Monte Carlo Radiation Simulation of a Radiological Accident in the Batan Indah Case

Nurhadiansyah and Juyoul Kim*
Department of NPP Engineering, KEPCO International Nuclear Graduate Nuclear School.,
658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan 45014
**Corresponding author: jykim@kings.ac.kr*

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1. Introduction

Globally, radiological accidents involving radioactive sources, such as incidents in Brazil [1], Thailand [2] and Georgia [3], have occurred. These cases involve abandoned radioactive sources from medical or industrial facilities. The Goiânia Incident in Brazil in 1987, where a 50.9 TBq ^{137}Cs source from an abandoned radiotherapy unit became an orphan source, exemplifies this. Orphan sources pose a significant radiological hazard, justifying regulatory control, yet they often remain unregulated due to factors like abandonment, loss, misplacement, theft, or unauthorized transfer [4].

Radioactive sources, such as ^{137}Cs, play a crucial role in radiation applications, serving both small-scale calibration and larger industrial and medical contexts. In Indonesia, we have had an experience orphan sources case known as the Batan Indah case in Indonesia. In January 2020, an orphan sources containing ^{137}Cs was found in the residential area of Batan Indah [5]. This study aims to simulate scenarios involving orphan sources, cleanup, and remediation based on the Batan Indah case using the PHITS code to obtain effective dose rates. Our primary objective is to optimize the remediation process cover to achieve simulated effective dose rates similar to the natural background radiation levels of 0.03 to 0.06 µSv/hr in the Batan Indah area [5].

2. Methods and Results

In our study, we created three scenarios: orphan sources, cleanup, and remediation. These scenarios mirror the practical steps taken by the Indonesian government in addressing the Batan Indah case. BAPETEN collaborated with other government institutions to conduct thorough measurements, define perimeters, measure dose rates, secure the orphan source, perform cleanup, decontamination, and site remediation. Subsequently, the Indonesian government issued a clearance status for the remediated area [6]. Fig. 1 illustrates the location of the orphan sources of ^{137}Cs at coordinates -6.326952, 106.671405. Three scenarios are simulated using the PHITS code, incorporating specific parameters for modeling each scenario.

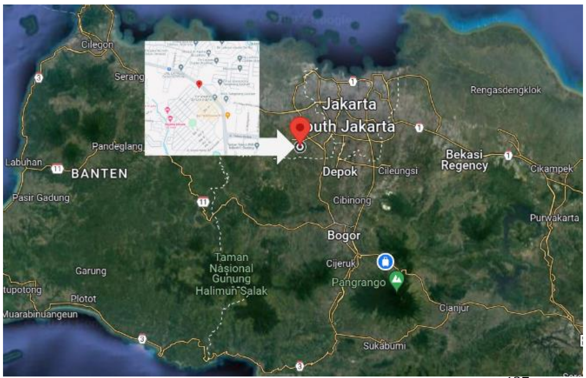

Fig. 1. A map of the location of the orphan source of ^{137}Cs at Batan Indah residential area

2.1 PHITS Code

The Particle and Heavy Ion Transport code System (PHITS) serves as a versatile Monte Carlo radiation transport code capable of simulating the behavior of various particle species with energies extending up to 1 TeV (per nucleon for ions) [7]. The most recent upgrade to PHITS occurred in 2023 [8]. Table I consists of data on the density of the layer used to simulate scenarios in the PHITS code.

Table I: Data for simulating the scenarios

Layer	Density (g/cm^3)	Ref.
soil	2.1	[9]
concrete	2.3	[10]

2.2 Orphan Source Scenario

In the orphan sources scenario, we recreated the Batan Indah case using ^{137}Cs as orphan sources from industrial devices with dimensions of length 3 cm and width 1 cm, and assumed that we found them at a thickness of 30 cm [11]. The assumed activity for ^{137}Cs is a minimum of 74 GBq or 2 Ci when utilized for gauging equipment following Indonesian regulatory [12]. Based on this, we make the assumption that ^{137}Cs orphan sources, which can no longer be used, have an activity of 7.4 GBq or 0.2 Ci. The simulation result from the PHITS code indicates that the effective dose rate at 10 cm above the ground (10 cm along the z-axis) is 194 µSv/hr. In the Batan Indah case, the measured dose rate at this height is 200 µSv/hr [5]. This indicates that the simulation closely represents the real situation in the Batan Indah case. Fig. 2 illustrates the flux from orphan sources at a depth of 30 cm below the ground using PHITS code.

