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Monte Carlo Evaluation of Radiation Dose Distribution in a 10 MeV Electron Beam Irradiation Facility

Banyapha Ubonsa-ard[a,b], Juyoul Kim[a*]
[a]*Department of Nuclear Power Plant Engineering, KEPCO International Nuclear Graduate School, 658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan 45014*
[b]*Office of Atoms for Peace (OAP), Vibhavadi Rangsit Road, Chatuchak, Bangkok 10900, Thailand.*
[*]*Corresponding author: jykim@kings.ac.kr*

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1. Introduction

Electron beam (E-beam) systems with energies up to 10 MeV are widely used in Thailand for medical sterilization, food irradiation, and material processing. When high-energy electrons strike the titanium exit window, Bremsstrahlung X-rays are produced. These secondary photons can penetrate shielding materials and potentially expose nearby workers. Although such facilities are designed with radiation shielding, actual dose levels during full-power operation or abnormal conditions may differ from the original design assumptions. To comply with Thailand's occupational dose limit of 20 mSv per year, radiation levels around the facility must be verified. In this study, the Particle and Heavy Ion Transport code System (PHITS) is used to model the geometry and materials of a 10 MeV electron beam irradiation facility, simulate the radiation distribution, and evaluate effective dose rates at worker-accessible locations. The objective is to confirm compliance with national radiation safety regulations and to support radiation protection and shielding optimization decisions.

2. Methods and Results

In this study, the PHITS was used to evaluate the radiation dose distribution around a 10 MeV electron beam irradiation facility. PHITS is a general-purpose Monte Carlo particle transport simulation code that has been widely applied in accelerator technology, radiotherapy, space radiation studies, and radiation shielding analysis [1]. The geometry of the electron beam shielding facility is shown in Fig. 1. The light-blue region represents the air inside the building, while the brown region corresponds to the concrete walls serving as the radiation shielding structure. The floor of the building is modeled as a concrete slab with a thickness of 250 cm, providing sufficient shielding against downward radiation streaming. The ceiling is also composed of concrete with a thickness of 200 cm, reducing upward radiation leakage. The material compositions and densities used in the PHITS simulation are summarized in Table I.

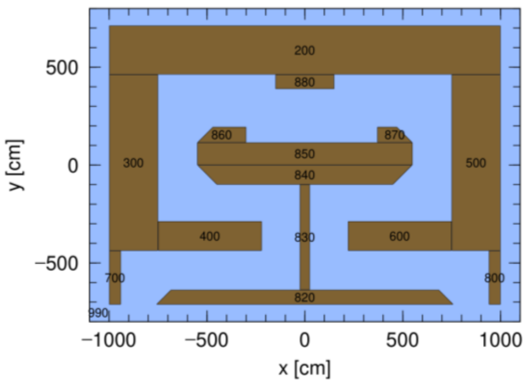

Fig. 1. First-floor layout of the electron beam facility

Table I: Material data of the electron beam

Material		Composition	
	Density (g/cm^3)	Element	Weight Fraction
Air	0.001205	N	0.784429
		O	0.210750
		Ar	0.004671
Concrete	2.3	H	0.001416
		C	0.562526
		O	0.011838
		Na	0.001400
		Al	0.021345
		Si	0.204119
		K	0.005656
		Ca	0.018674
		Fe	0.004264
Titanium alloy	4.43	C	0.003011
		O	0.005650
		N	0.001614
		H	0.006727
		Fe	0.003238

Al	0.102610
V	0.035493
Ti	0.841657

According to the recommendations of the International Commission on Radiological Protection (ICRP) and the regulations of the Office of Atoms for Peace (OAP), the annual effective dose limits are 20 mSv for occupational workers and 1 mSv for members of the general public [2]. The electron fluence distribution shown in Fig. 2 indicates that the highest fluence occurs directly below the titanium exit window, where the electron beam emerges from the accelerator. The red-colored region represents the primary interaction zone. As electrons propagate through air and concrete, their fluence rapidly decreases, and negligible leakage is observed outside the shielding. The X-Y and X-Z plane results confirm that electron fluence is well confined within the irradiation room. The photon fluence distribution shown in Fig. 3 demonstrates a broader spatial spread due to the higher penetration capability of Bremsstrahlung photons generated at the titanium window. Although photons penetrate deeper into the surrounding structures, their intensity significantly decreases outside the shielding. This confirms the effectiveness of the concrete walls in attenuating secondary photon radiation.

