

Monte Carlo Simulation of Radiation Dose in a Dismantling Room for Disused Sealed Radioactive Sources

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***Keywords:** disused sealed radioactive sources (DSRS), dismantling, dose, PHITS

1. Introduction

Disused Sealed Radioactive Sources (DSRS) are a byproduct of widespread applications of sealed radioactive sources in industry, medicine, and research. Over time, as these sources reach the end of their operational life, they must be managed safely to avoid potential radiation exposure to workers and the environment. Dismantling DSRS is a particularly sensitive stage that involves close handling of gamma-emitting radionuclides such as ^{137}Cs and ^{60}Co , which can lead to significant occupational doses if not properly controlled [1]. Therefore, understanding the spatial dose distribution and shielding effectiveness within a dismantling facility is critical for ensuring radiation protection and adhering to dose constraints.

The dismantling room studied in this work is a 40 cm thick concrete wall, containing two steel workstations: a primary dismantling table and a secondary table for placing the dismantled capsules. The main table includes a 1 cm thick lead-glass viewing window for operators to observe and visually check the DSRS. During dismantling, the worker stands behind the lead-glass while a point-source is placed on the table. With typical DSRS activities ranging from 50, 100, and 200 mCi for Cs-137 and 10, 25, and 50 mCi for Co-60, even brief exposures may accumulate substantial doses over time [2]. Although the dose limit is set to 20 mSv/year per worker, daily exposures could exceed 80 μSv , particularly if shielding or layout is suboptimal [3].

To evaluate the radiological conditions within the room, we utilize the Particle and Heavy Ion Transport code System (PHITS), a general-purpose Monte Carlo code suitable for simulating photon and neutron transport. PHITS enables detailed modeling of facility geometry, source characteristics, material shielding, and ambient air conditions [4]. This study aims to quantify the dose rate distribution within the dismantling room, focusing on the operator's exposure during active dismantling. Based on the simulation outcomes, we also assess whether additional local shielding or design modifications are necessary to meet ALARA (As Low as Reasonably Achievable) principles and enhance worker safety in future dismantling operations.

2. Method and Results

DSRS presents significant radiation hazards during dismantling. To quantify the room dose rate map, we

constructed a detailed Monte Carlo model of the dismantling room in PHITS. The geometry is a $7 \times 5 \text{ m}^2$ concrete-walled room (0.40 m wall thickness) containing two workstations: the main dismantling table ($2 \times 1.5 \text{ m}$) and a secondary table ($1.5 \times 1.0 \text{ m}$). A single DSRS (either ^{137}Cs or ^{60}Co , modeled as a 2 cm cylindrical source) is placed at the main table. A leaded-glass window ($0.50 \times 0.70 \text{ m}$, 1 cm thick) is included at the worker's station. All components and materials defined using PHITS geometry are detailed in Table 1. We used the PHITS code to transport γ -rays from the source through the room. PHITS has been extensively benchmarked for radiation transport and shielding applications, and its use in similar dosimetry studies has been experimentally validated [5].

Table 1. Material Composition

Material	Density (g/cm ³) [6]	Description
Source: Stainless steel (SS 304)	8.03	Cylinder
Air	0.001205	Surrounding the whole room
Concrete-portland	2.3	Whole walls, roof, and floor
Lead brick	11.35	Brick shielding
Lead glass	6.22	Glass shielding
Mild-steel	7.872	Workstation

Based on Table 1, the design was made and the results of the geometry input parameter are shown below in Fig. 1 and Fig. 2.

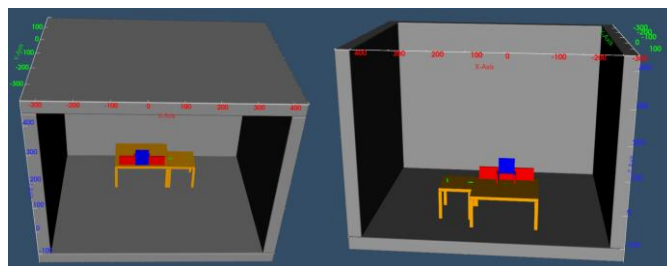


Fig. 1. The dismantling room from side and upper view (left to right)

