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Table of contents

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Previous issue Next issue

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View all abstracts

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Preface

Papers

^{137}Cs Radiological risk estimation of NSD facility at Karawang site by using RESRAD *onsite* application: effect of cover thickness

^{137}Cs Radiological risk estimation of NSD facility at Karawang site by using RESRAD *onsite* application: effect of cover thickness

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Abstract. The operational of near surface disposal facility during waste packages loading activity into the facility, or in a monitoring activity around disposal facility at Karawang area is predicted to give a radiological risk to radiation workers. The thickness of disposal facility cover system affected the number of radiological risk of workers. Due to this reason, a radiological risk estimation needs to be considered. RESRAD onsite code is applied for this purpose by analyse the individual accepted dose and radiological risk data of radiation workers. The obtained results and then are compared with radiation protection reference in accordance with national regulation. In this case, the data from the experimental result of Karawang clay as host of disposal facility such as Kd value of ^{137}Cs was used. Results showed that the thickness of the cover layer of disposal facility affected to the radiological risk which accepted by workers in a near surface disposal facility.

Keywords: near surface disposal, 137Cs, cover system, Kd, radiological risk

1. Introduction

Near surface disposal (NSD) is a disposal facility refers to the emplacement place of solid, or solidified radioactive waste packages containing predominantly short-lived radionuclides which located at or near the land surface [1]. In general, wastes suitable with the types of disposals are those containing a short-lived radionuclides and low concentrations of long lived radionuclides. The NSD type is also encompassing a wide range of disposal options, including disposal in engineered structures on the ground, a few meters of deep disposal in a simple earthen trench, disposal with engineered concrete vaults and also disposal in rock caverns in several tens of meters below the earth's surface such as shown at Fig. 1 [2,3].

The number of factors to the selection of disposal facility depth and the type of facility that is developed will depend on the nature of the waste and the local environmental conditions. Through a series of complementary barriers such as the waste form itself, waste containers, other engineered features associated with the facility design, and the local environment will provide wastes containment and isolation. In some ways, each of barriers serves to prevent the release of radionuclides from the waste form in the facility to the accessible environment as restricted the migration of contaminants area, and also may minimize radiological risk to the worker during operational of facility.

To reduce the associated risks to acceptable levels, radioactive waste is represented as a potential hazard to human health, due to it acts as a source of ionizing radiation must be carefully managed. The offender of disposal activity responsible for the implementation of protection of human health and the environment in accordance with a national system of radiation protection agreed with principles and requirements for radioactive waste management and radiation protection [4]. Through Government Regulation No.61/2013 [5], radioactive waste disposal facility options were classified according to their radioactivity levels as is illustrated at Figure 1, however in this paper the case was focused on the near surface disposal (NSD) facility.