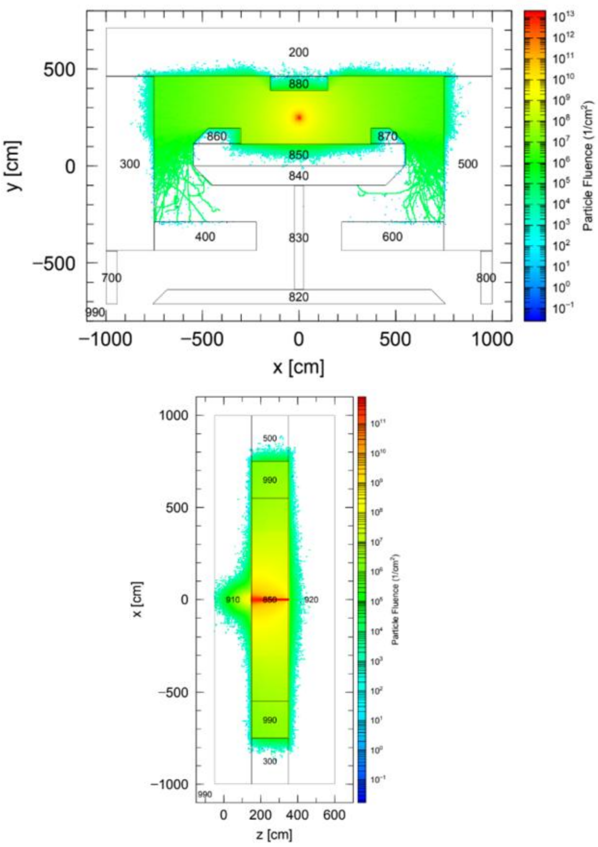

Fig. 2. Electron fluence distribution in the X-Y plane and X-Z plane.

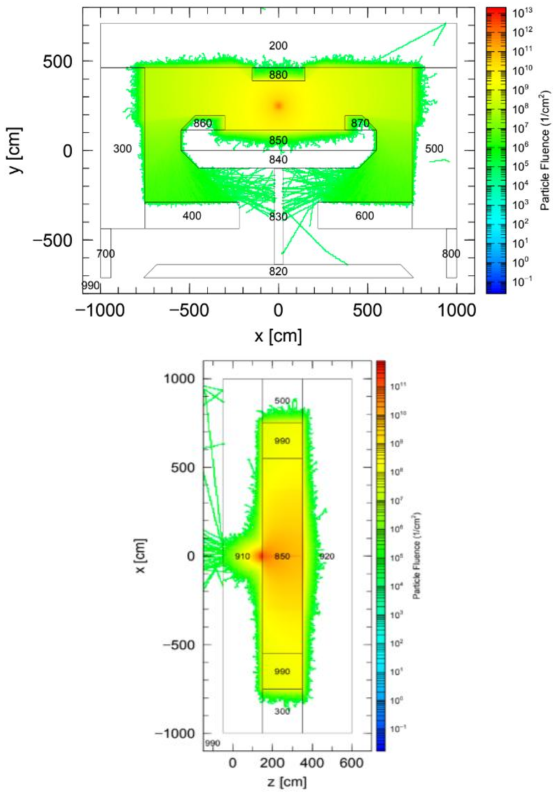

Fig. 3. Photon fluence distribution in the X-Y plane and X-Z plane.

Fig. 4 presents the effective dose rate distribution of electrons in the X-Y plane. A high-dose region is observed only below the titanium exit window, where the 10 MeV electron beam exits the accelerator. Electrons rapidly lose energy in air and are fully absorbed upon reaching the concrete walls. Fig. 5 shows the effective dose rate distribution of photons in the X-Y plane. The highest photon dose rate appears near the titanium window, where Bremsstrahlung photons are generated. Although photons travel farther than electrons, the concrete shielding effectively attenuates them, and no significant dose rate is observed outside the shielding structure.

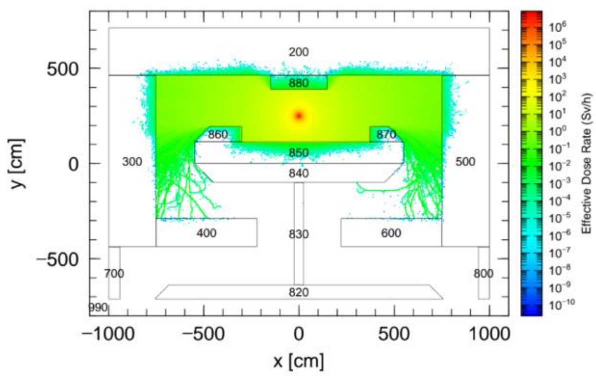

Fig. 4. Effective dose rate distribution by electron.

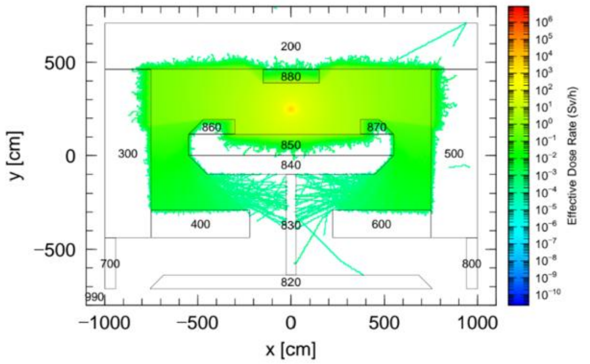

Fig. 5. Effective dose rate distribution by photon.

