Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

A Comparison Test on Isotopic Scaling Factors with Measured Scaling Factors of Dry Active Waste Forms

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1. Introduction

The scaling factor is very important to quantify difficultly measuring radioisotopes, which should be provided for radioactive waste disposal storage. In order to evaluate the predicted radioactivity, both scaling factor and dose-to-curie (DTC) conversion method are used. Various methods have been suggested and applied in the worldwide.[1][2][3] Two key isotopes are usually chosen such as Co-60 and Cs-137 in order to evaluate scaling factors. By using these key isotopes based scaling factors, the inventories of alpha and beta emitted isotopes are determined. Then the specific activities (Bq/g) are evaluated for the each waste packages. Those isotopic specific activity data is utilized to classify the level of radioactive waste. Recently, a technical paper has been issued by comparing radionuclide inventory between predicted and measured activity of various dry waste form from several nuclear power plants of South Korea.[4] Various measured activity data of radioactive wastes are provided and analyzed in order to estimate the trend of radioactive waste and isotopic sensitivity.

Based on the measured data in Ref.2, this paper deals with an application possibility of isotopic scaling factors which are obtained by the typical isotopic inventory estimate code such as the ORIGEN-S[5]. It is also applied to estimate the radioactive waste with unclear irradiation history. It is expected that the general trend of the specific isotopic trends is found from the comparison analysis with the measured data where some chemical or special waste treatments are applied.

2. Analysis Conditions

Among several measured data of dry waste form, Hanul unit 1 and 2 are chosen with 200L and 320L from the Ref. 4. The Hanul unit 1 and 2 start their operation since 1988 and 1989, respectively. The types and characteristics of two nuclear power plants are same. The operation power is 950 MWe and the fuel assembly type is Westinghouse 17X17. The fuel enrichment varies from 1.6 wt%U-235 to 4.5 wt%U-235. The average discharge burnup is 45 GWD/MTU. In order to obtain various database of scaling factor, the following 13 cases are selected by combining U-235 enrichment and discharge burnup as shown in Table I. The specific power is fixed as 38 MW/MTU and the cooling time is considered up to 30 years. 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: Irradiation Test Cases

Case	Enrichment (wt%)	Burnup (MWD/MTU)
test11	1.5	35,000
test12	1.5	40,000
test21	2.0	35,000
test22	2.0	40,000
test31	3.0	35,000
test32	3.0	40,000
test33	3.0	45,000
test41	4.0	35,000
test42	4.0	40,000
test43	4.0	45,000
test51	5.0	35,000
test52	5.0	40,000
test53	5.0	45,000

From the measured activity of the dry waste form, the following scaling factors are tabulated as shown in Tables II and III. Total 13 isotopes and total alpha emission isotopes are provided. For the key isotope of Co-60, 9 cases such as H-3, C-14, Fe-55, Co-58, Ni-59, Ni-63, Nb-94, Ce-144, and total alpha isotopes are used to evaluate scaling factors. In the case of Cs-137, 3 fission products such as Sr-90, Tc-99, I-129 are used for the scaling factor.

3. Simulation Results

For 14 cases of scaling factors, the trends of different enrichment and burnups are depicted with a function of cooling time. For examples, Fig.1 and Fig. 2 show the scaling factors of Ni-59 and gross alpha emission isotopes based on Co-60, respectively. Fig. 3 and Fig. 4 depict the scaling factors of Sr-90 and Tc-99 based on Cs-137, respectively. Triangle legend denotes the measured scaling factors for Hanul unit 1 and unit 2. As shown figures, depending on isotopes the estimated scaling factors varies significantly. The main reason comes from the lack of information of waste treatment and chemical conditions. In the case of alpha emission isotopes are almost actinides, which are rarely released from the fuel rod in the normal operation. In the low level dry waste, the release ratio of actinides might be considered. The similar large discrepancy is found in volatile fission products such as Tc-99 and I-129, which are mostly filtered in ventilation ash. Table IV shows the comparison of measured scaling factors for LLW of 200 L waste drum and estimated scaling factors of low enrichment case (test 21) and high enrichment case (test43) at 20 years cooling. Fig. 5 and Fig. 6 depict scaling factors for measured scaling factors of VLLW and LLW by comparison of estimated data, respectively. Large discrepancy happens in Co-58 and gross alpha emission isotopes, which requires additional constraints based on the known information of waste treatment.