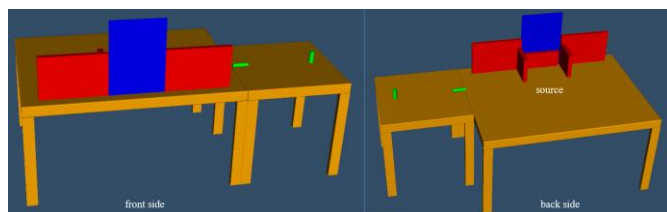


Fig. 2. The dismantling workstations from the front and back view (left to right)

2.1 Simulation Setup

The PHITS simulations were configured to accurately model photon transport and dose deposition throughout the dismantling room. A two-dimensional mesh tally was defined at a constant height of 110-160 cm above the floor (representing the typical human height organ), with each grid measuring 100×100 cm resolution. Within each grid, energy deposition from γ -rays was recorded and subsequently converted to dose

rate ($\mu\text{Sv/h}$) using established fluence-to-dose conversion factors. A total of 1×10^6 particle histories were tracked per run. This combination of fine spatial resolution, realistic source spectra, and high particle statistics ensured that uncertainties in high-dose regions remained below 5% and that scatter effects from walls, workstations, and the lead-glass window were fully accounted for.

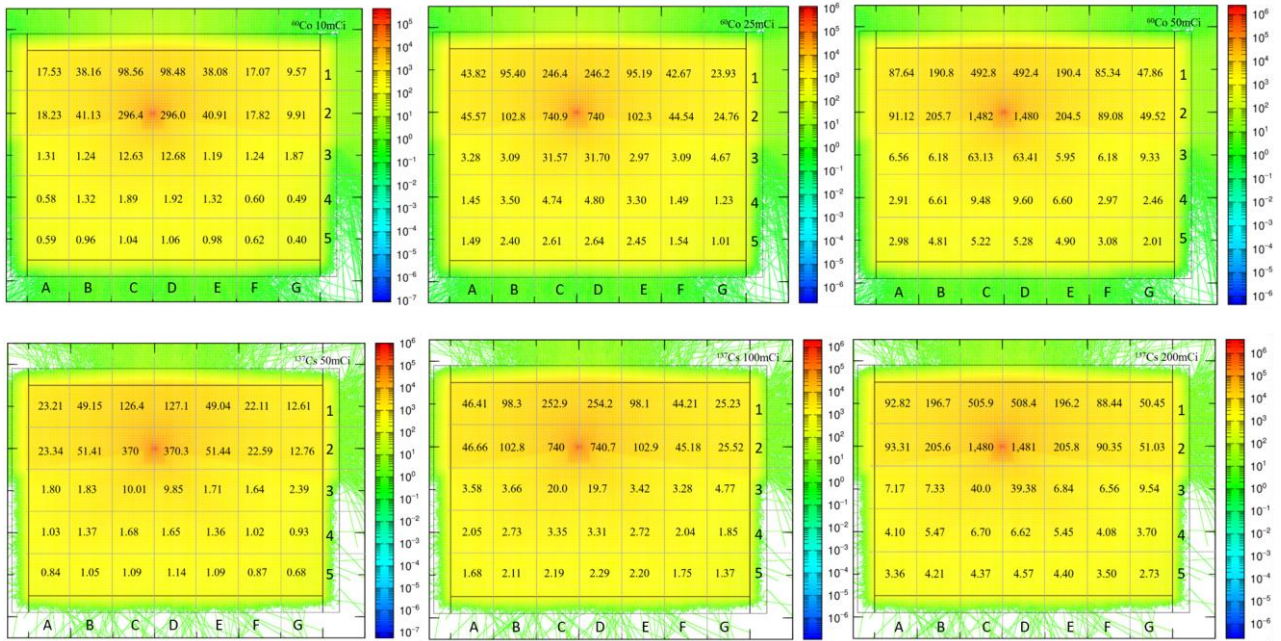


Fig. 3. Fluence particle along with the dose rate distribution for the entire dismantling room in $\mu\text{Sv/h}$

