Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Development of source-term estimation model for technical criteria regarding decommissioning wastes recycling and disposal

Hyungi Byun*, Juyub Kim, Tae Bin Yoon, Jae Won Park
FNC Technology Co., 32 Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin, Gyeonggi-do 16954, Korea
**Corresponding author: bhg1215@fnctech.com*

1. Introduction

In the Republic of Korea, decommissioning is defined as "to be exempt from the application of this Act by dismantling facilities and sites, or by removing radioactive contamination after permanently suspending the operation" in the Nuclear Safety Act [1].

Among the nuclear relevant facilities, especially the decommissioning of NPPs (Nuclear Power Plants) generates a lot of radioactive and non-radioactive wastes.

In United States, the Maine Yankee NPP has generated about 58,000 tons non-radioactive waste which is composed of 70 % concrete and 17 % metal [2]. In Japan, after the Fukushima accident, each unit of over 1,000MW PWR (Pressurized Water Reactor) or BWR (Boiling Water Reactor) is estimated to generate approximately 500,000 tons of waste, consisting of about 94% of non-radioactive waste and 1-2% of low-level waste. [3]

As described above, non-radioactive waste and low-level radioactive waste are generated in large quantities when decommissioning NPPs, and metal and concrete waste accounts for most of them.

In Korea, radioactive waste less than the allowable concentration for EW (Exempt Waste) in the Nuclear Safety and Security Commission Notice No. 2020-6 is defined to allow for use by recycling, incineration, and reclamation method. In addition, the individual's annual exposure dose limit is defined as 10 μSv per year in this notice.

Therefore, the radiological safety assessment is needed for the decommissioning waste recycling and disposal process. Especially, it has been demonstrated that appropriate quantities of waste and suitable scenarios are necessary for evaluating the safety of the disposal and recycling process of the radioactive metal and concrete generated during the decommissioning of NPPs [4].

For radiological safety assessment, a series of processes aimed at decommissioning waste recycling and disposal should be organized into exposure scenarios and evaluated, and the technical criteria for each recycling or disposal scenario should be presented as nuclide concentrations satisfying the individual's annual exposure dose limit.

In this study, the computational code STE (Source Term Estimation) model was developed for deriving the technical criteria of recycling and disposal regarding decommissioning waste. In order to develop the technical criteria of metal and concrete wastes which account for the most of decommissioning wastes, iron, aluminum, and concrete were selected and respectively six, three, and two scenarios were developed according to the final destinations. Finally, the computational code of the STE model derived the technical criteria which were concentrations of nuclides according to the recycling and disposal scenario for each material, and the results were compared with the allowable concentration suggested in the Nuclear Safety and Security Commission Notice No. 2020-6.

2. Methodology and scenario modeling

As mentioned earlier, specific final destinations should be established for recycling or disposal of metal and concrete wastes which are generated in large quantities during decommissioning and have less than the allowable concentration for EW in the Notice. And the technical criteria are needed to prove the radiological safety of each process regarding recycling and disposal final destinations.

2.1. Development of scenarios

In this study, scenarios applicable to the Korea were selected by referring existing methodologies developed by IAEA (International Atomic Energy Agency) and U.S. NRC (United States Nuclear Regulatory Commission), and exposure scenarios for each process were established accordingly.

The IAEA defined scenarios for recycling and reuse regarding iron, aluminum, and concrete materials, but reuse is not recommended in Korea. The IAEA's recycling scenario consists of total 7 stages, from waste generation, transportation, and manufacturing to the final destination, and this process is modeled by each exposure scenario. Exposure targets and pathways are classified according to the working environment and content of each exposure scenario [5].

And the IAEA developed disposal scenarios classified final destinations of disposal facility operation and after closure according to radioactive wastes. A disposal in trench scenario was presented in the IAEA: direct irradiation to worker, substances (i.e. gas, liquid and solid) release to worker and resident, exposure due to unpredictable fire, accidental spreading of waste and bathrubbing for trench in abnormal conditions. Only direct irradiation scenario of these scenarios was modeled as an exposure scenario in the STE model [6].

The U.S. NRC developed the recycling and disposal scenarios for non-radioactive wastes generated in nuclear facilities which have been proven to be below the concentration of the regulatory criteria prescribed by them. And they evaluated three exposure pathways likewise the IAEA's methodology: external exposure, internal exposure by inhalation and ingestion. The U.S. NRC classified final destination of recycling and disposal by material such as steel, copper, aluminum, and concrete. The recycling scenario consists of a total of 5 stages, from waste generation, transportation, and manufacturing to the final destination, and this process is modeled by each exposure scenario which is composed of exposure targets and pathways classified as similar as the IAEA [7].

