Comparison of Shielding Factors Derived from Point Kernel and Monte Carlo Methods

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1. Introduction

The radiation dose rate distributions in and out of the structure are evaluated for a design of facilities using radioactive sources (nuclear fuel, radionuclides, etc.). Particularly, the shielding factor is defined as the ratio of interior to exterior dose rate, and it is regarded as one of important parameters to assess the external gamma-radiation dose by radioactive materials released from nuclear facilities. Over several decades, the derivation of shielding factors has been performed in some countries to be used as regulatory guidelines, and the most widely used method is Monte Carlo technique due to accurate estimation in complex geometry.

However, it requires a lot of computing time for sufficiently reliable results, as the computational burden increases with geometric complexity, source diversity, and shielding materials. On the contrary, the point kernel method for the gamma transport analysis produces reasonably accurate calculation results, even its simplicity and real-time computing. Therefore, the computational codes based on point kernel method are widely used in radiation shielding calculations, and this can be an optimal technique for repeated calculations.

In this study, gamma-ray dose rates in a specific structure along with different gamma energies were evaluated by using the typical point kernel (QAD-CGGP[1]) and Monte Carlo (MCNP5[2]) codes. Moreover, shielding factors were derived with the results through two methods, and the practical applicability of point kernel code for deriving shielding factor is assessed by comparing these values.

2. Materials and Methods

The shielding factor is usually defined as the ratio of the indoor to outdoor dose rate from deposited activity on an infinite plane source on the ground surface [3]. More realistic calculations for residential areas, shielding factors need to consider the finite size of the surrounding ground surface, and also the building construction (i.e., size and position of a building, window areas, and thickness of walls, floors, and roofs, etc.). To obtain a shielding factor, it is required to detect radiation doses at two areas (i.e., inside and outside of the building). Therefore, two kinds of modeling were performed; that is, i) external dose calculation on the ground and ii) internal dose calculation in a specific building. As shown in **Figure 1**, a conceptual model of a structure was designed to derivate shielding factors, and a series of radiation dose calculations were performed using the QAD-CGGP and MCNP5 codes.

The structure is composed of three rooms and one living room dividing by the walls with the thickness of 20 cm. The pillars are made of reinforced concrete and located at each corner of the building. The structure is assumed to have the floor above 30 cm from the ground and the concrete roof with the thickness of 20 cm. The specification of materials used for modeling is shown in **Table 1**.

In these calculations, it was assumed to be a ground source of a cylindrical form with a radius of 40,000 cm. The internal and external gamma-ray dose rates were evaluated along with the energy range approximately from 0.2 MeV to 1.8 MeV, which are assumed considering the characteristics of the major fission products released from Shin-Kori nuclear power plant Unit 3, 4.

The radiation flux for the internal dose calculations is evaluated in A and B zones which are expected to have highest value in the building. The shielding factors were derived by dividing the external dose rates into internal ones. Flux-to-dose rate conversion factors were applied using ICRP Publication 74 [4].

The ANS 6.4.3 cross section data and Geometric Progression (GP) buildup factor were employed in the QAD-CGGP calculations [5]. The MCPLIB04 based on ENDF/B-VI cross section library was used in the MCNP5 calculations.