Table II: Measured Scaling Factor of Hanul unit 1

	200L Waste Drum		320 L Waste Drum	
	VLLW[a]	LLW[b]	VLLW	LLW
H-3	2.52E+00	2.69E+00	3.34E+00	3.38E+00
C-14	1.59E-02	1.78E-02	2.57E-02	2.63E-02
Fe-55	3.08E+00	2.85E+00	1.99E+00	1.94E+00
Co-58	9.75E-04	4.27E-04	2.44E-05	6.77E-06
Co-60	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Ni-59	3.73E-02	4.19E-02	6.04E-02	6.20E-02
Ni-63	1.33E+00	1.48E+00	2.10E+00	2.15E+00
Sr-90	1.60E-02	1.61E-02	1.60E-02	1.61E-02
Nb-94	2.38E-03	2.68E-03	3.85E-03	3.96E-03
Tc-99	3.63E-02	3.66E-02	3.99E-02	3.99E-02
I-129	4.16E-04	4.21E-04	4.58E-04	4.58E-04
Cs-137	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Ce-144	2.99E-02	6.95E-03	1.03E-02	3.35E-03
Gross alpha	2.55E-03	2.86E-03	4.12E-03	4.23E-03

[a]: Very low level waste, [b]: low level waste

Table III: Measured Scaling Factor of Hanul unit 2

	200L Waste Drum		320 L Waste Drum	
	VLLW	LLW	VLLW	LLW
H-3	6.64E+00	6.37E+00	4.93E+00	4.93E+00
C-14	9.72E-02	9.00E-02	5.67E-02	5.67E-02
Fe-55	4.09E+00	4.32E+00	6.30E+00	6.30E+00
Co-58	3.65E-03	5.84E-04	1.11E+00	1.11E+00
Co-60	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Ni-59	2.58E-01	2.39E-01	1.51E-01	1.51E-01
Ni-63	1.08E+00	1.00E+00	6.51E-01	6.49E-01
Sr-90	6.99E-01	6.99E-01	7.04E-01	7.03E-01
Nb-94	1.63E-03	1.51E-03	9.55E-04	9.54E-04
Tc-99	2.10E-01	2.10E-01	1.93E-01	1.93E-01
I-129	4.24E-04	4.23E-04	3.90E-04	3.89E-04
Cs-137	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Ce-144	5.13E-02	4.50E-03	3.37E-03	3.37E-03
Gross alpha	3.24E-02	3.01E-02	1.90E-02	1.90E-02