The STE model reflected final destination scenarios referred the IAEA methodologies in consideration of three materials: iron, aluminum, and concrete, which are generated in large quantities among decommissioning wastes, as shown in Table I.

Table I: Recycling and disposal scenarios in the STE model

Material	Final destination	Description
Iron	Appliance	Home appliance use fabricated with recycled iron
	Frying pan	Frying pan use fabricated with recycled iron
	Disposal	Disposal at industrial landfill
Aluminum	Automobile	Drive with fabrication of automobile engine
	Frying pan	Frying pan use fabricated with recycled aluminum
	Disposal	Disposal at industrial landfill
Concrete	Disposal	Disposal at industrial landfill

In the case of recycling scenario, the process of the scenario consisted of seven stages: generation, transportations, manufactures and final destination, and the disposal scenario process consisted of three stages: generation, transportation and disposal as shown in Fig. 1.

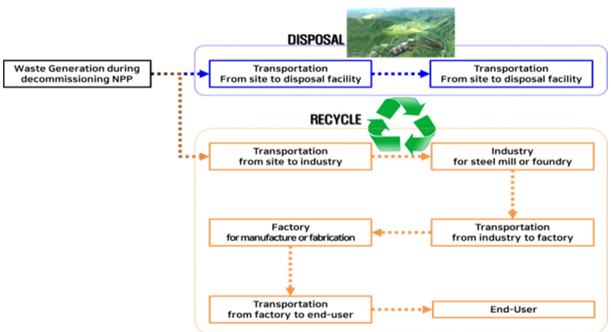

Fig. 1. Process composition of exposure scenarios for recycling and disposal in the STE model

All of the processes constituting each final destination were implemented as exposure scenarios and developed in the STE model. Exposure targets and pathways constituting exposure scenarios were reproduced according to the work environment and activity contents of the process.

2.2. Modeling for source-term estimation

As mentioned earlier, recycling and disposal scenarios were developed to demonstrate the radiological safety of the final destination for decommissioning waste less than allowable concentration for EW. The technical criteria were calculated by Eq. (1), (2) and (3). These were derived by converting into a matrix of each factor regarding dose assessment and entering an additional ratio of the nuclides.

$$D_{Total} = D_{EXT} + D_{INH} + D_{ING} \qquad (1)$$

$$\begin{pmatrix} t \cdot DF_{EXT,1} \cdot W \cdot P & \cdots & t \cdot DF_{EXT,n} \cdot W \cdot P \\ V \cdot t \cdot DF_{INH,1} \cdot W \cdot C_d & \cdots & V \cdot t \cdot DF_{INH,n} \cdot W \cdot C_d \\ t \cdot DF_{ING,1} \cdot W \cdot I & \cdots & t \cdot DF_{ING,n} \cdot W \cdot I \end{pmatrix} \times \begin{pmatrix} C_1 \\ \vdots \\ C_n \end{pmatrix} = \begin{pmatrix} D_{EXT} \\ D_{INH} \\ D_{ING} \end{pmatrix} \qquad (2)$$

$$C_2 = R_2 \cdot C_1,\ C_3 = R_3 \cdot C_1,\ \cdots,\ C_n = R_n \cdot C_1 \qquad (3)$$

where,
D_{Total} = sum of effective dose equivalent from one year's external and internal exposure pathway (Sv/yr)
D_{EXT} = effective dose equivalent from one year's external exposure pathway (Sv/yr)
D_{INH} = effective dose equivalent from one year's internal exposure of inhalation pathway (Sv/yr)
D_{ING} = effective dose equivalent from one year's internal exposure of ingestion pathway (Sv/yr)
t = duration of exposure for the individual (h/yr)
$DF_{EXT,i}$ = dose conversion factor of effective dose equivalent from external exposure to radionuclide i (Sv/h per Bq/g)
W = quantity of exempt material divided by the quantity of material (dimensionless)
P = number of people exposed (dimensionless)
$DF_{INH,i}$ = dose conversion factor of effective dose equivalent from internal exposure of inhalation pathway to radionuclide i (Sv/Bq)
C_d = concentration of respirable dust in air (g/m^3)
$DF_{ING,i}$ = dose conversion factor of effective dose equivalent from internal exposure of ingestion pathway to radionuclide i (Sv/Bq)
I = rate of secondary ingestion of removable surface contamination (g/h)
C_i = concentration of radionuclide i in the specific exposure scenario (Bq/g)

R_i = ratio of the concentration of radionuclides in i to 1 (dimensionless)

Among the DCFs (Dose Conversion Factors) according to each exposure pathway, internal exposure DCFs by inhalation or ingestion were referenced to ICRP (International Commission on Radiological Protection)- Publication 103, and external exposure DCFs were calculated by a program for gamma radiation shielding analysis, the MicroShield, and were stored in the database.

