Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

A study on the dose assessment for self-disposal site of decommissioning wastes after closure

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1. Introduction

Operating Nuclear Power Plants (NPPs) generate various types of waste during operation, and decommissioning of NPPs especially generates a considerable amount of wastes.

Exempt level wastes are possible to dispose by self-disposal including incineration, landfill, and recycling according to Enforcement Decree of Nuclear Safety Act.

Additionally decommissioning wastes involve a lot of management cost. In Korea, radioactive waste disposal cost is about 15.75 million won per a 200L drum according to Ministry of Trade, Industry and Energy Notice No. 2022-11. Assuming 14,500 drums of decommissioning wastes per unit [1], entire management cost of decommissioning wastes disposal accounts for about 25 % of total decommissioning cost. Also, huge amounts of decommissioning wastes may cause a lack of disposal capacity.

For solving these problems, recycling and self-disposal of decommissioning wastes should be considered as much as possible. In particular, the dose assessment is important not only for the operation period of disposal facility, but also over a long period of post-closure which might arise critical aspect to safety and human risk. For demonstrating compliance with a radiological aspect, an approach deals with important exposure scenarios from human to estimate resulting risk [2].

For this purpose, we developed an exposure conceptual model for the post-closure of landfill facility regarding self-disposal of decommissioning wastes in this study. This model is composed of various exposure scenarios; external exposure from contaminated soil, irrigation water ingestion exposure, ingestion exposure from foods grown up on contaminated soil, etc. And then this model is evaluated using a dose assessment code which was developed this study. Finally, the result of dose assessment is to verify its application by meeting the annual dose limits 10 microsieverts regarding the self-disposal of decommissioning wastes.

2. Methodology

For the dose assessment, a conceptual model consists of a generalized exposure scenario for possible situations in Korea. Therefore, scenarios involving sea pathways were omitted since most of self-disposal facilities might be located inland area. These situations are regarding post-closure of landfill facility which takes decommissioning wastes. A computational code was developed for calculating the exposure doses using this conceptual model for various nuclides. In this study, exposure conceptual model has been referred to International Atomic Energy Agency (IAEA) document [3] and simulated by using of a GoldSim program.

2.1. Conceptual model

For exposure conceptual model development, we referred methodology of IAEA-TECDOC-1380 published in 2003. This methodology was developed for presenting an approach of establishing radioactive waste acceptance criteria and illustrating its application in waste to be disposed in near surface disposal facilities. And it was developed for the use of a near surface disposal option requires design and operational measures to provide for the protection of human health and the environment, both during operation of the disposal facility and following its closure. This methodology evaluated three exposure pathways for the dose assessment: external exposure, internal exposures by inhalation and ingestion.

And exposure scenarios are presented in this methodology: external irradiation and dust inhalation by contaminated soil, irrigation water drinking, and ingestion of crop, beef, and milk which are grown from contaminated soil. For dose assessment, exposure conceptual model is developed by organizing all of these exposure scenarios, and this model shown in Fig. 1.

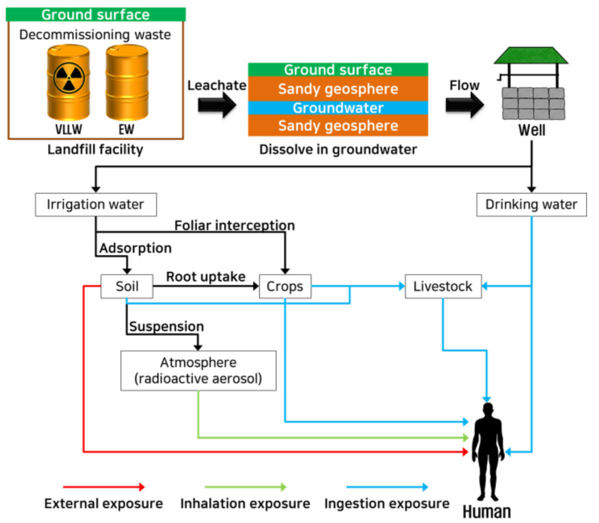

Fig. 1. Exposure conceptual model for landfill facility post-closure

2.2. Dose assessment code

A computational code was developed to calculate exposure dose by simulating exposure conceptual model as mentioned earlier. This code was developed by using GoldSim program. This program is a general simulation package that can estimate a mass movement via medium.