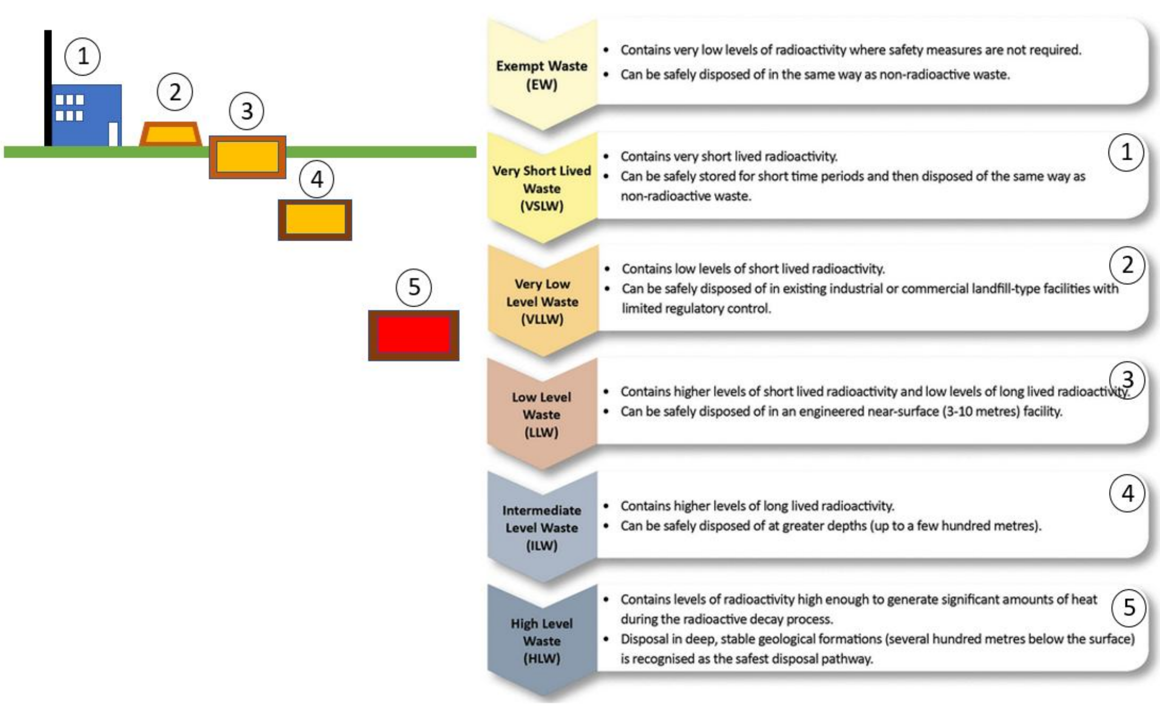

Figure 1. Disposal types option, an illustration [2,3].

Radiation exposure results from all activities related to NSD shall represent the principles and requirements of protection of human health and the environment. The number of doses received by workers shall be kept within dose limits. The various pathways by which humans might be exposed to radiation needed to be given particular attention to the assessment during the operation of a repository and after its closure. As a result of operations at the waste repository facility must be optimized, the radiation protection of persons who are exposed must be optimized and the exposures of individuals must be kept within dose limits.

Karawang area is one of selected area for site candidate of NSD facility at Java Island [6]. In the future on the operational of NSD facility, one things that need to be taken into account properly is the estimation of radiological risk during the operational phase of a repository. In such situation, the operator shall apply the dose limits for occupational exposure for workers and for members of the public. Determination of the cover thickness of NSD facility has become one things that need to be considered to ensure the radiation safety of workers during the operational of facility period.

In this case the ^{137}Cs radionuclide is used as the referenced radionuclide due to it has long half-life, easy to associated with the materials in groundwater and terrestrial, and it make easier to the radionuclide enter into food chain before going into the human body through various pathway. Based on scheme of waste classification in IAEA, radiocesium (^{137}Cs) is included in the categorized as low-level waste with half-live 30 years and placed into a NSD facility [7].

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To minimize the level of acceptance dose of worker, the problem of cover thickness of NSD facility need to be estimated, and RESRAD onsite application code can be used. The assessment of radiological risk for the NSD facility which was planned in Java Island almost has been not performed, and the assessment of the effect of cover thickness of NSD facility becomes important to be done. Objective of the activity is to assess the needs of cover thickness on designing of NSD facility to protect the workers from acceptance doses risk during operational or closure stages of NSD. The assessment based on the result of previous activity [8], where Kd values from the previous activity was used as one of input on RESRAD code application. The expected results of the activity are getting an estimated radiological risk when the cover thickness of NSD is implemented.

