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DESIGN OF RADIATION SHIELDING FOR THE PBP-CMU ELECTRON LINAC LABORATORY

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Abstract

The local radiation shielding is designed for the electron linear accelerator beam dump at the PBP-CMU Electron Linac Laboratory (PCELL) with the aim to control the annual ambient dose equivalent during the operation. The study of radiation generation and design of radiation shielding is conducted based on the Monte Carlo simulation toolkit GEANT4. The study results include an annual ambient dose equivalent map and design of local shielding for the first beam dump downstream the linac section. With this design, the leaking radiation outside the accelerator hall is completely blocked and the average annual ambient dose equivalent on the rooftop of the hall is within the IAEA safety limit for the supervised area. The shielding model will then be used as a guideline for the construction in the near future.

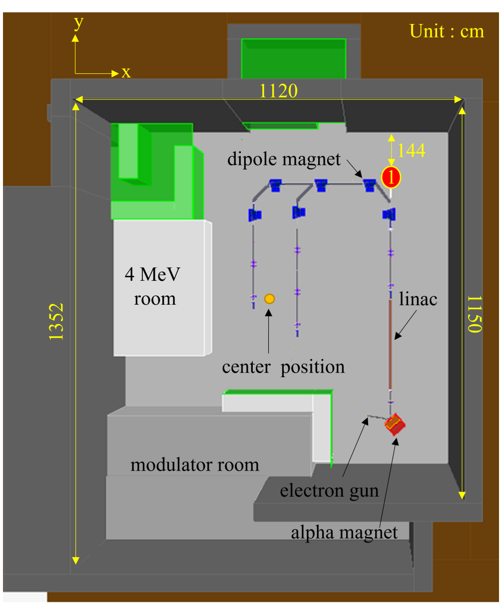

Figure 1: The top view of GEANT4 3D drawing of the PCELL accelerator hall based on the actual dimension. The linear accelerator (linac) can be seen as a red pipe housed inside the hall. The red circle with number 1 marks the position where the electron beam is dumped into a Faraday cup [1].

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INTRODUCTION

Operation of an electron linear accelerator can possibly produce unwanted ionizing radiations such as high energy photons and neutrons, with the fluence depending on the electron beam energy and charge. Our previous studies have shown that an electron beam with energy in the range of 10-25 MeV and the bunch charge of 60-80 pC is optimized for the generation of the aimed terahertz transition radiation (THz-TR), mid-infrared free-electron laser (MIR-FEL), and terahertz free electron laser (THz-FEL) at our facility [2–4]. Based on these energy and bunch charge ranges, we apply the Monte Carlo method for studying the radiation produced in the accelerator hall and the surrounding area. The local radiation shieldings are then designed for the case with highest radiation dose, which is the 25 MeV electron beam with a bunch charge of 60 pC hitting the beam dump. The aim of this study is to obtain the shielding design that can control the radiation to be below 6 mSv/year for the supervised area according to the annual ambient dose equivalent, *AADE* [5–7].

METHODOLOGY

Simulation setup

The accelerator hall with the accelerator system was constructed in the GEANT4 software as shown in Fig. 1. Beam dump No.1, which is the main focus of this study, is the first beam dump located downstream the linac structure. The concerned position of the radiation generated in this work is at the Faraday cup inside the beam dump No.1. The Faraday cup is a hallow copper tube with 10.35 cm of outer diameter and 5.74 cm of inner diameter. The vacuum tube with 5.74 cm of diameter is connected between the dipole beam dump chamber and the Faraday cup with the bending angle of 60°. The primary electrons were injected along the center line of this vacuum tube at the starting position of 25 cm directing to the Faraday cup. In the simulation, 1000 million primary electrons per task was suggested to prevent the empty bin for radiation fluence collection [1]. However, it would require enormous simulation time. Due to the time limitation, we took the advantage from the theory of sampling distribution of the mean, which states that the mean of the sampling distribution is approximately to the population mean [8]. Thus, we simulated ten times of 100 million primary electrons for one set of simulation. By using this method, the simulation