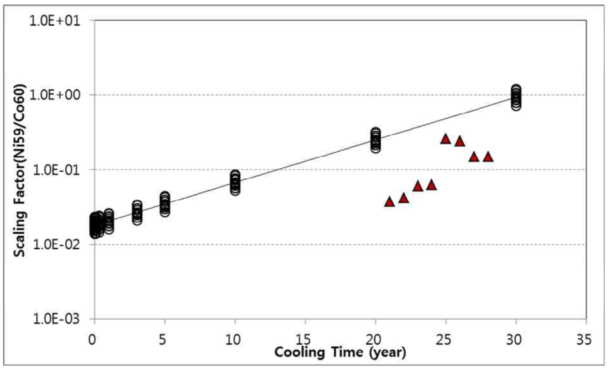

Fig. 1. Estimated Scaling Factors for Ni-59

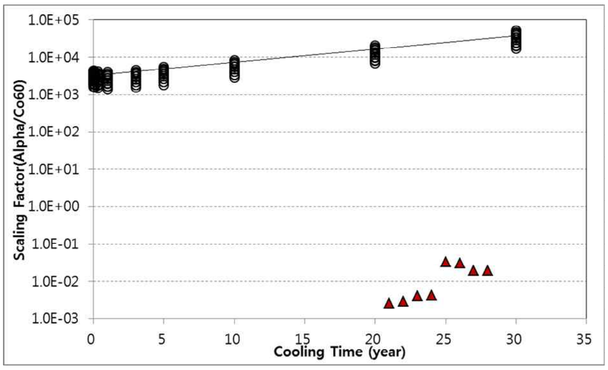

Fig. 2. Estimated Scaling Factors for gross alpha emission isotopes

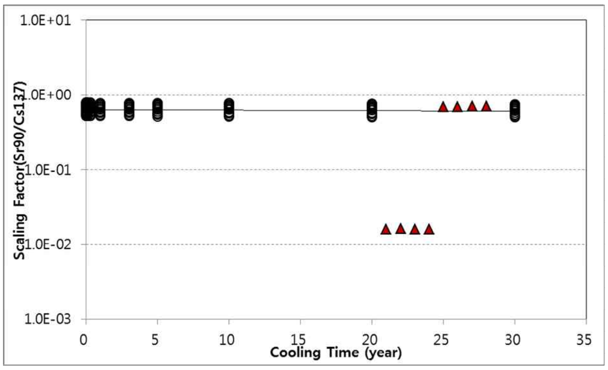

Fig. 3. Estimated Scaling Factors for Sr-90

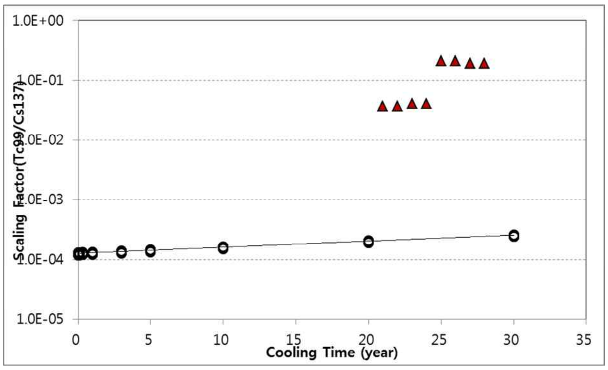

Fig. 4. Estimated Scaling Factors for Tc-99

Table III: Comparison of Scaling Factors

	Hanul1	Hanul2	test21	test43
H-3	2.69E+00	6.37E+00	3.02E+01	4.32E+01
C-14	1.78E-02	9.00E-02	2.28E-03	3.04E-03
Fe-55	2.85E+00	4.32E+00	1.34E+01	1.18E+01
Co-58	4.27E-04	5.84E-04	2.43E-29	3.10E-29
Co-60	1.00E+00	1.00E+00	2.50E-01	2.36E-01
Ni-59	4.19E-02	2.39E-01	1.00E+00	1.00E+00
Ni-63	1.48E+00	1.00E+00	2.97E+01	2.73E+01
Sr-90	1.61E-02	6.99E-01	5.89E-01	6.80E-01
Nb-94	2.68E-03	1.51E-03	2.60E-05	2.92E-05
Tc-99	3.66E-02	2.10E-01	1.54E-04	1.97E-04
I-129	4.21E-04	4.23E-04	3.55E-07	4.05E-07
Cs-137	1.00E+00	1.00E+00	1.00E+00	1.56E+04
Ce-144	6.95E-03	4.50E-03	3.37E-03	4.45E-03
Gross alpha	2.86E-03	3.01E-02	9.83E+03	1.31E+04