2. Theory

The RESRAD (RESidual RADioactivity) code is a software tools have been developed by the Argonne National Laboratory, US Department of Energy (DOE) and US Nuclear Regulatory Commission (NRC) since 1989. This code is used to evaluate radiological contaminated sites [9-11] and also to make regulatory decisions to help determine how clean the radioactivity levels at nuclear sites [9]. The RESRAD code calculates both radiological dose and risk. RESRAD allows users to specify the features of their site and to predict the dose received by an individual at time over the next 100,000 years. When estimating the possibility of radionuclide migration and the magnitude of the radiation exposure received by workers and member of public around the NSD facility, scenario shall be created and selected in a few different ways. Selected scenario at safety assessment is a normal radionuclide dispersion scenario through groundwater pathway to radiation workers and member of public as shown schematically at Figure 2. [11,12]

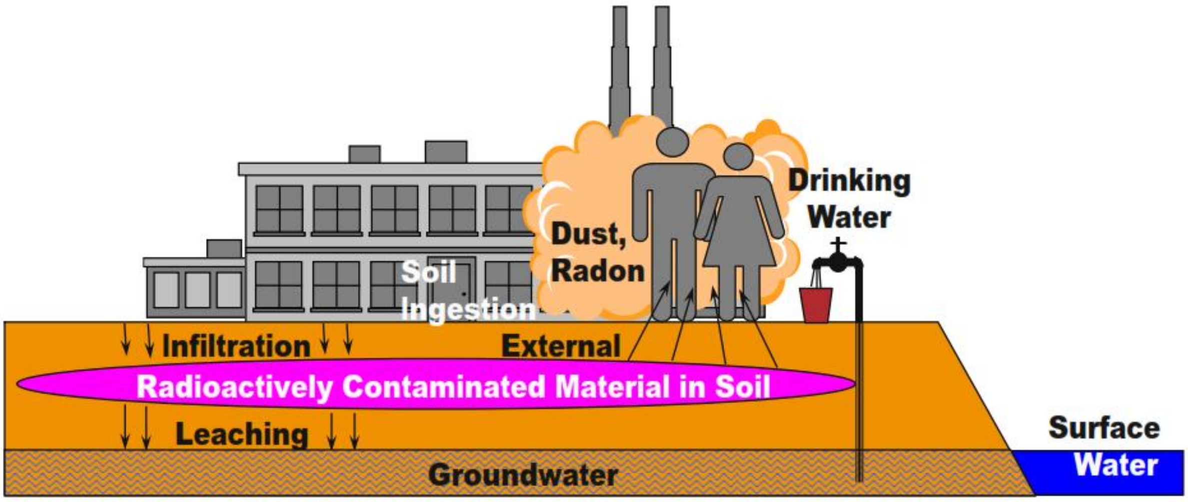

Figure 2. Radiation pathway on RESRAD onsite application [11].

For the purposes of acceptance dose and risk estimation, the individual as objective study is assumed to be standing at above of the disposal facility. The workers are supposed to perform 8 working hours daily at the facility. Drinking water assumed come from water supply, and the worker does not ingestion any foods (plant, meat or milk) grown or raised on the site. At the top of disposal facility were dumped with clay as the disposal cover to minimize radiation exposure on the surface of facility and to reduce the acceptance doses received by workers.

For analysing the results, some inputs were needed on the application, such as radionuclide type, waste activity, specific of Kd value, thickness of contaminated area, density and porosity of cover. This code is used to predict the Total Effective Doses Equivalent, probability excess radiological risk incurred by worker exposed to radioactive emission from waste packages during operational or closure stages of NSD. The acceptable level of radioactive material complies with criteria adopt by regulatory body, are based on the following principles: (1) Total effective dose equivalent should not exceed than 30 mrem/y (0.3 mSv/y), and (2) Doses should be kept as low as reasonably achievable (ALARA) [13].

3. Methodology

The number of received effective doses equivalent depends on the occupancy and shielding factor, the depth of nuclide specific and thickness cover factor, and also specific area factor as shown in Figure 3. A different thickness of cover layer of disposal facility is expected to give a different value of received doses by workers.

