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Estimation of Exposure Doses for Several Scenarios of the Landfill Disposal of NORM Wastes

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1. Introduction

The Act on safety control of radioactive materials around living environment was promulgated to protect citizen's health and environment in 2013. According to this Act, the integrated plan for radiation protection and the necessary safety guides for treatment, reuse, and disposal of NORM wastes have to be made. And NORM wastes have to be disposed in landfill sites by reducing the concentration of radionuclide, and they should not be reutilized. In this study, we estimated exposure doses for several scenarios for NORM (Naturally Occurring Radioactive Materials) waste disposal into a reference landfill site to check the radiological safety. Also, we estimated the amount of NORM wastes for different activity levels of important radionuclides in wastes to be disposed into a landfill site based on the exposure dose limits to support the establishment of technical bases for safety guide.

2. Methods and Results

The landfill disposal of NORM wastes may cause a radiation exposure to the residents nearby the site. Therefore, the exposure doses have to be estimated to secure the radiological safety for several scenarios of landfill disposal of NORM wastes. We used RESRAD code [1] to estimate exposure doses. The important input data for the estimation of exposure doses are the size and shape of a landfill site, the amount of wastes to be disposed, the activity level of radionuclides included in wastes, hydrogeological and atmospheric environmental characteristics, and so on. The input data are derived from many literature sources and user's manual of RESRAD code. The principal radionuclides in NORM wastes considered in this study are isotopes belonging to the radioactive series headed by the three long-lived isotopes ^{238}U (uranium or U series), ^{232}Th (thorium or Th series), and ^{40}K. We did not consider actinium series including ^{235}U because they might cause very low exposure doses due to very low abundance ratio and dose coefficients.

The conceptual design of a landfill site for NORM wastes are shown in Figure 1. We assumed that the area of the site is 400,000 m^2, the thickness of the contaminated zone is 4 m, the soil cover depth is 0.5 m, the distances to the residential area and the surface water are 300 m and 1,000 m, respectively. And it is assumed that the radionuclides in the NORM wastes are uniformly distributed within the whole contaminated zone. Dose coefficients are derived from the references [2, 3, 4, 5] for each pathway. All the radionuclides are assumed to be in radioactive equilibrium. According to the IAEA report [6], the institutional control period of 300 years are adopted for low and intermediate level radioactive waste repository in most countries. Therefore, we estimated maximum exposure dose at 300 years although the peak exposure dose times are different for U series, Th series, and ^{40}K.

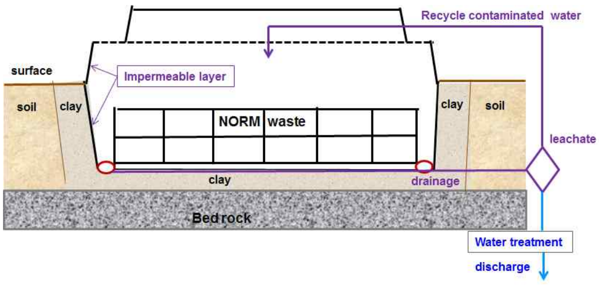

Fig. 1. Conceptual design of a landfill site for NORM wastes.

2.1 Estimation of maximum exposure doses

We consider three scenarios for the estimation of maximum exposure doses; a reference scenario, ingestion pathway exclusion scenario, and low leach rate scenario. The reference scenario is a scenario that consider all the exposure pathways and derived input data. The ingestion pathway exclusion scenario is a scenario that does not consider the ingestion pathway to estimate exposure doses more realistically because the ingestion of plant foods, meat and milk, drinking water, fish, and soil contaminated by the radionuclides nearby the landfill site is very low. The low leach rate scenario is a scenario that uses a reduced rainfall rate. Almost all landfill sites have a facility that restrict the release of water produced autonomously in the landfill site and leachates to the soil. In order to consider the effect of reduced release of them to the soil we controlled the amount of water passing the contaminated zone by using the 1% of rainfall rate of the reference scenario.

