.78E+01
H-3	1.66E+01	1.65E+01	1.66E+01	1.65E+01
I-129	1.41E-03	1.41E-03	1.41E-03	1.40E-03
Nb-94	7.02E-06	7.02E-06	7.03E-06	6.99E-06
Ni-59	5.87E-02	5.87E-02	5.87E-02	5.83E-02
Ni-63	7.39E+00	7.39E+00	7.39E+00	7.34E+00
Sr-90	2.70E+03	2.70E+03	2.71E+03	2.69E+03
Tc-99	6.47E-01	6.47E-01	6.47E-01	6.44E-01
tot-alpha	4.47E+03	4.47E+03	4.47E+03	4.49E+03

For Cs-137 based scaling factors, Figs. 1 and 2 depicted for 30 days cooling and 10 years cooling, respectively. As expected as Co-60 cases, similar scaling factors are obtained except Ce-144. Fig.3 shows the Ce-144 scaling factors based on Co-60 and Cs-137. Case IV shows slight increases compared with the others, which means that fission product of Ce-144 is strongly dependent on power histories due to the shorter half-life of 285 days.

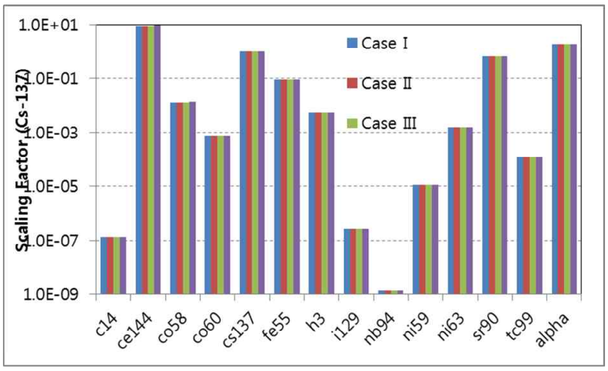

Fig. 1. Comparison of scaling factors based on the Cs-137 after 30 days cooling.

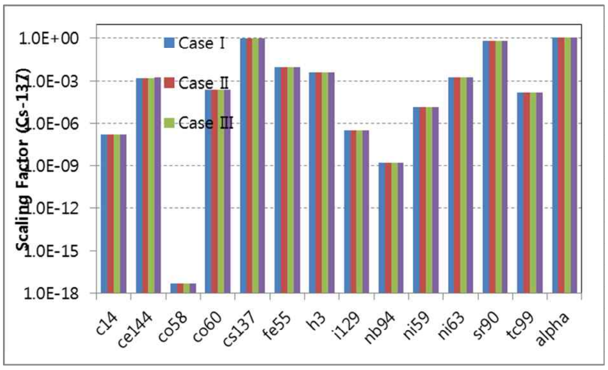

Fig. 2. Comparison of scaling factors based on the Cs-137 after 10 years cooling.

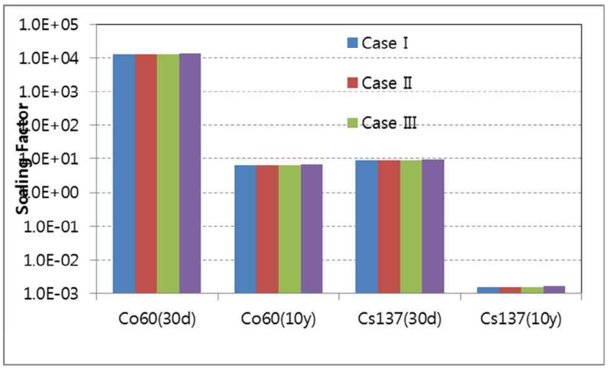

Fig. 3. Comparison of scaling factors of Ce-144 for different Key isotopes.

From the results, the relative scaling factors are obtained based on the uniform power history case (Case I). Figs. 4 and 5 depict the relative scaling factors based on Cs-137 and Co-60 after 10 year cooling, respectively. From the results, Ce-144, Co-58, and Fe-55 changes largely with increased power histories for two Key isotopes of Cs-137 and Co-60. Additionally, total alpha isotopes are slightly dependent on the power histories for both Key isotopes.

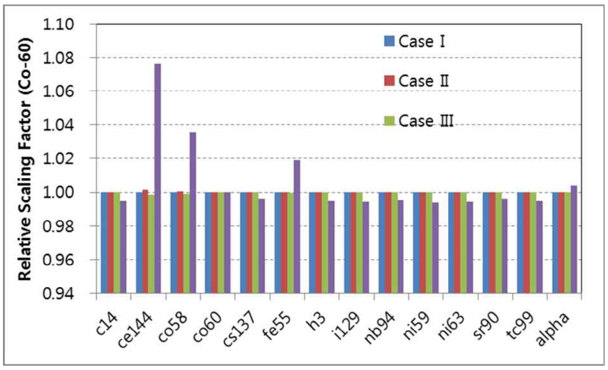

Fig. 4. Comparison of relative scaling factors based on Co-60 after 10 years cooling.

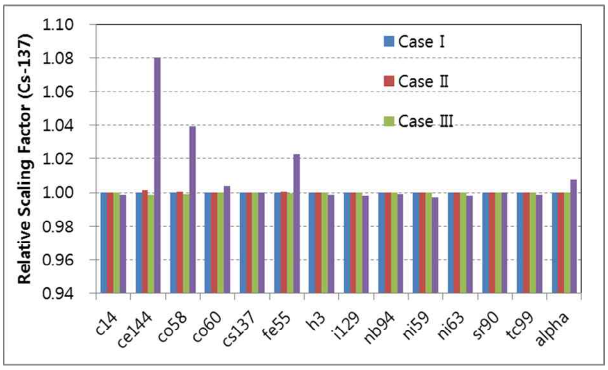

Fig. 5. Comparison of relative scaling factors based on Cs-137 after 10 years cooling.

4. Conclusions

By using the ORIGEN-S code, scaling factors are evaluated with various power histories. It is found out that significant change in power histories gives an effect on the scaling factors for a couple of isotopes such as Ce-144, Co-58, and Fe-55. In case of Ce-144, about 8% increases in scaling factors for both key isotopes such as Co-60 and Cs-137.

From the results of this study, it is important to follow reactor-wise irradiation histories for estimation scaling factors. Thus, it is also recommended this effect may be included as an uncertainty of scaling factors.

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