$ETF\ (t) = FO_1 \text{ x } FS_1 \text{ x } FA_1 \text{ x } FCD_1\ (t)$

where *ETF* : Environmental transport factors
FO : occupancy and shielding factor
FS : nuclide sp.shape factor
FA : nuclide sp.area factor
FCD : nuclide sp.depth and cover factor

Figure 3. Some factors affected to the total effective dose equivalent [11].

Its means that the affected factors would be depend on the fraction of time spent in indoors and outdoors, the γ-shielding, the thickness and density of contaminated area and cover, geometry of area and the place of receptors received the doses factors.

Total effective dose equivalent is the sum of dose equivalent weight of different organ proportioned with risk potential of radiation emission received to each organ. Distribution doses in the human body depends on distribution pattern of radionuclides in the environment, assumed that radionuclide distribution at infinite or semi-infinite areas are homogeneous. To determine the contribution of effective dose equivalent from externally radiation at time t after measurement is,

$$DSR(t) = \sum DCF \text{ x} \sum \int_{t}^{t-t_{int}} ETF(t) x SF(t)$$

where
DSR : doses/sources ratio,
DCF : dose conversion factor (mSv/y per-Bq/g), was taken from Federal Guidance Report,
ETF(t) : in time t (g/y),
SF(t) : sources factor at time t, ingrowth, decay, leaching factors of radionuclide.

Radiological risk to the individual that received a radiation exposure while working at a contaminated area is calculated by the equation,

$$Radiological\ risk = \sum_{i=1}^{M} ETF(t) x SF(t) x S(0) x RC x ED$$

where
RC : risk coefficient for externally radiation (risk/y)/(pCi/g),
ED : exposure time (30y),

S(0) : radionuclide concentration in clay at t=0.

A series of input data were used to estimate the doses and risk of the NSD facility to the workers as shown in Table 1.

Table 1. Input data on doses estimation with RESRAD onsite application.

Items	Parameters	Value	
Transport	Kd value of sample-1	21,714 ml/g	**
	Kd value of sample-2	4,035 ml/g	**
Regulation Standard	Federal Guide Regulatory	FGR	
Time	Time of observation	1, 10 and 100 years	
Contaminated zone	Contaminated area	10,000 m^2	
	Thickness of contaminated area	1 m	
	Depth of unsaturated area	10 m	
Uncontaminated zone	Density	1.5 g/cm^3	*
	Total porosity	0.4	*
	Hydraulic conductivity	10 m/y	*
Hydrology on the contaminated zone and cover	Cover thickness	1.2 m	***
	Cover density	1.5 g/m^3	***
	Cover erosion factor	0.001 m/y	*
	Contaminated zone density	1.5 g/cm^3	*
	Erosion rate in contaminated zone	0.001 m/y	*
	Precipitation	1 m/y	*
	Runoff coefficient	0.2	*
External–γ εxposure	Exposure time	30 y	*
	External shielding factor	0.7	*
	Indoor fraction	0.5	*
	Outdoor fraction	0.25	*
	Contaminated zone shape	circular	*

* RESRAD default ** [8] *** [14]

The information of Kd values, we used the specific Kd values of ^{137}Cs from Karawang clay experiments [8]. ^{137}Cs is a long-lived radionuclide, it may accordance in clay samples, accumulated in plants and has high risk potential with time for a certain period. The sample-1 and 2 represented the capability of Karawang clay to absorb ^{137}Cs in a highest and lowest of Kd values, where in higher value implies that the ^{137}Cs will be closely tied to the clay sample and slow release to environment and *vice versa*. Release fraction used solubility factor to estimate maximum concentration of radionuclide leachate. Observation time is done gradually starting from 1st, 10th until the 100th. The results and then are compared with the national radiation protection regulation issued by regulatory body/BAPETEN.

4. Results and Discussion

Kd values were obtained from the previous activity [8], and the result was shown in Figure 4. ^{137}Cs becomes saturated in the sample after a few days contacted, where radiocesium achieved to fulfil the active site of the clay samples with Kd values were 21,714 and 4,035 ml/g for sample-1 and 2, respectively. The values obtained from the experiment is then used as the input of RESRAD application to estimate the doses and radiological risk.