The estimated maximum exposure doses for three scenarios are summarized in Table 1. The maximum exposure doses are directly proportional to the activity level of each radionuclide. For the reference scenario, the most important pathway is the ingestion of plant foods grown in the contaminated soil and irrigated with contaminated water for the case of U series and Th series. But the ingestion of fish from a contaminated pond is the most important pathway for the case of ^{40}K. This is due to the difference in the values of distribution coefficient and solubility. The values of the distribution coefficients for U series, Th series, and ^{40}K used in this study are 50 cm^3/g, 60,000 cm^3/g, and 5.5 cm^3/g, respectively. For the case of Th series, the concentration in the groundwater is very low due to the high value of distribution coefficient. Therefore, the exposure pathway of the direct ingestion of plant foods is the most important pathway. For the case of U series, there is a similar trend as for the case of Th series although the value of distribution coefficient of U series lower than that of Th series. However, the ingestion of fish from a contaminated pond is the most important pathway because ^{40}K is highly soluble and has the smallest value of distribution coefficient.

Table 1: Maximum exposure doses for different scenarios (mSv/yr)

Radionuclides	Scenario	Activity (Bq/g)				
		0.1	0.3	1.0	3.0	10.0
U series	1	2.85×10^{-1}	8.56×10^{-1}	$2.85\times10^{+0}$	$8.56\times10^{+0}$	$2.85\times10^{+1}$
	2	1.01×10^{-2}	3.03×10^{-2}	1.01×10^{-1}	$3.03\times10^{+0}$	$1.01\times10^{+0}$
	3	3.39×10^{-1}	$1.02\times10^{+0}$	$3.39\times10^{+0}$	$1.02\times10^{+1}$	$3.39\times10^{+1}$
Th series	1	4.84×10^{-1}	$1.45\times10^{+0}$	$4.84\times10^{+0}$	$1.45\times10^{+1}$	$4.84\times10^{+1}$
	2	2.08×10^{-2}	6.25×10^{-2}	2.08×10^{-1}	6.25×10^{-1}	$2.08\times10^{+0}$
	3	4.85×10^{-1}	$1.46\times10^{+0}$	$4.85\times10^{+0}$	$1.46\times10^{+1}$	$4.85\times10^{+1}$
^{40}K	1	2.56×10^{-1}	7.69×10^{-1}	$2.56\times10^{+0}$	$7.69\times10^{+0}$	$2.56\times10^{+1}$
	2	7.69×10^{-5}	2.31×10^{-4}	7.69×10^{-4}	2.31×10^{-3}	7.69×10^{-3}
	3	4.72×10^{-2}	1.42×10^{-1}	4.72×10^{-1}	$1.42\times10^{+0}$	$4.72\times10^{+0}$

For the ingestion pathway exclusion scenario, only the direct exposure from the contaminated soil material occurred and the maximum exposure doses are lower than those for the reference scenario.

For the low leach rate scenario, the exposure doses have the similar characteristics to the reference scenario, however, exposure dose levels are higher than those for other scenarios. The radionuclides in the contaminated zone for the low leach rate scenario dissolve less and remain more than those in the reference scenario. The increased concentration of each radionuclide in the contaminated zone can have more influences on the root of plants, which are ingested by the exposed individuals. Therefore, the exposure dose by U series and Th series slightly increase from the reference scenario after 300 years of landfill disposal. In the case of ^{40}K, due to the same reason, the ingestion of the contaminated plants has more influence on the total dose than that of the reference scenario, and the impact by the ingestion of groundwater and fish, which is caught in the surface water body affected by the contaminated groundwater, decreased. However, the total dose by ^{40}K decrease up to about 20% of the reference scenario because the limited precipitation caused the less amount of contaminated groundwater than the reference scenario, and the contaminated groundwater contributes to major part of the dose by ^{40}K.

2.2 Dose estimation considering activity level and disposal amount of wastes

In the estimation of exposure doses for three difference scenarios, we assumed that the NORM wastes are uniformly distributed within the whole contaminated zone. However, the amount of NORM wastes to be disposed in a year may be dozens of tons or hundreds of tones. Therefore, this assumption may be unrealistic. We estimated exposure doses by assuming that the thickness of the contaminated zone is 2 m, the density is 2 g/cm^3, and the soil cover depth is 0.5 m, the removal rate by erosion and leaching is 0.001 mm/yr for the more realistic estimation. Then, we estimated the exposure doses considering the ingestion pathway as a function of activity level and the amount of wastes to be disposed. Although the regulatory limit of exposure dose for the general public is 1 mSv/yr, we also compare the results with 0.3 mSv/yr which is a exposure dose level for the disposal of 100 tons of wastes including Th series with the activity level of 1 Bq/g. The amount of 100 tons of wastes is the assumed maximum amount of wastes which may be disposed in a year.

