Journal of RADIATION INDUSTRY
Vol. 19, No. 1, pp. 101-106, 2025
https://doi.org/10.23042/radin.2025.19.1.101

Technical article

Shielding Evaluation for the Cabinet-Type 200 kV Radiation Generator Using MCNP

Gyo-Seong Jeong[1], Sang-Bong Lee[1,2], Hyun-Jin Lee[1], Dae-Sung Choi[1], and Hwa-Yeon Yeo[3,*]

[1]Radiation Protection Team, Korea Atomic Energy Research Institute, 29, Geumgu-gil, Jeongeup-si, Jeollabuk-do 56212, Republic of Korea
[2]Department of Quantum System engineering, Jeonbuk National University, 567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do 54896, Republic of Korea
[3]Nambu University, 1, Nambudae-gil, Gwangsan-gu, Gwangju 62271, Republic of Korea

ABSTRACT The Advanced Radiation Research Institute's Electron Beam Demonstration Research Center has 10, 2.5 MeV, and 200 kV radiation generators. At the Electron Beam Demonstration Center, atmospheric purification, cross-linking, and grafting technologies using electron beams can be used in the functional material development process, and the treatment process can be simplified compared to existing chemical treatment methods. It is also an environmentally friendly technique in terms of pollutant generation. We plan to use these radiation generators to develop various functional materials such as air purification, medical materials, nano bio center electrodes, conductive nanocomposites, and low-cost graphene fillers. This study calculated the radiation leaking outside the cabinet during operation of a 200 kV radiation generator, a cabinet-type radiation device, and calculated the expected radiation dose rate at key locations inside and outside the radiation generator using the MCNP code. The maximum values of radiation dose rates were identified as 7.21 μSvh^{-1} at the upper part of the source room, 8.97 μSvh^{-1} on the floor of the utility room, and 4.23 and 4.02 μSvh^{-1} in the ventilation and electrical corridors, respectively. These values meet the standard of 10 μSvh^{-1} for the surface radiation dose rate of the cabinet-type radiation equipment (Article 17, Section 5 of Notice No. 2018-1 by the Nuclear Safety and Security Commission).

Key words: Radiation generator, Shielding calculation, MCNP code

1. Introduction

The Advanced Radiation Research Institute (hereinafter referred to as the 'ARTI') at the Korea Atomic Energy Research Institute conducts research and development of various utilisation technologies using unsealed radioactive isotopes, sealed radioactive isotopes, and radiation generators. It promotes the use of radiation technology in various industries across our entire industry and conducts fundamental research on materials, biology, food and other fields.

Among the facilities utilizing radiation generators at the ARTI, the Radiation Equipment Research and Fabrication Center (hereinafter referred to as the 'Center') operates a 10MV linear accelerator, a 2.5 MV linear accelerator, and a 200 kV radiation generator. The linear accelerators installed at the Center aim to expand practical applications through supporting proof-of-concept research for the radiation industry and create new industries in the future. The fields of application for the linear accelerators are diverse. In the research and support field, they include energy materials such as battery and solar cell materials for verification research, carbon fiber and floater materials for verification research on composite materials containing carbon, and medical materials such as patches, micro-needles, and artificial blood vessels. Therefore, the Center is aimed at fostering domestic radiation industries through customized proof-of-concept research support tailored to the needs of the radiation industry.

Among the important matters for safe operation of electron beam testing centers equipped with these linear accelerators is evaluating radiation shielding. Linear accelerator facilities are installed behind concrete shielding walls. The facility calculates and compares/analyzes the occupational exposure dose to external workers and members of the public from radiation caused by the direct electron beams or deceleration radiation resulting from the electron beams, in order to provide reference data to other institutions that operate similar setups [1].

ISSN 1976-2402 **http://www.ksri.kr/**

Copyright© 2025 by Korean Society of Radiation Industry

***Corresponding author:** Hwa-Yeon Yeo
Tel: +82-62-970-0157, Fax: +82-62-970-0118, E-mail: yhy@nambu.ac.kr

Received 22 January 2025 **Revised** 18 March 2025 **Accepted** 24 March 2025

In this study, we employed the Monte Carlo N-Particle Transport Code (MCNP) to calculate and evaluate the dose rate outside a 200 kV cabinet-type radiation source installed in an electron beam facility and compared it with the standards of the Nuclear Safety Act taking into account the working hours of radiation workers [2].

