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Shielding calculation of a Duct Structure in the Industrial 10 MeV-Electron Irradiation Facility

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1. Introduction

Industrial facility irradiating a 10 MeV, 30 kW electron beam on a metal target, was designed and the biological shield of the target station were investigated with the evaluations using the MCNPX code[1] simulation. Neutron and photon fluences at each detector positions in the duct were calculated and those are compared with the results of DUCT-Ⅲ design code[2] calculation. By converting the fluences to the effective dose in a phantom, the user's safety was demonstrated.

2. Simulations and Results

To get the fluences of the neutrons and photons produced by the irradiation of an electron beam on a Pb target, the simulations were executed, and the obtained results were compared with the phantom detector positions. The fluences were converted to the Effective Dose Equivalent by using the fluence-to-effective dose conversion coefficients as a function of each particle incident energy for ISO (**iso**tropically irradiated) geometrical conditions[3].

2.1 Facility Structure

The electron irradiation facility structure which is optimal for doing various relevant experiments was designed. The overall structures used in the MCNPX code simulation is presented in the Figure 1.

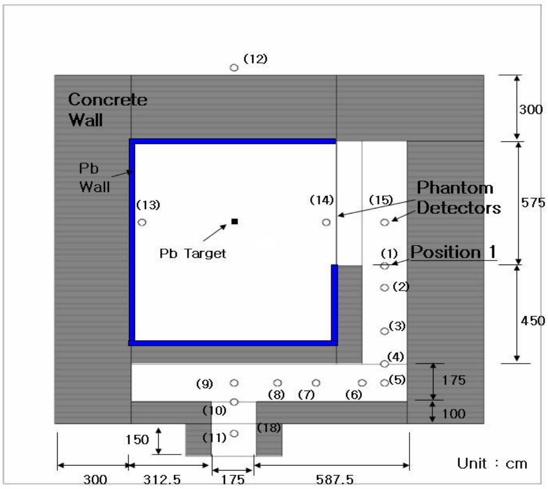

Figure 1. Geometric structure used in the simulation. It's top-down view with horizontal-cross section. The electron beam is directed to the paper direction and on a Pb target.

The electron beam size is 1 cm in diameter and a Pb target has the length 5 cm and diameter 5 cm. The target room in center was shielded with concrete (100~300 cm in thickness) and 5 mm- thick Pb. The upper and bottom are also covered by those materials.

2.2 Fluences Calculation

The fluence is generally defined as $\phi = dN/da$ where dN represents the differential number of gamma-ray photons or neutrons that are incident on a sphere with differential cross-sectional area da. The phantom detectors used in these simulations were sphere typed ones with a diameter 30 cm and the composite material was set as void to avoid the interferences. F4 Tally [particles/cm^2/history] was used for calculating the fluences. The phantom detector positions were selected by the order of the distances farther from the Pb target. The produced particle fluences were calculated with the history number of 20,000,000 in the MCNPX code simulation and the relative error was generally 1~10 % with different detector positions.

The results of the calculated fluences of the photons were described in Figure 2. The electron beam intensity was assumed to have 30 kW power and 3 mA current. The neutron tallys were zero in all phantom detectors. The direct term that is detected through the wall was minor in the ist Labyrinth but 2nd and 3rd Labyrinths ,with the displacement of the void wall to the concrete and 5 mm thickness Pb wall between the target room and the duct inlet.

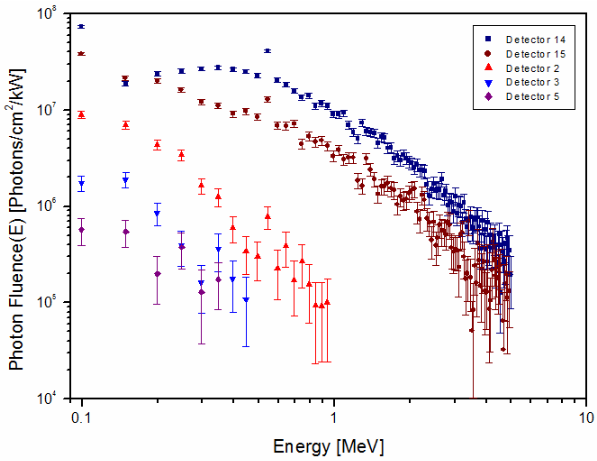

Figure 2. Photon fluences calculated with Tally F4 in the phantom detectors located at different positions as in Fig. 1.