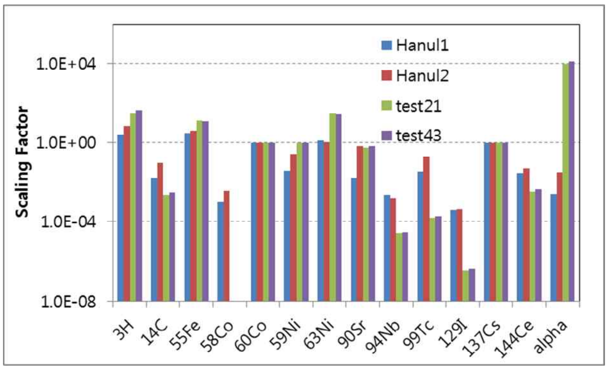

Fig. 5. Comparison of measured and estimated scaling factors for very low level waste (VLLW)

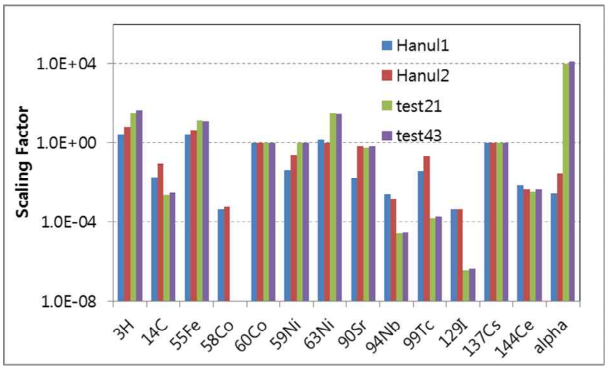

Fig. 6. Comparison of measured and estimated scaling factors for low level waste (LLW)

Assuming the measured data of LLW waste from Hanul unit 2 providing the reference, the adjustment factor for estimated scaling factors are obtained by averaging two scaling factors of low enriched case (test21) and high enriched case (test43). The obtained adjustment factors are tabulated in Table IV. Using adjustment factors, estimated scaling factors are changed and are compared with measured scaling factors of VLLW as shown in Fig. 7. The difference from measurement data decreases significantly.

Table IV: Adjustment Factors for Estimated Scaling Factors Based on measured data from Hanul unit 2

Isotopes	SF Adjustment Factor
H-3	1.74E-01
C-14	3.39E+01
Fe-55	3.44E-01
Co-58	2.11E+25
Co-60	1.00E+00
Ni-59	2.39E-01
Ni-63	3.51E-02
Sr-90	1.10E+00
Nb-94	5.48E+01
Tc-99	1.19E+03
I-129	1.12E+03
Cs-137	1.00E+00
Ce-144	1.15E+00
Gross alpha	2.62E-06

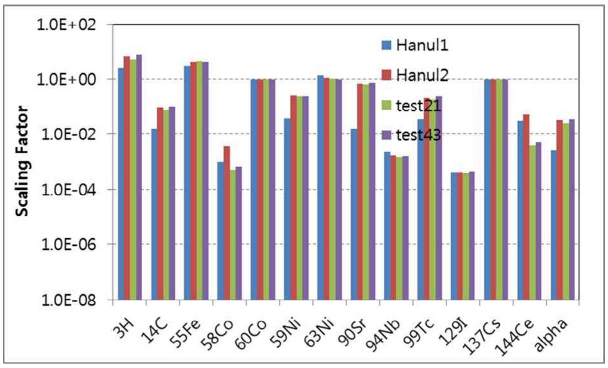

Fig. 7. Comparison of measured and adjusted estimated scaling factors for very low level waste (VLLW)

4. Conclusions

Comparison tests of estimated scaling factors are carried out based on the measured scaling data from Hanul unit 1 and unit 2. As expected, large discrepancies between measured and estimated scaling factors are found depending on isotopes, which results from the different conditions of waste treatment or package storage. Based on the measured scaling factors, the adjustment factors are also obtained in order to fit estimated scaling factors into real applications.

From the comparison test of this study, it is important to know the detail information of radioactive waste drum including reactor-wise irradiation histories, waste form and chemical treatment conditions. In future, uncertainty estimation could be possible by accumulation database of measured scaling factors for various nuclear power plants.

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