2.2 Simulation Results

^{60}Co and ^{137}Cs are widely used gamma-emitting radionuclides in industrial and medical applications, each with distinct decay characteristics affecting radiation protection strategies. ^{60}Co undergoes beta decay, emitting energetic beta particles and subsequently two high-energy gamma photons with energies of approximately 1.17 MeV and 1.33 MeV, both with nearly 100% intensity [8]. The beta particles are generally absorbed near the source or within shielding materials and thus contribute minimally to external exposure. However, the penetrating gamma rays require substantial shielding, particularly in occupational environments where workers may be exposed for extended durations. ^{137}Cs , by contrast, decays into a metastable daughter, $^{137\text{m}}\text{Ba}$, which emits a single gamma photon at 661.7 keV in about 85.1% of decays [9].

Figure 3 shows the fluence particle distribution along with the effective dose-rate for the entire dismantling room ($\mu\text{Sv/h}$) on the 110-160 cm from the floor, as representative human height. The maps reveal a pronounced “hot spot” (grid C2-D2) directly in the dismantling table, where fluence peaks at roughly $296 \mu\text{Sv/h}$ for 10 mCi ^{60}Co and scales nearly linearly to about $1,480 \mu\text{Sv/h}$ for 50 mCi ^{60}Co ; ^{137}Cs

follows a similar trend, with $370 \mu\text{Sv/h}$ at 50 mCi rising to approximately $1,482 \mu\text{Sv/h}$ at 200 mCi. Moving just one grid cell (C3-D3) away from the source, the dose rate drops to $\sim 63 \mu\text{Sv/h}$ at 50 mCi ^{60}Co and $\sim 40 \mu\text{Sv/h}$ at 200 mCi ^{137}Cs . This grid is the worker's standing location for visual observation during dismantling activities. Dose falls off steeply with distance: moving below a single grid step reduces the rate by roughly 70%, underscoring the efficacy of simple distancing. Statistical uncertainties in each grid remained below 5%, confirming the robustness of these results.

Comparing these rates to occupational dose limits shows that allowable exposure times are very short in the high-rate zones. Using the standard occupational limit of 20 mSv/year (20 mSv/250 work-days $\approx 80 \mu\text{Sv/day}$), one can compute the maximum time per day a worker could remain in each zone. For example, at $12 \mu\text{Sv/h}$, the $80 \mu\text{Sv}$ daily budget is used up to 400 min; at $30 \mu\text{Sv/h}$ is up to 154 min are allowed. In contrast, at $63 \mu\text{Sv/h}$ as the highest dose rate in the worker area (C3–D3 for 50 mCi ^{60}Co), the time allowed is up to 76 min. In practical terms, a single worker can work within 1 hour to conduct a conservative analysis. These simple calculations (time_max $\approx 80 \mu\text{Sv} / \text{dose rate}$) make clear that staying near the source or window, even for fractions

of an hour, can consume the dose budget. Because direct visual inspection and manual handling cannot be fully avoided, optimization must emphasize shielding. In practice, this means adding local shields (lead apron) at the hottest regions and increasing the lead-glass thickness of the viewing port. Thus, the lead apron barrier would significantly reduce the dose reaching the worker's torso. Likewise, doubling the lead-glass thickness (lead-equivalent ~3 cm) would reduce the transmitted dose to a few percent (as typical HVL data imply) while still allowing visual monitoring. These results underscore the necessity of keeping operators behind the lead glass barrier and of considering supplemental mobile shields or remote handling to maintain exposures well within ALARA targets.

3. Conclusions

This analysis underscores that radiation safety hinges on managing time near sources and maximizing shielding. The very high dose rates close to ^{60}Co (up to 63 $\mu\text{Sv/h}$ in the worker area) allow up to 1 hour of unshielded exposure before regulatory limits are reached. Our simulation results (dose drop-off with distance and partial lead barriers) are entirely consistent with practical observations. In real experience, the comparison with the real measurement equipment should be conducted to enhance the working planning and management. Thus, placing operators behind thick lead glass, wearing aprons, and using time management are effective real strategies. In summary, even simple added shielding and a few seconds more distance can cut exposures to a few percent, keeping occupational doses comfortably below limits.

Acknowledgment

This research was supported by the 2025 Research Fund of KEPSCO International Nuclear Graduate School (KINGS), the Republic of Korea.

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