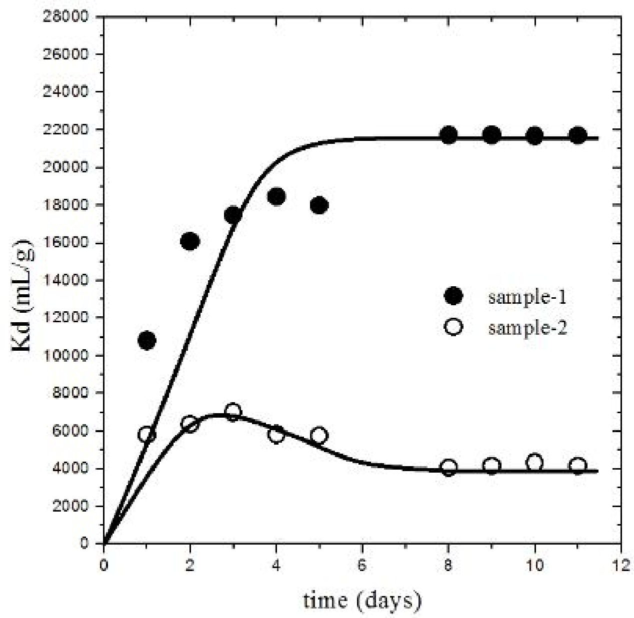

Figure 4. Kd values of ^{137}Cs as a function of time [8].

Total effective dose equivalent for workers at a disposal facility with sample-1 clay host and has cover thickness 0.6 m gave dose value was 2.35 mSv/y at 1st year dispose as shown at Figure 5.

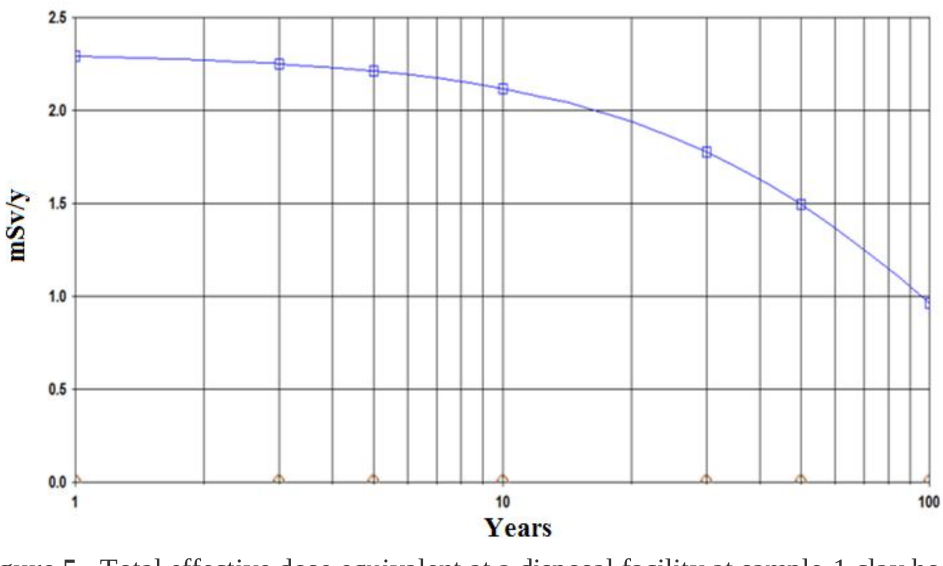

Figure 5. Total effective dose equivalent at a disposal facility at sample-1 clay host, with cover thickness 0.6 m.

