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Approximate Equation to Correct Point Source Assumption

Kyung-O KIM*, Gyuhong ROH, and Byungchul LEE
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea
**Corresponding Author: k5kim@kaeri.re.kr*

1. Introduction

The evaluation of radiation shielding has been performed for the design and maintenance of facilities using radioactive sources (e.g., accelerator, radionuclide, and nuclear fuel). In this process, a considerable amount of numerical calculations are required to analyze the radiation flux and dose rate distribution around these facilities. For this reason, various computational codes and methods are introduced in the field of radiation shielding, and the most widely used methods can be classified into two main groups: Monte Carlo [1-3] and point kernel methods [4-6].

When the specific source as a spherical volume that emits the radiations to be isotropically moved over the 4π solid angle is placed in a simple structure, the evaluation of the radiation shielding can be easily conducted by introducing certain assumptions. In particular, if the size of the source volume is small in comparison with the distance from the radiation source to the detection point, the source can be assumed an equivalent point source. That is, this assumption ignoring the source volume can lead to a significant error for the radiation flux (dose) distribution near the radiation source. In this study, an approximate equation is defined to correct significant errors produced by employing a point source assumption, and spherical volume source without radiation shield is assumed, as shown in **Figure 1**.

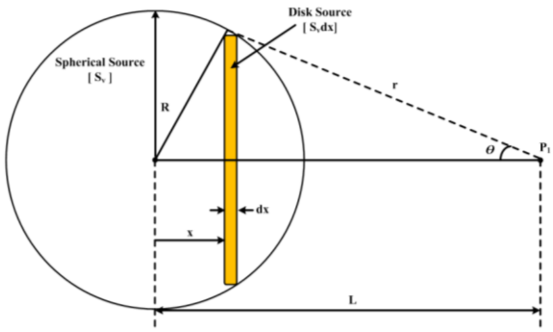

Figure 1. Spherical Volume Source without Radiation Shielding

2. Methods and Materials

A spherical volume source of radius R emits isotropically S_V particles per unit volume, and a detector is positioned at point P_1, and the distance from the sphere center to the detection point is L. In this case, the differential uncollided flux ($d\phi_u^{sph}$) of particles emitted in dx about x can be defined using the total uncollided flux for finite disc source as Eq.(1) [7], and thus the total uncollided flux (ϕ_u^{sph}) at P_1 becomes Eq. (2). Also, the total uncollided flux (ϕ_u^{pnt}) of equivalent point source considering the sphere volume can be simply defined as Eq. (3), and an approximate equation to correct the point source assumption is finally derived from those equations. In addition, the reactions between the emitted radiations and sphere source (i.e., self-shielding effect) are not considered to derive a simplified equation.

$$d\phi_u^{sph} = \frac{S_v dx}{2} ln(sec\theta) \qquad (1)$$

$$\begin{aligned}\phi_u^{sph} &= \frac{S_v}{2}\int_{-R}^{R} ln(sec\theta)\, dx \qquad (2)\\ &= \frac{S_v}{2}\int_{-R}^{R}\left(\frac{\sqrt{R^2+L^2-2Lx}}{L-x}\right)dx\\ &= \frac{S_v}{8L}\left[\begin{array}{c} 2(L^2-R^2)\left(ln2+ln\big(L\times(L-x)\big)\right)\\ -(L^2+R^2-2Lx)\\ \times\left(2ln\left(\frac{\sqrt{L^2+R^2-2Lx}}{L-x}\right)+1\right)\end{array}\right]_{-R}^{R}\\ &= \frac{S_v}{4L}\left[(L^2-R^2)ln\left(\frac{L-R}{L+R}\right)+2LR\right]\end{aligned}$$

$$\begin{aligned}\phi_u^{pnt} &= \frac{S_v}{4\pi L^2}\times\left(\frac{4}{3}\pi R^3\right) \qquad (3)\\ &= \frac{S_v R^3}{3L^2}\end{aligned}$$

$$\therefore \frac{\phi_u^{sph}}{\phi_u^{pnt}} = \frac{3L}{4R^3}\left[(L^2-R^2)ln\left(\frac{L-R}{L+R}\right)+2LR\right]$$