For dose assessment of exposure conceptual model, exposure scenarios were constructed according to migration path of nuclide. And these scenarios were represented as a mechanism for exposure dose received by human.

2.2.1. External exposure.

An external exposure is a situation in which leaked radionuclides are dissolved in groundwater and adsorbed into the soil. And this contaminated soil according to this mechanism directly expose to human. This external exposure pathway was calculated by equation 1.

$$D_{ext} = A_{soil} \cdot 8760 \cdot DF_{ext} \quad (1)$$

Where,

D_{ext} is dose due to external exposure (μSv/yr)

A_{soil} is concentration of nuclide in soil (Bq/g)

8760 are hours in a year (hr/yr)

DF_{ext} is external exposure DCFs (μSv/hr per Bq/g)

For dose assessment of external exposure pathway, Dose Conversion Factors (DCFs) referred to IAEA-TECDOC-1380.

2.2.2. Internal exposure by inhalation.

An internal exposure by inhalation is a situation in which leaked radionuclides are dissolved in groundwater and adsorbed into the soil. And radioactive aerosol is generated in the atmosphere by suspension from this contaminated soil. By this mechanism, a human can be received internal exposure through inhalation. This internal exposure pathway was calculated by equation 2.

$$D_{inh} = A_{soil} \cdot b_r \cdot 8760 \cdot DF_{inh} \cdot \{dust_{act} \cdot \%_{occup} + dust_{norm} \cdot (1 - \%_{occup})\} \quad (2)$$

Where,

D_{inh} is dose due to internal exposure by inhalation (μSv/yr)

b_r is breathing rate (m^3/hr)

DF_{inh} is DCFs of internal exposure by inhalation (μSv/Bq)

$dust_{act}$ is dust concentration during ploughing activities (g/m^3)

$\%_{occup}$ is occupancy factor for ploughing activities (dimensionless)

$dust_{norm}$ is dust concentration during non-ploughing activities (g/m^3)

2.2.3. Internal exposure by ingestion.

An internal exposure by ingestion contains three mechanisms: irrigation water drinking, crop ingestion, and livestock ingestion.

First, mechanism of drinking irrigation water is a situation in which leaked radionuclides are dissolved in groundwater. This groundwater flows into a well which is used as a drinking water by residents near landfill facility, and then ingestion exposure is occurred as they drink it. This mechanism was calculated by equation 3.

$$D_{ing\_water} = Q_{water} \cdot C_{water} \cdot DF_{ing} \cdot \frac{1}{1+K \cdot d_w \cdot part} \quad (3)$$

Where,

D_{ing_water} is dose due to internal exposure by water ingestion (μSv/yr)

Q_{water} is intake rate of drinking water (m^3/yr)

C_{water} is concentration of nuclide in water (Bq/m^3)

DF_{ing} is DCFs of internal exposure by ingestion (μSv/Bq)

Kd_w is distribution coefficient for water (m^3/kg)

$part$ is suspended particle concentration in water (kg/m^3)

Second, mechanism of crop ingestion is a situation in which leaked radionuclides are dissolved in groundwater and adsorbed into the soil. Then, if crops are grown in this contaminated soil, radioactive nuclides migrate into the crops. Following this mechanism, ingestion exposure is occurred as they were consumed it. A dose of internal exposure by crop ingestion was calculated by equation 4. As mentioned in previous of this paper, root and grain are set as representative crop in order to simulate general situations and Korean conditions.

$$D_{ing\_crop} = \sum_{root,grain} \left\{ Q_{crop} \cdot DF_{ing} \left(S_{water} \cdot \frac{Irrig \cdot Int}{Yield} \cdot A_{soil} \cdot TF_{crop} \right) \right\} \quad (4)$$

