Radiation Shielding Design for IFMIF/EVEDA accelerator Vault

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(Received: 30 October 2009 / Accepted: 23 January 2010)

A new deuteron accelerator facility is being built at Rokkasyo-site in IFMIF/EVEDA and its shielding design was required urgently before the construction. Therefore, a shielding analysis was done for the prototype model of IFMIF/EVEDA accelerator vault with the Monte Carlo radiation transport code, MCNP5, and cross section library, FENDL-2.1. The neutron dose rates were 0.5 μSv/h at the side of the beam dump and 0.05 μSv/h at the center of the beam axis. These were smaller than the limitation dose rate of the regularly accessible controlled area, 25 μSv/h.

Keywords: IFMIF/EVEDA, shielding analysis, MCNP, FENDL,

1. Introduction

The Engineering Validation and Engineering Design Activities (EVEDA) of International Fusion Materials Irradiation Facility (IFMIF) have been carried out as a part of the Broader Approach Activities. In IFMIF/EVEDA, an accelerator of a deuteron beam of up to 9 MeV and 125 mA will be tested at Rokkasyo-site in Japan. Because intense neutrons will be produced at beam loss points such as a deuteron beam dump, enough radiation shield is required for the facility of the accelerator to meet the criteria of the Japanese Law Concerning the Prevention from Radiation Hazards due to Radio-isotopes, etc. The outside wall of the accelerator vault is planned to be the boundary of the regularly accessible controlled area and its limitation dose rate is provided 1 mSv/week by the law, which corresponds to 25 μSv/h assuming 8-hour work per day and 5 working days per week. The dose rates outside of the wall must meet this criterion. The radiation shielding design was required urgently before building the accelerator facility and we carried out a radiation shielding design for the prototype accelerator vault in the facility.

2. Design Conditions

2.1 Calculation code

The neutron shielding design was performed with the three dimensional Monte Carlo radiation transport code, MCNP5.14 [1] and the cross section library set, FENDL/MC-2.1 [2].

2.2 Geometry

The prototype design was adopted because the specification has not been fixed yet. The calculation model included the accelerator vault, the beam dump cone and the beam dump peripherals. The accelerator vault was modeled as a cylindrical vessel, of which wall thickness, inner radius and length were 150 cm, 370 cm and 3800 cm respectively. The wall of the vault consisted of ordinary concrete. The beam dump cone of 10 cm in bottom radius and 250 cm in height was made of a 1 cm-thick plate of nickel. As an additional shield, a water tank and a concrete shield were installed around the beam dump cone. The water tank of 100 cm in outer radius and 350 cm in length were enclosed by a 50 cm-thick concrete shield. The calculation geometry is illustrated in Fig. 1.

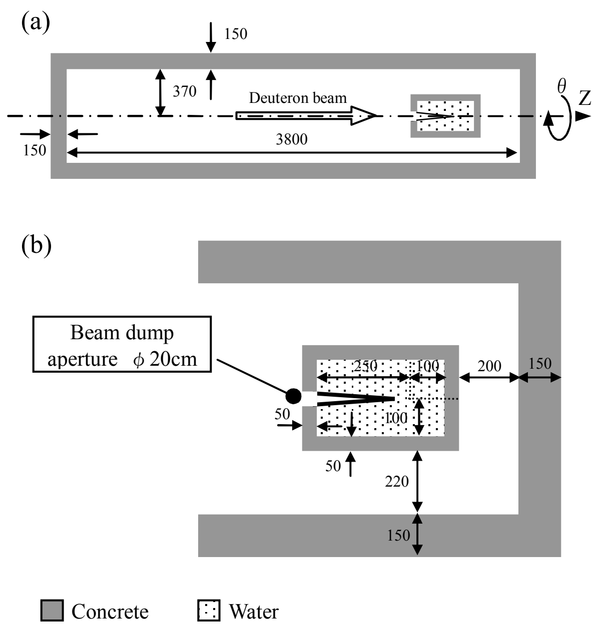

Fig. 1 Calculation model (Unit: cm)
(a)Whole vault. (b)Beam dump close-up.