3. Results and Discussions

A spherical volume source (^{60}Co, R=10cm) was assumed to confirm the effect of correcting the point source assumption. The source emission is assumed to have a uniform strength of S_v (100 Bq/cm^3), and the energies of two gamma-rays are 1.1732 MeV and 1.3324 MeV, respectively. The gamma-ray flux distribution around the spherical volume source is analyzed using MCNP5-1.60 [8] and QAD-CGGP codes [4], and normalized fluxes are presented in **Figure 2** and **Table 1**. As shown in the table, the results applied with the point source assumption have a maximum different ~30% in a radiation flux near the source, compared with the MCNP5 result. On the other hand, this difference is sharply reduced from ~30% up to ~11% by correcting the point source assumption. That is, the significant errors produced from a point source assumption can be reduced by applying the approximate equation considering the volume of radiation source.

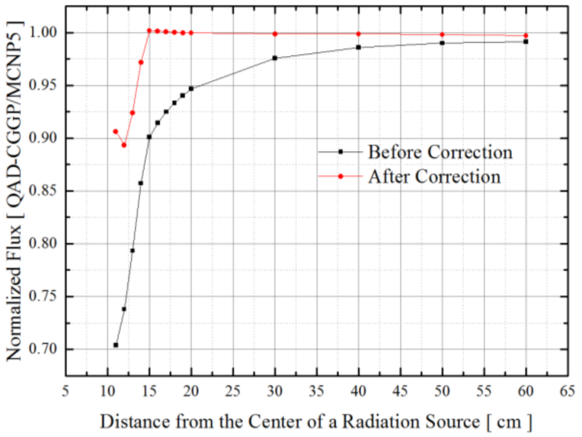

Figure 2. Correction Before and After Gamma-ray Flux Normalized by MCNP5 Results

Table 1. Point Source Assumption Correction Before and After Gamma-ray Flux

r* [cm]	QAD-CGGP			MCNP5
	Before Correction	Correction Factor	After Correction	
11	5.51E+00	1.29E+00	7.09E+00	7.83E+00
12	4.63E+00	1.21E+00	5.60E+00	6.27E+00
13	3.94E+00	1.17E+00	4.59E+00	4.97E+00
14	3.40E+00	1.13E+00	3.86E+00	3.97E+00
15	2.96E+00	1.11E+00	3.29E+00	3.29E+00
16	2.60E+00	1.10E+00	2.85E+00	2.85E+00
17	2.31E+00	1.08E+00	2.50E+00	2.49E+00
18	2.06E+00	1.07E+00	2.20E+00	2.20E+00
19	1.85E+00	1.06E+00	1.96E+00	1.96E+00
20	1.67E+00	1.06E+00	1.76E+00	1.76E+00
30	7.40E-01	1.02E+00	7.58E-01	7.59E-01
40	4.16E-01	1.01E+00	4.22E-01	4.22E-01
50	2.66E-01	1.01E+00	2.69E-01	2.69E-01
60	1.85E-01	1.01E+00	1.86E-01	1.87E-01

r is the distance from the center of a radiation source to the detection point*

3. Conclusions

Some calculations were performed to quantitatively investigate the errors produced from a point source assumption, and an approximate equation was derived to correct the error. The QAD-CGGP known as a representative point kernel code was employed for a series of calculations, and the calculation results were compared with the reference data obtained from the MCNP5-1.60 code. The results applied with the point source assumption have a maximum different ~30% in a radiation flux near the source, compared with the MCNP5 result. By applying the approximate equation, the difference in the calculation results derived from MCNP5 and QAD-CGGP codes is sharply reduced from maximum ~30% up to maximum ~11%.

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