Where,

D_{ing_crop} is dose due to internal exposure by crop ingestion (μSv/yr)

Q_{crop} is consumption rate of crop (kg/yr)

S_{water} is solubility of nuclide in water (g/l)

$Irrig$ is irrigation rate (m/yr)

Int is interception factor (dimensionless)

Yield is crop yield (kg/m^2-y)

TF_{crop} is soil to plant concentration factor for crop (dimensionless)

Third, mechanism of livestock ingestion is a situation in which leaked radionuclides are dissolved in groundwater and adsorbed into the soil. Then, if livestock is grown in this contaminated soil, radioactive nuclides migrate in the body of livestock. Following this mechanism, ingestion exposure is occurred as they were consumed it. A common situation in livestock ingestion is when livestock are consumed as a meat or milk from livestock. Therefore, dose of internal exposure by livestock ingestion was calculated by equation 5.

$$D_{ing\_livestock} = \sum_{beef,milk}\{Q_{livestock} \cdot DF_{ing} \cdot TF_{livestock}(q_{soil} \cdot A_{soil} + q_{water} \cdot C_{water} \cdot q_{pasture} \cdot A_{soil} \cdot TF_{pasture})\} \quad (5)$$

Where,

$D_{ing\_livestock}$ is dose due to internal exposure by livestock ingestion (μSv/yr)

$Q_{livestock}$ is consumption rate of livestock (kg/yr)

$TF_{livestock}$ is transfer coefficient to beef or milk (day/kg, day/l)

q_{soil} is daily soil intake by livestock (kg/day)

q_{water} is daily water intake by livestock (m^3/day)

$q_{pasture}$ is daily pasture intake by livestock (kg/day)

$TF_{pasture}$ is soil to plant concentration factor for pasture (dimensionless)

For dose assessment of internal exposure of both inhalation and ingestion pathway, DCFs referred to Federal Guidance Report (FGR) publication no. 13.

3. Dose assessment result

In this study, we performed dose assessment of exposure conceptual model. It is composed of exposure scenarios for landfill facility post-closure regarding self-disposal of decommissioning wastes.

Duration of institutional control period after closure of landfill facility is typically considered that duration of between 100 and 300 years. However, since the assessment period depends on the half-life and radioactivity of radioactive nuclides, it is set from hundreds to tens of thousands of years to confirm of the impact on after closure [3].

Therefore, dose assessment period is set for hundred thousand years after the closure of landfill facility. We selected a dominant nuclide (i.e. Co-60) and dose assessment was performed based on unit specific activity (1 Bq/g). Table I shows results. As a result of assessment for other nuclide such as Cs-137, it was confirmed that they have little dominant effect on dose.

Table I: Dose assessment results for landfill facility post-closure regarding decommissioning waste material

Exposure pathway	Co-60 (μSv/yr)
Total	8.19E-04
External	8.03E-06
Inhalation	7.17E-12
Water ingestion	6.62E-06
Crop ingestion	8.04E-04
Livestock ingestion	7.79E-08

4. Conclusion

In Korea, .radioactive wastes can be treated as exempt wastes if the annual individual dose received by the waste is proven as less than 10 microsieverts. In former studies [4], we developed the computational code called REDISA for estimating the annual dose and developing technical criteria based on the recycling scenarios.

In addition, it should be proven that the post-closure scenario of landfill facility also satisfies the annual dose limit. For this reason, the dose assessment has been carried out using the exposure conceptual model and computational code which were developed in this study. The result of dose assessment shows that the post-closure scenario of self-disposal landfill facility causes negligible effects on the public health. It means that, for the self-disposal scenarios of the decommissioning wastes, transportation and operation stages should be considered more carefully than the post-closure stage of self-disposal landfill facility.

Following these results, it could be possible to establish a more detailed self-disposal strategy. And it is expected to contribute for enhanced radiological safety management of decommissioning wastes. Also it is possible to improve the radiation protection system. Therefore, the result of this study will contribute to establishing the technical bases of the EW wastes from decommissioning of nuclear facilities considering circumstances.

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 (MOTIE) (No. 20203210100430)

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