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2.3 Materials

Three materials, concrete, water and air, were used in the calculation geometry, omitting accelerator tube, vacuum vessel and other instruments for simplicity. While the chemical composition of air is almost the same in troposphere all over the world, that of concrete vary significantly depending on production region of its raw materials and constructing conditions. Therefore some standard composition data are provided for concrete. We adopted the composition data for concrete used in the ITER nuclear analysis [3] provided by ANS. For conservative estimation, the density of concrete was reduced to 2.1 g/cm^3 from the original data in our calculation. The chemical composition of concrete is tabulated in Table 1.

Table 1 Composition of concrete (2.1 g/cm^3).

element	wt %
H	0.555
O	49.748
Na	1.708
Mg	0.256
Al	4.691
Si	31.471
S	0.128
K	1.922
Ca	8.283
Fe	1.238

It should be remarked that this composition is more conservative from the view of neutron shielding than that used in Japan normally. In Japan, for official licensing, the concrete composition data recommended by Nuclear Safety Technology Center (NUSTEC) [4] are widely used. The hydrogen fraction in ordinary concrete in this work is 1.17×10^{-2} g/cm^3 while that by NUSTEC is 2.16×10^{-2} g/cm^3.

2.4 Neutron Source

Neutrons generated by a deuteron beam were assumed to be produced at the surface of the beam dump cone. This assumption is also conservative because an actual deuteron beam tends to be focused on the center of axis, therefore most of neutrons are generated at deeper position and the water tank shields them more effectively.

Because experimental data about secondary neutron spectrum in the Ni(d, xn) reaction from 9 MeV deuteron injection were absent, we used the data in the Be(d, xn) reaction[5] with smoothing its discrete peaks. The neutron source intensity was assumed to be 2.0×10^{14} (neutrons/second), which was estimated from 125 mA of the beam current and 2.0×10^{-4} (neutrons/deuteron) of neutron yield from EAF-2007 [6]. The neutron spectra and angular distribution used in this work are shown in Figs. 2 and 3.

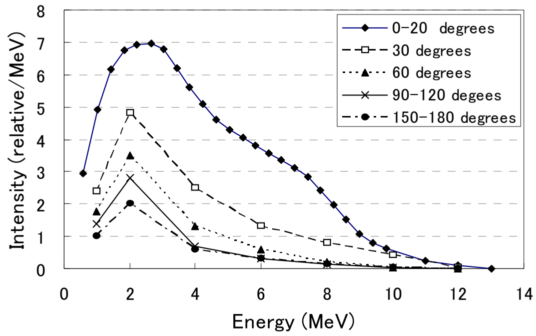

Fig. 2 Neutron energy spectra.

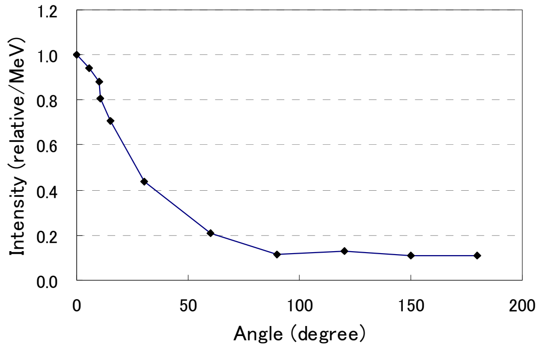

Fig. 3 Angular distribution.

3. Results and Discussion

The effective dose rates were calculated in the axis direction, in the radius direction across the entrance of the beam dump and on the outside surface of the accelerator vault. These positions are illustrated in Fig. 4.

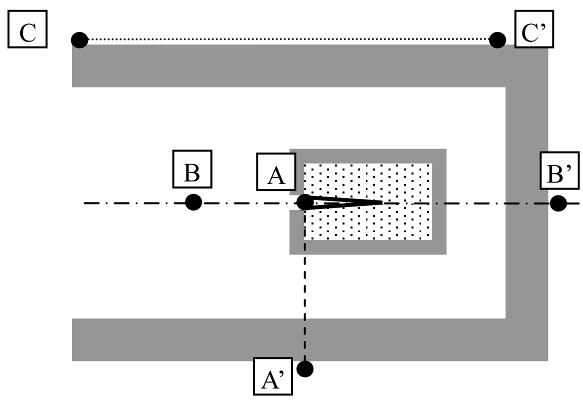

Fig. 4 Calculation positions. (A-A') : Radial direction, (B-B') : Axis direction, (C-C') : Outside of vault.