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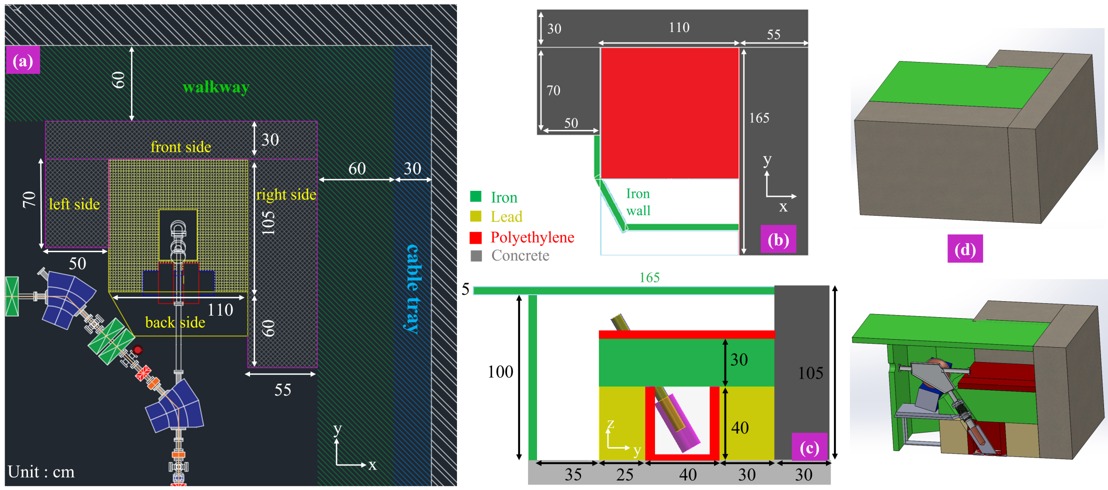

Figure 2: (a) The sketch of the beam dump No.1 and its local shielding with the surrounding area. (b) Top view and (c) side view of the final model of the shielding. (d) The 3D model of local shielding for the beam dump No.1 (top) and the model with cutting plane at center of the beam dump (bottom) [1].

time has dropped from 170 to 12 hours for each simulation set based on our CPU performance.

We then collected the radiation fluence (ϕ) of photons and neutrons with the bin of scorer size optimized at $10 \times 10 \times 10$ cm^3. Next, the fluence to ambient dose equivalent conversion coefficient (F) was used to convert the fluence to the ambient dose $H^*(10)$ map for the accelerator hall and the surrounding area. According to P. Jaikaew's thesis [1], F was calculated for the photon generated from an electron accelerator with energy ranging from 0.01 to 30 MeV. Our result was benchmarked with the ICRP reports and the simulation with FLUKA code [9, 10]. In case of neutron, the value of F was not performed in our work because it is not our major concern regarding low energy electron beam. Thus, we took the database provided by the ICRP report and from the study of Ferrari *et al.* [9, 11].

Radiation investigation

We investigated the radiation by collecting ϕ of generated photons and neutrons within the volume of 50×50×10 cm^3 surrounding the beam dump No.1. When dumping 100 million primary monoenergetic electrons (25 MeV) into the Faraday cup, the energy distribution of produced photons and neutrons are presented at two lateral levels, the center of the Faraday cup level (z=25 cm) and at the beamline height (z = 82.5 cm) where a beam loss monitor is generally located to investigate particles leaking out of a beam pipe [12]. We found that photons, the product of Bremsstrahlung interaction, have energies from a few keV to 25 MeV, while neutrons, which are the main product of the photonuclear reaction, have energies from a few eV to 10 MeV. The majority of photon energy range is about 0.15 to 5 MeV, corresponding to 96.50% and 98.37% of photons at the Faraday cup center and at the beamline height, respectively. With the same method, 98.15% of neutrons at the Faraday cup center and 97.32% of neutrons at the beamline height were found to have energy in a range of about 0.1 to 4 MeV. Therefore, these energy ranges are the major concern in the radiation shielding design.