2. Materials and Methods

2.1. 200 kV Radiation Generator Overview

A 200 kV radiation generator (hereinafter referred to as the 'radiation generator') was developed for the purpose of developing air purification technology, developing medical materials based on polymers, developing energy materials using polymers, developing conductive nano-composite materials for use in electrode materials for nano-biosensors, and mass-producing low-cost graphene-based composite materials [1].

The radiation generator is composed as shown in (Fig. 1). Limit switches are attached to all doors of the activation device, as shown in (Fig. 2), so that operation cannot be performed if any door is not closed. Additionally, a key-lock mechanism is installed on each door so that it cannot be opened during operation of the electron generator. If the shield door is open while the device is operating, the control program automatically stops the activation device. A warning device in the form of an alarm light is installed at the top of the shield cabinet, and a red light is lit during device operation, green during standby mode, and yellow with an alarm sound during emergency situations [1].

2.2. Evaluation of shielding using MCNP code

The radiation generator in this setup is a cabinet-type radiation generator and has minimized the leakage of radiation outside the cabinet during operation. The radiation leakage due to the radiation source is caused by the interaction between electrons and internal structures, resulting in braking radiation. Therefore, for shielding against braking radiation, lead shielding materials were placed between the 2mm thick steel inner and outer casing materials as shown in (Table 1). Additionally, using the MCNP code, we calculated the predicted radiation dose rates at major positions within the cabinet as depicted in (Fig. 3) [1].

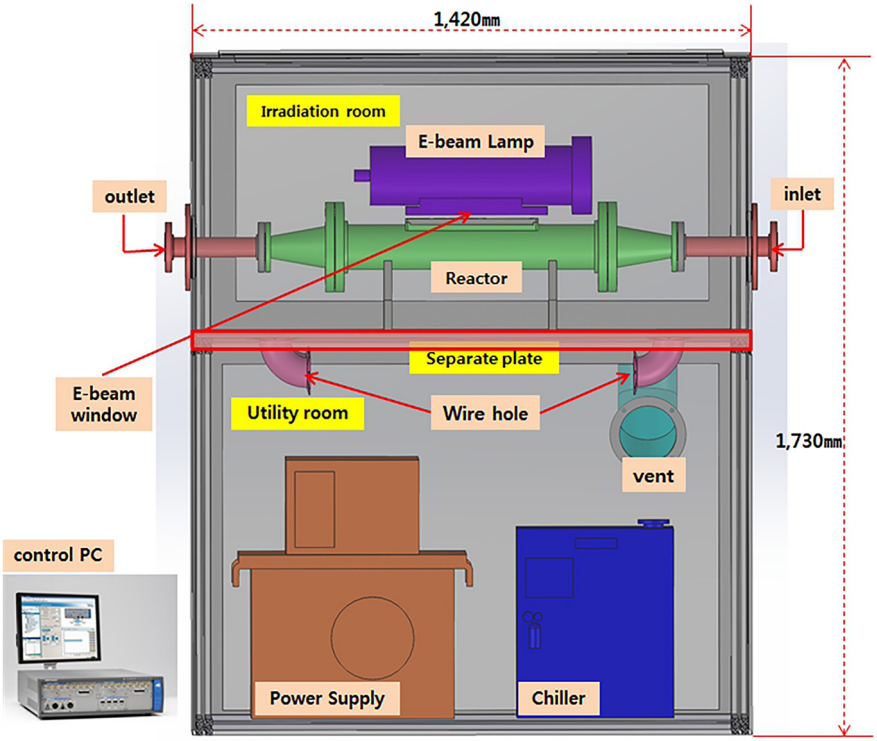

Fig. 1. 200 kV radiation generator schematic diagram.