The calculated effective dose rates are shown in Figs. 5, 6 and 7. At first, in the radial direction, the dose rate is attenuated significantly in the water tank and in the wall of the vault and the effective dose rate on the outside of the wall, 0.5 μSv/h, is smaller than the limitation dose rate. Secondly, in the axis direction, the dose rate decreases in the water tank but increases in the concrete shield around the beam dump and stays constant in the room air and finally decreases again in the wall of the vault. Consequently, the dose rate on the outside surface of the vault in the axis direction becomes 0.06 μSv/h.

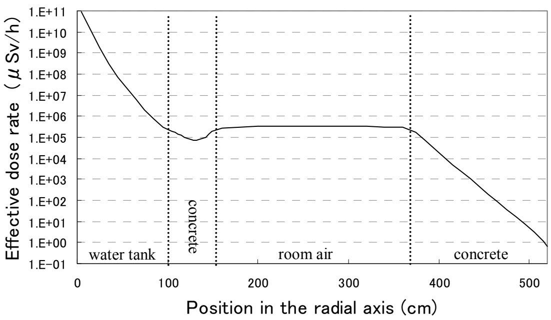

Fig. 5 Effective dose rate in the radial direction.

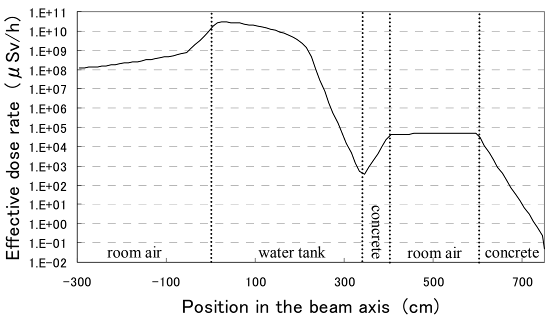

Fig. 6 Effective dose rate in the axis direction. The origin of x-axis is located at the entrance of the beam dump cone.

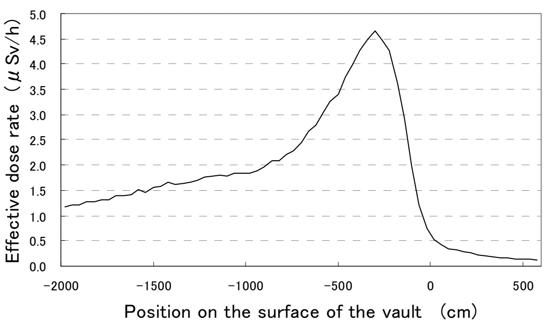

Fig. 7 Effective dose rate outside the vault. The origin of x-axis is located at the entrance of the beam dump cone.

Thirdly, on the lateral outside surface of the vault, the dose rate at the nearest position from the entrance of the beam dump (corresponding to x=0 in Fig. 7) is 0.5 μSv/h but the maximum dose rate in Fig. 7 is 4.6 μSv/h at x=-300 cm. This means that not the neutrons which come from the source positions directly, but those leaked from the aperture of the beam dump are dominant on the outside of the wall. Figure 8, two-dimensional effective dose rate distribution, shows such a situation clearly. However, the effective dose rates are less than the limitation dose rate of regularly accessible controlled area anywhere on the boundary of the vault.

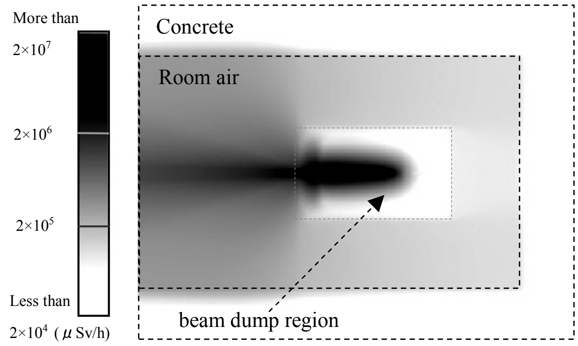

Fig. 8 Two-dimensional dose distribution.

4. Conclusion

The neutron effective dose rates were calculated for the prototype model of the IFMIF/EVEDA accelerator vault with the Monte Carlo radiation transport code. The water tank and the concrete shield around the beam dump cone were very effective and the effective dose rates on the boundary of the vault were less than that of the regularly accessible controlled area. As a further work, we will perform a shielding design for the final model of the vault.

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