The dose came from external radiation exposure way of waste packages decreased with the operation time of waste packages in disposal facility. Decreasing of dose is due to the occurrence of radioactive decay and the influence of nature phenomena such as evaporation, precipitation and release of radionuclide. At the time to the 100th years of disposal operation, the doses received by workers is about 1 mSv/y. If the obtained result is compared with BAPETEN Chairman Regulation No. 4/2013 about Radiation Protection and Safety on Nuclear Energy Application [13] showed that the obtained value is still higher. In the article 23 mentioned that the dose limit to member of public in the form of effective dose is 1 mSv/y, and on the article 41 also stated that the permit holder should specify dose limit to achieve optimization of radiation protection and safety. For that reason, a cover of disposal facility with a thickness of 0.6 m sample-1 clay could not be recommended.

When the thickness of disposal cover was added 2 times fold i.e. to 1.2 m, the effective dose equivalent received by workers at 1st year dispose will be much going down to 4.47 x 10^{-4} mSv/y or dropped 5,000 times lower than the previously received doses, see Figure 6. This is due to the presence of influences the shielding factor, depth of nuclide specific and thickness cover factor that play a sufficiently role to reduce large value of effective dose equivalent that will be received by the workers. At time of 100th years dispose, the dose becomes about 1.86 x 10^{-4} mSv/y. The values then were compared to the national regulation of radiation protection issued by regulation body indicated that the values are still below the dose limit, by 0.3 mSv/y [13]. By adding the cover thickness of disposal system, it can significantly reduce the magnitude of effective dose that will be accepted by the workers.

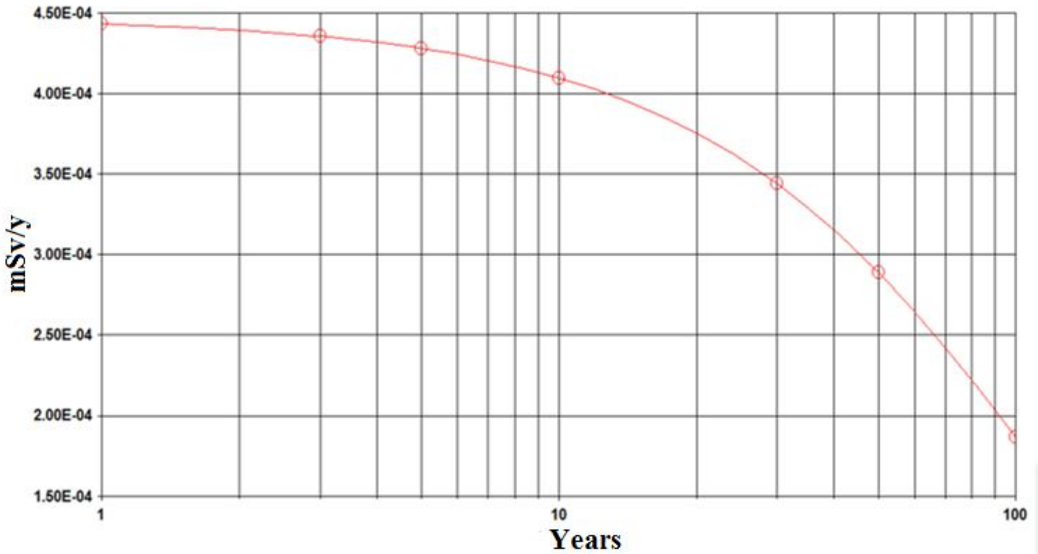

Figure 6. Total effective dose equivalent at a disposal facility at sample-1 clay host, with cover thickness 1.2 m.

In the analysis of radiological risk, the hazardous of ^{137}Cs to the human body is in associated with cell damage due to the result of ionizing radiation decay, and it will generate a potential cause of cancer. Estimation of the mortality risk by cancer assumes 6 of 100,000 peoples or 6 x 10^{-5} are exposed continuously to radiation from contaminated clay layers with 1 pCi/g of ^{137}Cs activity will suffer a fatal cancer [15].