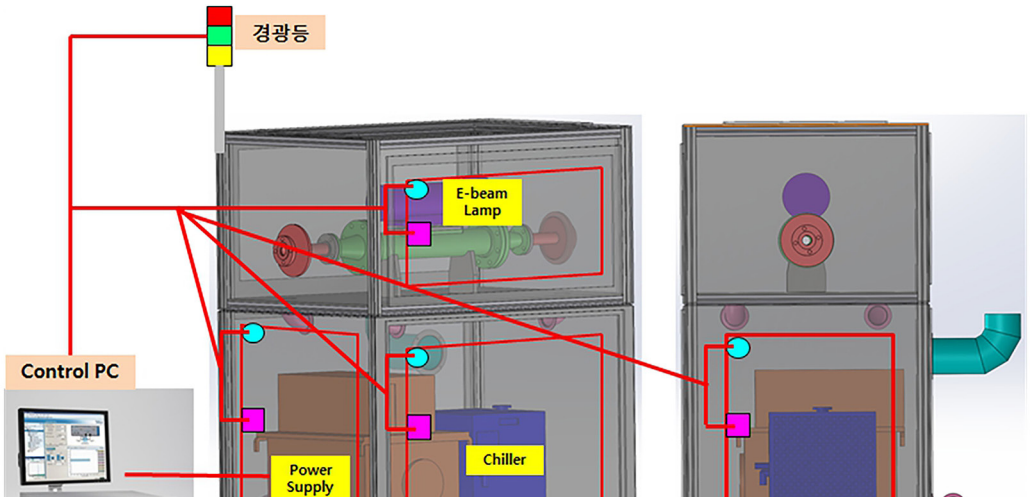

Fig. 2. Shielding door schematic diagram.

Table 1. Thickness of Source and utility room

	Front, Back, Side	Top	Bottom
Source room	11 mm	11 mm	12 mm
Utility room	5 mm	12 mm	5 mm

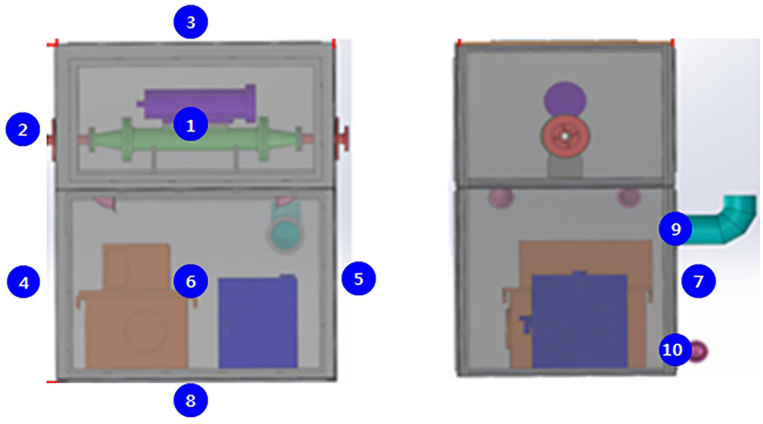

Fig. 3. Source room bulk Dose rate calculation location.

3. Results

3.1. Source room bulk shielding calculation

A cylindrical electron beam with an energy of 200 kV and a current density of 18.7 mA is directed along the -Z-axis, and shielding assessments have been performed in the front, side, and top directions. The computational model used is as shown in (Fig. 4). Since the source position is located at the center of the source room and the beam direction points downwards, the front and (left) sides correspond to the rear and (right) sides, respectively. The dose assessment for each direction's lead shielding was calculated using an F2 tally from 1 to 19 mm. In dose calculation, the ICRP74 dose conversion factor was applied. Additionally, a geometry splitting method with a variance reduction technique was used to enhance computational efficiency [1,2,3].

The results of the dose calculations for the source room in the front, side, and top directions according to different lead thicknesses are shown in (Fig. 5). The lead thickness that satisfies the surface radiation dose rate criterion of 10 $\mu Sv h^{-1}$ (as per Notification No. 2018-1 from the Nuclear Safety and Security Commission, Article 17, Paragraph 5) for cabinet-type radiation equipment is as listed in (Table 2). During operation, the actual shielding thicknesses of the source room were found to be 11