The results are plotted in Figs. 2, 3, and 4. For the case of U series with the activity level of 1 Bq/g, the exposure dose does not exceed 1 mSv/yr if the amount of wastes does not exceed 2,000 tons. Therefore, we can dispose safely maximum 2,000 tons of NORM wastes containing U series with the activity level of 1 Bq/g. The results for Th series show similar trends as for U series. However, we can dispose safely maximum 600 tons of NORM wastes containing Th series with the activity level of 1 Bq/g. Therefore, more careful radiological management for wastes containing Th series than that for wastes containing U series is required for wastes containing Th series. The exposure dose for the disposal of wastes containing ^{40}K with the activity level of 10 Bq/g exceeds 1 mSv/yr if the amount of wastes exceed 1,000 tons.

If we do not consider the ingestion pathway, any amount of wastes containing U series with the activity level of 10 Bq/g or lower can be disposed because the exposure dose does not exceed 1 mSv/yr. And any amount of wastes containing Th series with the activity level of 5 Bq/g or lower can be disposed because the exposure dose without the ingestion pathway does not exceed 1 mSv/yr. The exposure doses do not exceed 0.3 mSv/yr for the case of disposing wastes containing ^{40}K with the activity level of below 30 Bq/g and the amount of below 10,000 tons.

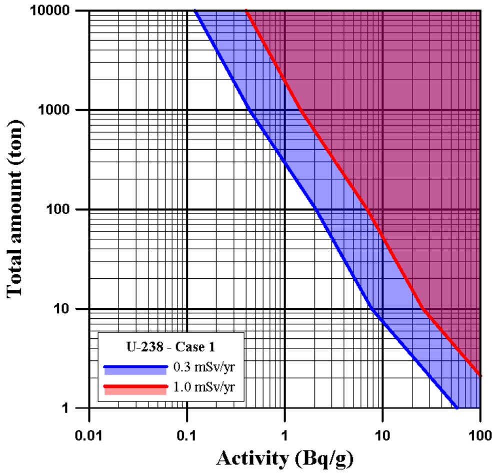

Fig. 2. Exposure doses as a function of activity level and the disposal amount of wastes containing U series.

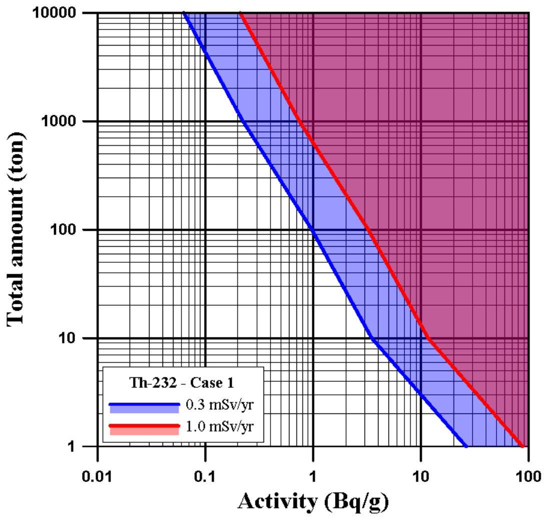

Fig. 2. Exposure doses as a function of activity level and the disposal amount of wastes containing Th series.

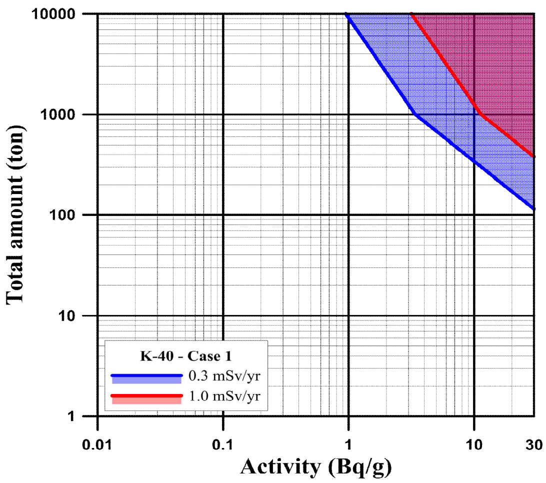

Fig. 3. Exposure doses as a function of activity level and the disposal amount of wastes containing ^{40}K.

3. Conclusions

We estimated exposure doses for several scenarios for the disposal of NORM wastes containing U series, Th series, and ^{40}K into a reference landfill site to check the radiological safety. Also, we estimated the amount of NORM wastes for different activity levels of wastes containing U series, Th series, and ^{40}K based on the exposure dose limits. The results of this study can be used as technical bases to support the establishment of a guide for the safe management of NORM waste disposal.

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