For calculating external exposure DCFs, tens of thousands of input data were generated according to modeling of exposure situation by assuming source-term geometry, amount of material, and distance between exposal target and source-term. After input data production in this way, the effective dose per 1 Bq/g of each radionuclide was derived, and the most conservative result was selected for among 7 exposure directions (e.g. antero-posterior, postero-anterior, isotropic, and etc.).

Finally, it can be considered 526 nuclides only for external exposure, 49 nuclides only for internal exposure, and 682 nuclides for both external and internal exposure, and all of these nuclides information was stored in the STE model database.

3. Source-term estimation result

In this study, the STE model was developed to estimate the radioactive nuclide concentration of waste generated at the time of decommissioning based on the exposure dose to end users or workers. The STE model considers a period from waste generation to exposure, and the radioactive nuclides ratio of the current source-term.

As mentioned earlier, the STE model has the database for 1,257 nuclides, but in this paper, the estimation results for Co-60 and Cs-137 are presented as a sample.

The technical criteria are derived by calculating all exposure scenarios constituting each of recycling or disposal scenario based on the individual's annual exposure dose limit (i.e. 10 μSv), and the minimum concentrations of each radioactive nuclide are presented as the technical criteria for conservatism. Table II shows the result of the technical criteria for two sample nuclides.

Table II: Results for technical criteria from the STE model

Material	Final destination	Co-60 (Bq/g)	Cs-137 (Bq/g)
Iron	Appliance	2.45E+01	1.03E+02
	Frying pan	1.01E+01	4.13E+00
	Disposal	4.37E+01	7.92E+03
Aluminum	Automobile	1.16E+01	4.18E+00
	Frying pan	1.43E+00	6.67E+00
	Disposal	3.78E+01	4.38E+03
Concrete	Disposal	3.96E+01	4.67E+03

4. Conclusion

In this study, the technical criteria satisfying the individual's annual exposure dose limit defined by the Nuclear Safety and Security Commission Notice No. 2020-6 were developed to prove the radiological safety when decommissioning waste is to be recycled or disposed. In addition, the technical criteria considered recycling or disposal scenarios of metal and concrete wastes with non-radioactive or exempt level generated in large quantities during decommissioning.

For deriving the technical criteria, the STE model which has function of source-term estimation and is made up of recycling and disposal scenario constituting each exposure scenarios and all evaluation factors, was developed. Users for source-term estimation through the STE model should select a scenario of metal or concrete recycling and disposal and input several factors such as annual effective dose limit to target, a period from waste generation to exposure, and the current radioactive nuclides ratio.

Through the source-term estimation, the technical criteria were calculated for each scenario to meet the individual's annual dose limit of 10 μSv regarding each radioactive nuclides with specific activity unit. And results were presented as technical criteria for each scenario.

The two sample nuclides have the standard specific activity of 0.1 Bq/g in the Nuclear Safety and Security Commission Notice No. 2020-6. However, the technical criteria through the STE model showed different concentrations for each scenario. These can present more delicate results for recycling and disposal scenario and demonstrate an enhanced radiological safety. However, it needs to be modified later as it is still in the stage of supplementing the scenario.

These technical criteria are expected to increase reliability in proving the radiological safety on recycling or disposal of metal and concrete decommissioning waste.

ACKNOWLEDGMENTS

This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 20203210100430)

REFERENCES

[1] Nuclear Safety Act, Nuclear Safety and Security Commission, 2020.

[2] EPRI (Electric Power Research Institute), Maine Yankee Decommissioning - Experience Report: Detailed Experiences 1997-2004, 1011734, 2005.

[3] JNES, Reports on Measure of Abolition, Handbook 09-0001, 2010.

[4] C. Lee, H. Kim, and S. Lee, Radiological Safety Evaluation of Dismantled Radioactive Concrete from Kori

Unit 1 in the Disposal and Recycling Process, Vol. 53, No. 6, pp. 2019-2024, 2021.
[5] IAEA, Application of Exemption Principles to the Recycling and Reuse of Materials from Nuclear Facilities, Safety Series No. 111-P-1.1, 1992.
[6] IAEA, Derivation of activity limits for the disposal of radioactive waste in near surface disposal facilities, TECDOC-1380, 2003.
[7] U.S. NRC, Radiological Assessments for Clearance of Materials from Nuclear Facilities, NUREG-1640, 2003.