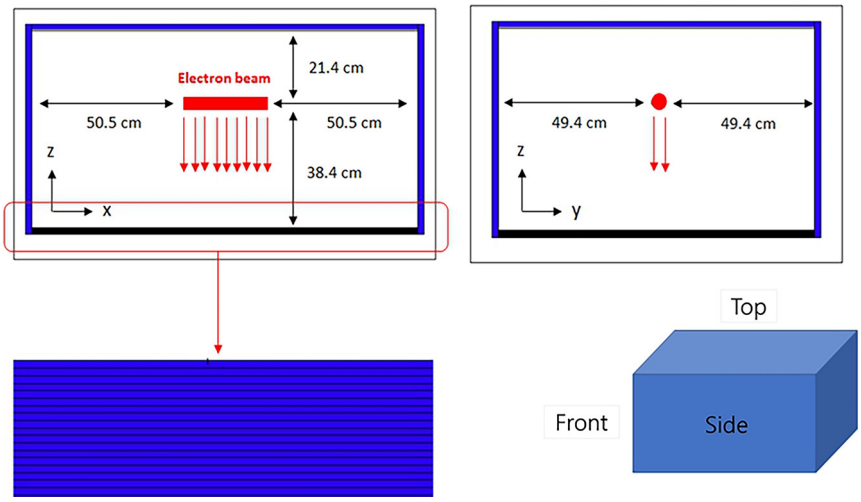

Fig. 4. Source room bulk shielding calculation model.

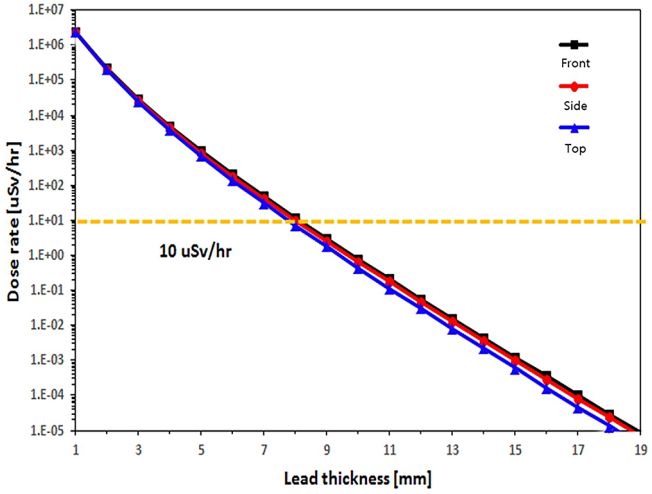

Fig. 5. Does rate according to source room shielding thickness.

mm on the front/rear, sides, and top, while it was 12 mm on the bottom. The surface dose rate during operation is expected to be lower than currently measured [4,5].

3.2. Utility room bulk shielding calculation

A 200kV electron beam does not directly head towards the utility room but, upon reacting with lead on the deck of the control room, produces a deceleration X-ray that emerges through holes in the control and utility rooms. The radiation dose evaluation for each direction's lead shielding was performed using an F2 tally up to 1~5 mm to calculate the front, side (left, right), rear, and bottom directions of the utility room, and the calculation model is as shown in (Fig. 6). The photon spectrum of the radiation-emitting device is shown at various angles as depicted in (Fig. 7). In the dose calculation, the ICRP74 dose conversion factor was applied, and a variance reduction technique using the geometry splitting method was employed for efficient calculations [2,3].

The results of the dose calculations for various thicknesses of lead in front, side (left and right), rear, and bottom directions are shown in (Fig. 8), and the corresponding thicknesses of lead that satisfy a surface dose rate of 10 μSvh^{-1} according to the standard established by the Nuclear Safety Commission (Korean Government Ordinance No. 2018-1, Article 17, Clause 5) are listed in (Table 3). It is estimated that the actual shielding thickness for the utility silo will be 5 mm in all directions during operation of the generator, resulting in a lower surface dose rate [6].