The effective dose rate along the X-axis from the source is shown in Fig. 6. The maximum dose occurs at the closest position to the source (0–5 cm), with a total dose rate of approximately 1.23 × 10^{12} µSv/h. This extreme value results from the direct electron beam and concentrated Bremsstrahlung photons at the exit window. As distance increases, the dose rate decreases by several orders of magnitude and approaches zero beyond the shielding wall, confirming adequate radiation attenuation. Similarly, the effective dose rate along the Y-axis was evaluated to assess side-wall shielding performance as shown in Fig. 7. After passing through the concrete shielding, the dose rate rapidly decreases to negligible levels, demonstrating effective protection in worker-accessible areas.

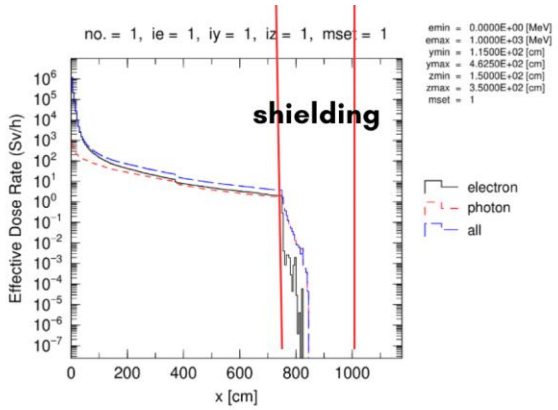

Fig. 6. Effective dose rate along X from source.

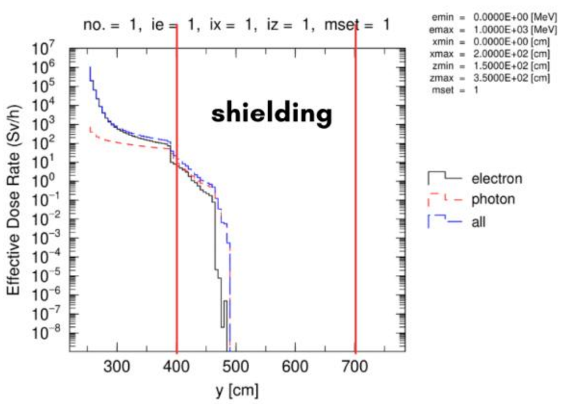

Fig. 7. Effective dose rate along Y from source.

Table II and Fig. 8 present the effective dose rates at key worker locations, including the entrance, exit, side walls, and back wall of the facility. The calculated dose rates at all evaluated locations are approximately 0 µSv/h, which is far below the Thai occupational dose constraint of 10 µSv/h. These results confirm that routine operation poses no radiological risk to workers.

Table II: Effective dose at the key locations

Location	Coordinate	Effective Dose(µSv/h)	Status
Entrance	(-850,705,150)	0	Safe
Exit	(850,705,150)	0	Safe
Side wall (left side)	(-1005, 0, 150)	0	Safe
Side wall (right side)	(1005, 0, 150)	0	Safe
Back wall	(0, 705, 150)	0	Safe

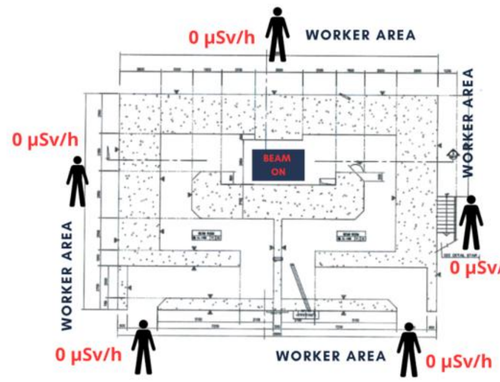

Fig. 8. The key locations of workers.

3. Conclusions

The radiation dose distribution around a 10 MeV electron beam irradiation facility was evaluated using PHITS Monte Carlo simulations. The results demonstrate that Bremsstrahlung X-rays generated at the titanium exit window are effectively attenuated by the concrete shielding structure. Although extremely high dose rates occur near the beam exit, radiation levels decrease rapidly beyond the shielding walls. At all worker-accessible locations, the calculated dose rates are significantly below the Thai regulatory limit of 10 µSv per hour. Therefore, the current shielding design is considered adequate for full-power operation. This study confirms that the facility provides a safe working environment and complies with national radiation safety standards.

Acknowledgment

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REFERENCES

[1] T. Sato et al., PHITS: Particle and Heavy Ion Transport code System, Version 3.35 User Manual, Japan Atomic Energy Agency, 2022.
[2] Office of Atoms for Peace, Ministerial Regulation on Radiation Safety B.E. 2561, 2018.