Design of radiation shield for RI production beam line

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A radiation shield for a target of new radioactive isotope (RI) production beamline at the large irradiation room in the Linac building was designed. Figure 1 shows the schematic of the shield. A 7.18 MeV/nucleon helium-4 beam is irradiated from upward to downward on a bismuth target. In this study, the conceptual structure of the radiation shield for the side direction from the target was designed using the radiation transport code PHITS.[1)] The size of the shield was limited to less than 2 m because the new RI production beam line will be installed at the small space in the large irradiation room. In addition, the requested shield weight was less than 10 ton owing to the load capacity of the floor. Although the PHITS calculation is not well studied in this helium-4 beam energy region, the benchmark has already been obtained via measurement of the neutron yield with the same beam condition.[2)]

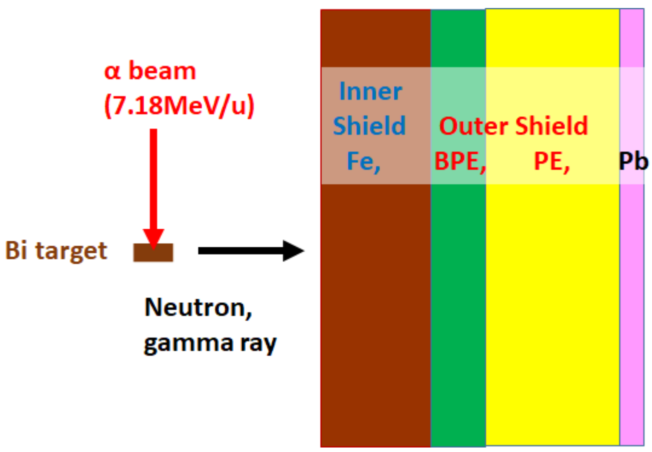

Fig. 1. Schematic of the radiation shield.

The radiation dose around the target is 3×10^8 μSv/h at the beam intensity of 100 particle μA. This study aimed to reduce the neutron and γ-ray dose rate below 10 μSv/h on the surface of the shield. A simple shield composed of one substance is not effective when neutrons and γ rays in wide range energies are mixed. The maximum energy of neutrons from the target is about approximately 15 MeV. In general, polyethylene (PE) or water, a hydrogen-rich material, is effective in shielding neutrons up to several MeV. For the higher energy neutron, iron or other heavy metal material is applied as an inner shield to reduce the neutron energy by inelastic scattering. Subsequently PE is applied as an outer shield to reduce the neutron dose rate. In addition, the secondary γ ray generated in the shield is absorbed in the heavy material such as lead set outside PE as shown in Fig. 1.

Figure 2 shows position distribution of the neutron and γ-ray radiation dose rate calculated by PHITS. Although the tungsten-inner shield was also assumed, iron was selected considering the cost and weight. The iron thickness was optimized to realize the minimum thickness of the shield satisfying the requested neutron dose rate at the shield surface. Despite the 30-cm-thick iron and 50-cm-thick PE successfully reducing the neutron dose rate, the γ-ray dose was still serious. The main component was a 2.2 MeV secondary γ ray attributed to the reactions between neutrons and proton included in the outer PE shield as shown at black-dashed line in Fig. 2. Therefore, additional heavy weight lead shield outside PE is necessary to reduce the γ ray. To render the lead thickness thinner, reduction of low-energy neutron entering to outer PE shield was considered. PE with 10% B_2O_3 (BPE) was installed between the iron and the PE to apply $^{10}B(n, \alpha)$ reaction. Red lines in Fig. 2 show the effect of 10 cm BPE. The generated γ ray is reduced down to 1/8 by BPE shield at the border between inner and outer shield. Although the 50 cm thick BPE was also evaluated as an alternative to the PE, 10 cm BPE was sufficient because low energy neutron from iron-inner shield was absorbed by the first 10 cm of BPE. Owing to the boron effect, the thickness of the lead was successfully reduced approximately 5 cm. Owing to the design, the shield of iron 30 cm thick, BPE of 10 cm, PE of 40 cm, and lead of 7 cm satisfied the requirement of 10 μSv/h on the surface against 100 particle μA helium-4 beam.

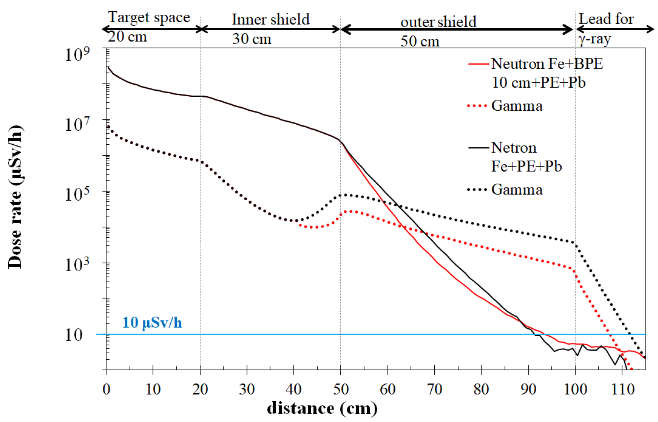

Fig. 2. Radiation dose distribution calculated with PHITS. The assumed helium-4 beam intensity was 100 particle μA.

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