3.3. Ventilation pipe and electrical wiring pipe

The gamma rays resulting from the irradiation of a 12 mm thick lead with electrons, as shown in (Fig. 9), were used for the central dose rate measurement at the ventilation pipe and elec-

Table 2. Calculation result of source room

ROI		Lead thickness for limits (10 μSvh^{-1})	Radiation rate (μSvh^{-1})	Relative error (%)
①	Side	9 mm	2.54	4
②	Front	9 mm	2.98	3
③	Top	8 mm	7.21	2

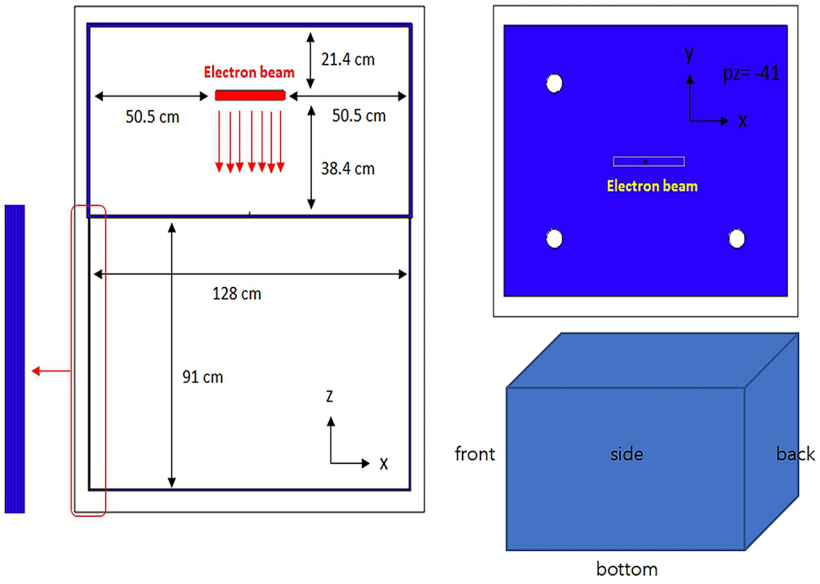

Fig. 6. Utility room bulk shielding calculation model.

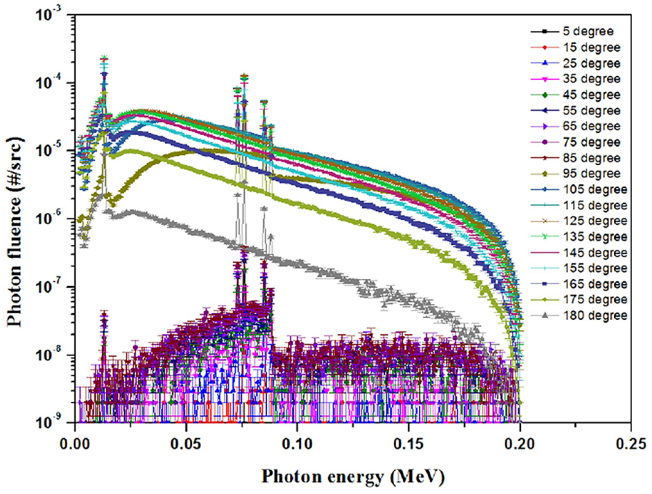

Fig. 7. Photon spectum of Radiation Generator by angle.

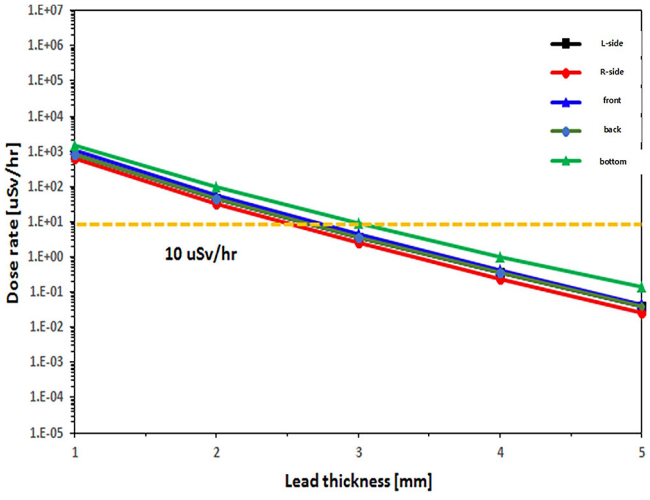

Fig. 8. Does rate according to utility room shielding thickness.