The facility was assumed has clay cover with thickness 1.2 m. Figure 7 showed that FGR morbidity of radiological risk at 1th year operation of disposal facility with sample-1 as clay host which contaminated with ^{137}Cs. Probabilistic the individual to accept the radiation exposure that can result the radiological risk or cancer was 9.92 x 10^{-7} from all the possible causes of cancer to individual. While the probabilistic of radiological risk with cause of death to workers (mortality) was 6.85 x 10^{-7}. In the risk assessment of both samples, the result of radiological risk (morbidity and mortality) were not significant different. However, the area was represented by both results if compared with the ANL limitation has fulfil the safety requirement of individual effective dose equivalent received by workers and member of public. In the previous study stated that the location with higher Kd value the ^{137}Cs bound more strongly on a contaminated area, it was proved with the occurrence of small concentration of ^{137}Cs in the hypothesis well (with distance 30 m). Means that the ^{137}Cs less dispersed into environment than the location that has small Kd value [16].

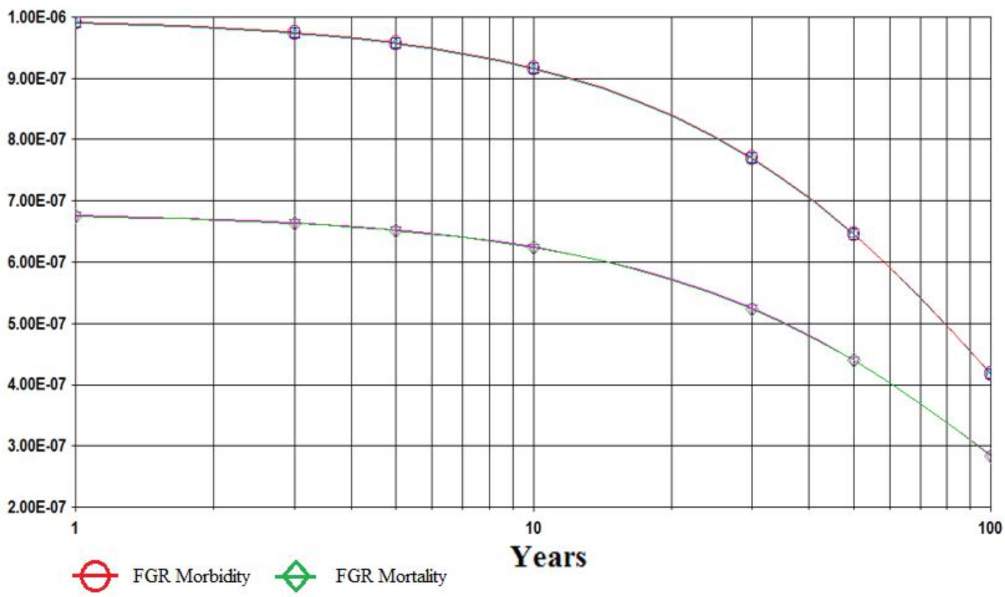

Figure 7. Estimation of radiological risk at sample-1

Summary of the study was compiled in Table 2, which some data came from the result of calculation (specially for sample-2).

Table 2. The results of RESRAD onsite calculation.

Parameters	Sample-1	Sample-2
Kd values	21,714 ml/g	4,035 ml/g
Dose at cover thickness 0.6 m	2.35 mSv/y	2.25 mSv/y
Dose at cover thickness 1.2 m	4.47×10^{-4} mSv/y	4.38×10^{-4} mSv/y
Estimation of cancer at cover thickness 1.2 m, FGR morbidity	9.92×10^{-7}	9.72×10^{-7}
Estimation of cancer at cover thickness 1.2 m, FGR mortality	6.85×10^{-7}	6.7×10^{-7}

5. Conclusion

The thickness changing of clay cover of disposal facility can reduce the quantities of effective dose equivalent was received by workers. At a higher Kd value will give the effective dose equivalent and radiological risk also higher, although the range of both values is not significant different. Thickness of clay cover that is 1.2 m has enough give the received dose values lower than the limit doses set by the regulatory body.

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