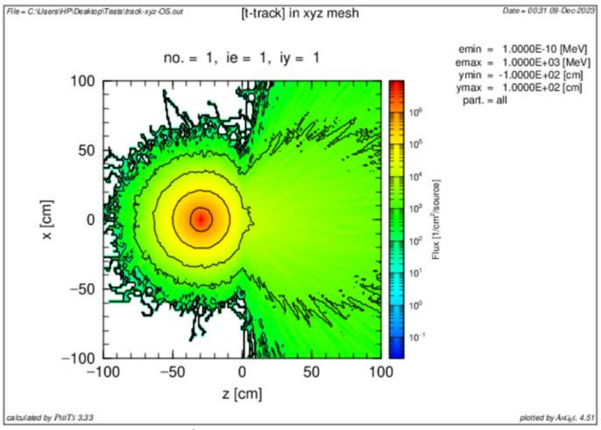

Fig. 2. The flux of ^{137}Cs in an orphan source scenario at a soil depth of 30 cm.

2.3 Cleanup Scenario

In the cleanup scenario, ^{137}Cs serves as an orphan source, which has been secured. The contaminated soil, with a thickness of 35 cm, is dredged and transported to a radioactive waste facility. Assuming the contamination layer's (thickness 0.0001 cm, radius 100 cm) activity of ^{137}Cs is 2.5% of the initial activity, it is estimated to be 0.185 GBq or 0.005 Ci. The simulation result from the PHITS code shows that the effective dose rate at 10 cm above the contamination layer of ^{137}Cs is 72.51 μSv/hr. Fig. 3 illustrates the flux from the cleanup scenario.

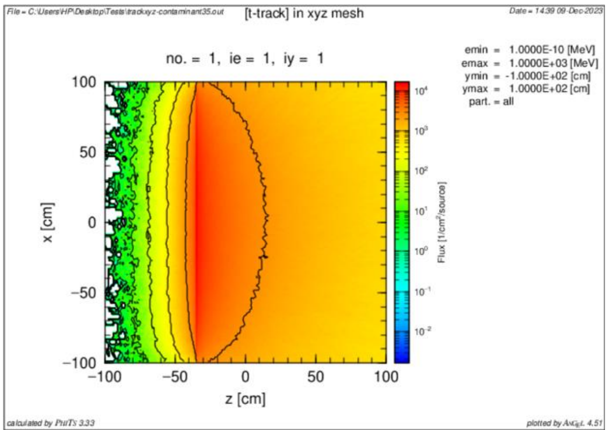

Fig. 3. The flux from contamination layer of ^{137}Cs after clean-up scenario

2.4 Remediation Scenario

In the final scenario, remediation actions were taken in this area. We conducted a sensitivity analysis for the 35 cm cover layer, varying the soil layer alone, concrete layer alone, and a combination of both soil and concrete layers. Fig. 4 displays flux differences as part of a sensitivity analysis for each variation in the cover layer. Based on PHITS code results, shows in Fig. 5 the lowest effective dose 0.059 μSv/hr was observed with a 5 cm soil layer and a 30 cm concrete layer. These rates are comparable to the natural background radiation in the Batan Indah residence area 0.03 to 0.06 μSv/hr [5], and this interesting finding needs further investigation.

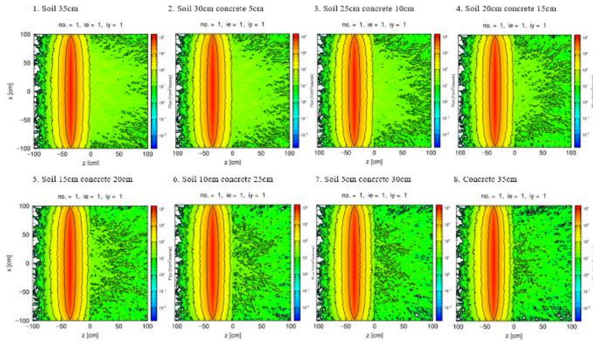

Fig. 4 shows graphics depicting the flux from the remediation scenario with variations in cover soil thickness and concrete thickness.

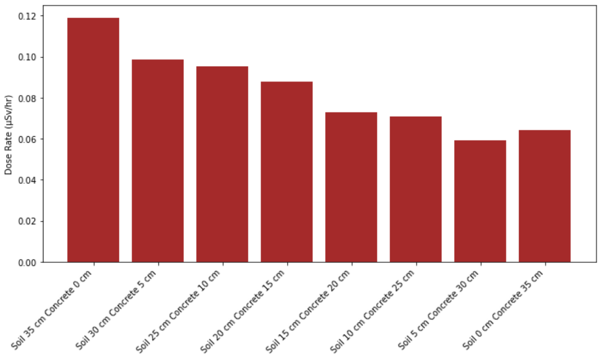

Fig. 5. Dose Rate vs Cover Thickness Variation

3. Conclusions

Simulating the Batan Indah case with the PHITS code for three scenarios provides the following results: the estimated effective dose for the orphan sources scenario is 194 μSv/hr, for the cleanup scenario it is 72.51 μSv/hr, and for the remediation scenario, the optimal combination of a 5 cm soil cover and a 30 cm concrete layer results in an estimated dose of 0.059 μSv/hr comparable to the natural background radiation in the Batan Indah residence area, ranging from 0.03 to 0.06 μSv/hr.

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