Table 3. Calculation result of utility room

ROI		Lead thickness for limits (10 μSvh^{-1})	Radiation rate (μSvh^{-1})	Relative error (%)
④	front	3 mm	4.58	6
⑤	back	3 mm	3.66	8
⑥	L-side	3 mm	3.61	7
⑦	R-side	3 mm	2.59	8
⑧	bottom	3 mm	8.97	6

trical wiring pipe. The dose evaluation was performed using the F5 tally, and the ICRP74 dose conversion factor was applied to the dose calculation. The results are shown in (Table 4) [2,3].

4. Conclusions

The radiation levels at the point of interest due to leakage ra-

Table 4. Calculation result of ventilation pipe and electrical wiring pipe

	ROI	Radiation rate (μSvh^{-1})	Relative error (%)
⑨	ventilation pipe	4.23	1%
⑩	electrical wiring pipe	4.02	5%

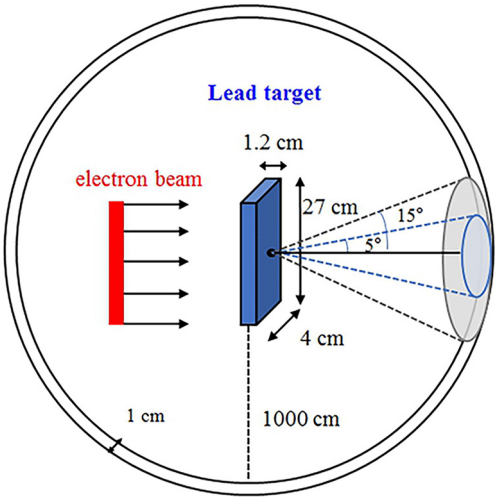

Fig. 9. Gamma source term calculation model.

diation were confirmed by calculations to be at background levels using the existing radiation generator, which is constructed from cabin materials and supplemented with lead shielding.

The maximum values of radiation dose rates were identified as 7.21 μSvh^{-1} at the upper part of the source room, 8.97 μSvh^{-1} on the floor of the utility room, and 4.23 and 4.02 μSvh^{-1} in the ventilation and electrical corridors, respectively. These values meet the standard of 10 μSvh^{-1} for the surface radiation dose rate of the cabinet-type radiation equipment (Article 17, Section 5 of Notice No. 2018-1 by the Nuclear Safety and Security Commission).

Additionally, limit switches are installed on all shield doors of the radiation generator, so that interlocks are set up to prevent operation unless the doors are closed. Furthermore, a key-lock system exists for each shielding door, such that interlocks are engaged during radiation generator operation to prevent forced opening of the doors. If the shield door is opened during device operation, the control program automatically stops the operation of the incident device. On top of the shield cabinet, an alarm system comprising red indicator lights is installed, which shine red during operation, green when the device is stopped, and yellow in emergency situations with a warning sound.

Therefore, the essential risk associated with the radiation generator is not only in terms of radiation intensity but can also be considered as physically sufficient.

Acknowledgements

This work was supported by a research grant from the Korea Atomic Energy Research Institute (Grant No. 523170-20).

References

1. HJ Lee, DS Choi, SB Lee and GS Jeong. 2020. *Radiation Safety Report of Radiation Use License for Radiation Generators in KAERI-ARTI.*
2. LANL. 2003. MCNP - A General Monte Carlo N-Particle Transport Code, Version 5, LA-CP-03-0245.
3. ICRP. 1996. Conversion Coefficients for use in Radiological Protection against External Radiation, *ICRP Publication 74,* ICRP 26 (**3-4**), ISSN 0146-6453.
4. Nuclear Safety Act, Enforcement Decree of the Nuclear Safety Act and Enforcement Regulation of the Nuclear Safety Act.
5. SH Moon, HS Choi, SK Kwon and JC Yook. 1987. Radiation Shielding Analysis for the X-ray Facility, *Journal of Radiation Protection and Research Vol.12* No.1:**34-39**, pISSN 2508-1888 (eISSN 2466-2461).
6. TH Kim, KS Kim, YJ Ahn, SA Yoo, SH Choi and SR Kim. 2010. Measurement of Lead's Shielding Capability for 300 kV or Less Radiation Generator Primary X-ray, *Journal of Radiation Protection and Research,* Vol.2010 No.11:**426-427**, pISSN 2508-1888.