As expected the calculated photon numbers are decreasing as the distance from the target is farther. The particle numbers at detector 9 , 10 and 11 are minor and the detected photons are those passed through the 100 cm thickness wall. There were no detected particles in detector 12 that is outside of the 300 cm thickness wall. It shows a good shielding effect outside the working areas.

The photon fluence rates [p/cm^2/s/kW] at different positions were also calculated by DUCT-Ⅲ code and the results were compared in Figure 3 with those calculated by the MCNPX code simulation. In this case the electron beam intensity was assumed to be 2×10^{16} per second and the produced photon spectrum around the Pb target were inputed as a point source in DUCT-Ⅲ code simulation.

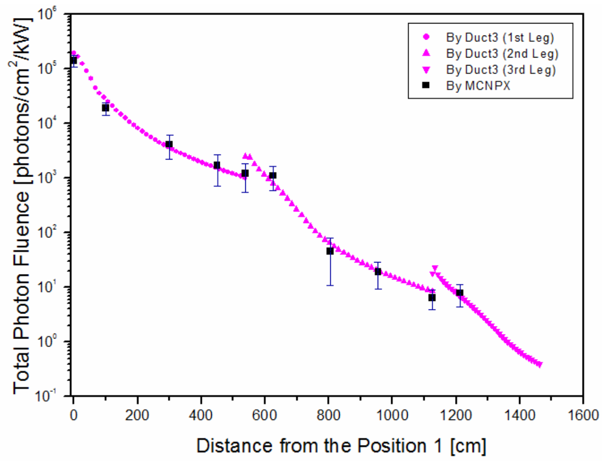

Figure 3. Comparison of the total photon fluences calculated by the DUCT-Ⅲ code with those of the MCNPX code calculation at different distances through the labyrinths.

2.3 Effective Dose Equivalent

The fluence-to-dose conversion coefficients are the basic data for the shielding calculations and dose evaluations around targets. In 1990 the ICRP revised the definition of effective dose and the method of calculation [4].

In this thesis, the effective doses [Sv/electron] at each phantom positions were obtained by multiplying the fluences [particles/cm^2/electron] with the fluence-to-dose conversion coefficients [Sv·cm^2].

Practical considerations of potential exposures of persons moving around the facility and at random orientations in scattered particle radiation fields, lead to the conclusion that the ISO irradiation geometry is the most appropriate for calculations of the Effective Dose, so the conversion coefficients data for the ISO geometrical condition was adopted.

Figure 4 shows the calculated Effective Dose Rate with the distances from the detector position (1). The dose equivalent values of 10 is not negligible as it's about 100 mSv/h and that of the position 11 is also inferred as large about 0.1 mSv/h on operation even with perfect shield, from the calculated result of the DUCT-Ⅲ code.

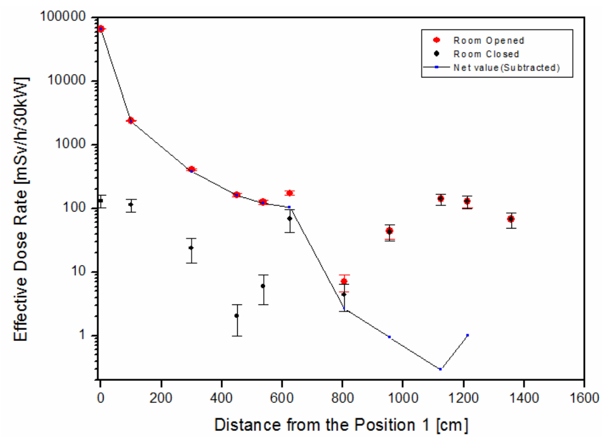

Figure 4. Claculated Effective Dose Rate at different phantom detectors located in the order of the farther distances from the detector position (1).

3. Conclusion

Facility irradiating 10 MeV, 30 kW electron beam on a metal target was designed and the shielding of the structure was evaluated using the MCNPX code simulation. Obtained fluences were compared with the calculation results of the DUCT-Ⅲ design code and they showed good agreements. The fluences in the 2nd labyrinth were almost derived from the direct particles passing through the wall not through the inside tunnel, and those particles are origination of the effective dose values on the phantom detectors.

The dose rate inside the labyrinths are exceeded the recommend limit (20 mSv/yr) to exposure on the whole-body for the worker. To reduce the number of direct particles passing through the walls, the 100 cm thickness walls are need to be more thickened.

REFERENCES

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