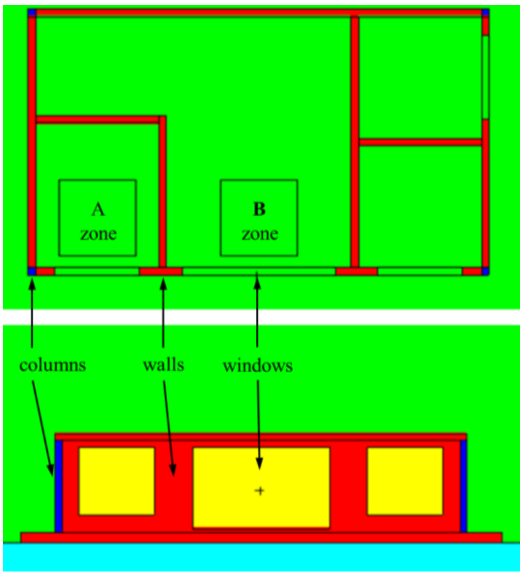

Fig. 1. Conceptual Model for Deriving Shielding Factors

Table 1. Specification of Materials used for Modeling in QAD-CGGP and MCNP

Material	Density (g/cm^3)	Element	Composition (wt%)	Material	Density (g/cm^3)	Element	Composition (wt%)
Reinforced Concrete	2.4	H	1	Soil	1.4	O	46.6
		O	52.2			Na	2.8
		Na	2.8			Al	8.1
		Al	3.3			Si	27.7
		Si	33			K	2.6
		C	4.3			Ca	3.6
		Fe	3.2			Fe	5
Concrete	2.3	H	1	Air	0.001225	N	24
		O	53.2			O	76
		Na	2.9	Glass	2.579	O	62.8
		Al	3.4			Na	8.2
		Si	33.7			Mg	1.1
		C	4.4			Al	0.2
		Fe	1.4			Si	22.1
						Ca	5.6

3. Results and Discussion

The gamma-ray dose rates in the external and internal areas were calculated using the QAD-CGGP and MCNP5 codes. **Figure 2** shows the normalized dose rates in-and-out of the building resulted from both codes. In the cases of external dose calculations, the dose rates gradually increase along with the energy of gamma-ray, even though the difference between both codes also increases. While the results from QAD-CGGP in the internal dose calculations do not show the same tendency with others, and they produce the irregular patterned values at the whole energy level. These results effect to the derivation of shielding factors which are produced using the external and internal dose rates. Meanwhile, the shielding factors calculated using QAD-CGGP were evaluated to be approximately 2 to 6 times higher compared to those from MCNP.

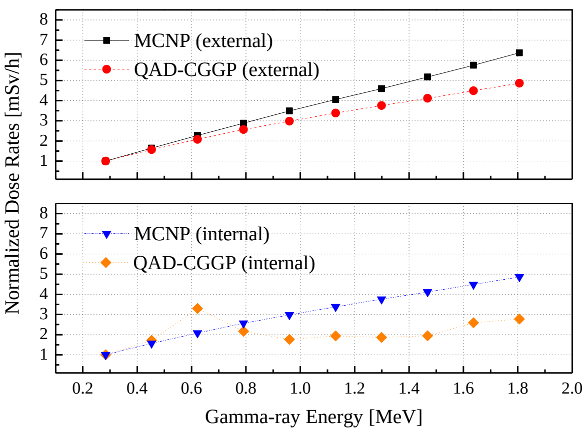

Fig. 2. Normalized Dose Rates in External and Internal Dose Calculations (MCNP and QAD-CGGP)

These phenomena may be from the reasons that QAD-CGGP is restricted up to 100 intervals for the source meshes although the source volume in this study is extremely large. As the total radius (*R*) of source is 40,000 cm, one mesh is divided into 400 cm along with *R*. It does not seem to be enough when considering the dimension of the building with 1200 cm (x) $\times$700 cm (y). In addition, shielding with several layers of materials and geometric complexities can yield radiation streaming paths. The point kernel method does not account for radiation scattering from walls, ceilings, floors, or other structures. This scattering effect can distort the calculated results depending on the shielding structure and point detector locations [6-7].

4. Conclusion

To derive shielding factors using the point kernel and Monte Carlo methods, gamma-ray dose rates in the specific structure were evaluated using the QAD-CGGP and MCNP5 codes. As a result, the dose rates inside the building calculated using QAD-CGGP were shown to have irregular values compared to others, and the shielding factors were derived to be higher than those from MCNP5. As the point kernel method is usually reliable when the problem set has simple systems (e.g., a source, solid homogeneous shielding material, and detector point, etc.), the evaluated results may differ depending on how the whole geometry is designed (as mentioned in **Results and Discussion**). Therefore, in order to apply the point kernel method for the evaluation of shielding factors in a variety of circumstances including some complex geometry, it is required to be investigated with more case studies.

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