RESULTS AND DISCUSSION

Our goal is to shield the above radiation with optimized cost of shielding materials and installation space. Lead and polyethylene are the primary considerations for shielding photons and neutrons, respectively. The space for radiation local shielding at the beam dump No.1 is limited by the available hall area, excluding the cable tray (30 cm from the wall), the required walkway for safety reasons, (60 cm from the cable tray), and the box space for Faraday cup (30×40 cm^2), as shown in Fig. 2 (a). According to the beam parameters at the beam dump No.1, we can calculate the number of electrons per second which equals to 7×10^{13}. In the considered energy range (0.15 to 5 MeV), the ratio of photon fluences per electron are in the order of 10^5, we then calculated fluences of photon per second which is 7×10^8 cm^{-2}s^{-1}. To shield these photons, the exponential attenuation theory of photon was applied [13]. It was found that the estimate thickness of lead about 30-40 cm is required to reduce the number of photons by the orders of 10^7,10^8 and 10^9 times smaller than before shielding. The design of the shielding for beam dump No.1 started from the first barrier consisted of 40, 40, and 25 cm of lead and 40 cm of concrete at the front, left, back and right sides, respectively. For the top side, 30 cm of iron with 5 cm of polyethylene was chosen. There is a small space between the first barrier and the Faraday cup. Hence, the polyethylene was filled in this space to reduce the number of neutron. After adding the first barrier, the average $AADE$ for photon at the roof decreased from more than 10^5 mSv/year to 56.96 mSv/year. However, the value is still over our expectation, which is 6 mSv/year. Thus, concrete walls

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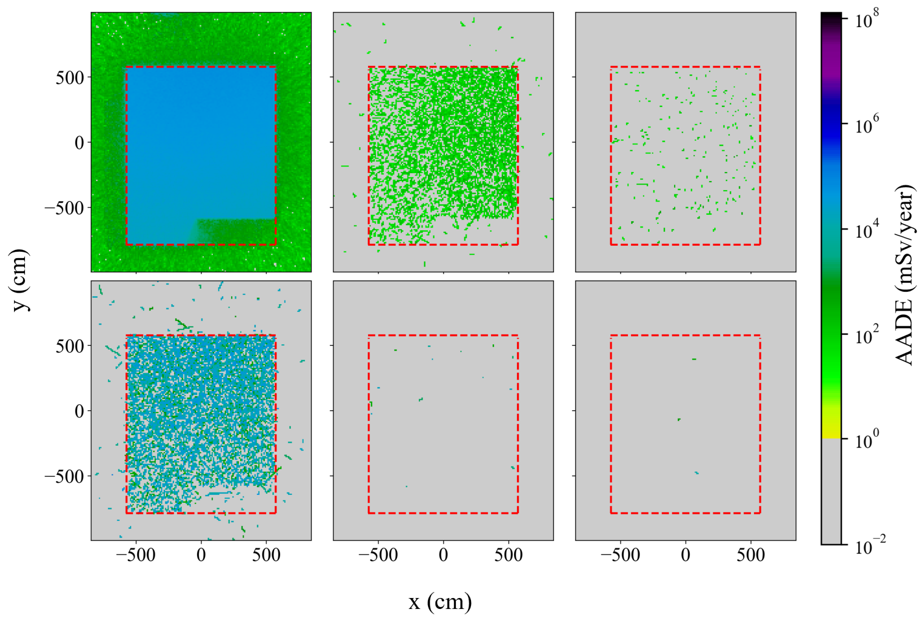

Figure 3: $AADE$ maps of photon (top) and neutron (bottom) at the roof of the accelerator hall, in the case of without shielding (left), adding the first barriers (center), and final model of shielding (right).

with thickness of 50 cm and 55 cm were added on the left and right sides following the first barrier. For the front side, the 30 cm concrete wall was added after moving up the cable tray above the local shielding to get the same space as the walkway. Then, 5-cm iron sheets were included to cover the beam dump and to enclose the shielding as illustrated in Fig. 2 (b, c). As shown in Fig. 3, the final value of the average $AADE$ at the roof after adding this shielding design is 2.90 mSv/year for photons. The intensity of the neutron dose is clearly lower. As a result, the model will be used as a guideline for the actual construction.

CONCLUSION

The design of local shielding for electron linac beam dump was focused in this work to limit radiation inside the accelerator hall and surrounding area by using GEANT4 Monte Carlo method. The radiation fluences were investigated to construct the radiation dose map and calculate the approximate shielding thickness. The model of shielding was designed under the limitation of the available hall area. From the results, the average of the $AADE$ values at the roof level is under 6 mSv/year, which is the requirement for the supervised area. However, there are other two beam dumps constructed at the end section of the MIR-FEL and THz-FEL beamlines that also need the local shielding. Thus, the roof is still currently defined to be a forbidden area during the accelerator operation until we can propose the design of local shielding of the rest beam dumps.

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