Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

A Preliminary Study on the Optimization of Source Angular Bias for Monte Carlo Simulation in a Large Radiation Generation Facility

Do Hyun KIM [a], Song Hyun KIM [a], and Jong Kyung KIM [a,*]
[a] *Department of Nuclear Engineering, Hanyang University, Seoul, Korea,*
**Corresponding Author: jkkim1@hanyang.ac.kr*

1. Introduction

In a large radiation generation facility, some restrictions of the gamma radiation shielding analysis using direct Monte Carlo simulation can be occurred due to the stochastic error of the calculation results in the large space. To increase the calculation efficiency, various variance reduction techniques are introduced for the large facility. The angular source biasing is one of the variance reduction techniques, which is that the true angular probability is biased with adjusting the source importance [1]. However, the optimization of the angular biasing is not easy and some calculation error can be generated without the specific technique. In this study, a first collision method for the decision of the gamma source angular bias is proposed, and a radiation shielding problem in a large space was evaluated and verified with MCNP code calculations [2].

2. Methods and Results

In Monte Carlo method, the initial source direction of the radioactive material was randomly sampled. The use of angular source biasing technique changes the source directional probability from the initial source distribution with changing the source weight. It is known that it is a useful method to reduce relative error in calculating a large facility radiation shielding; however, the probability of angular contribution for deciding each angular bias value must be properly considered to prevent the calculation error. In this study, an optimization method of the source angular bias is proposed by using the first collision approximation of each source angular direction.

2.1 Development of Source Angular Biasing Method

In a large facility, the influence of each source angular direction significantly affects the tally region. Especially, the evaluation result at the tally region is proportionally increased by the effect of the first scattering radiation. Thus, it is assumed that the angular bias is decided by the effect of the first scattering into the tally region. The overview of the first collision approximation is shown in Fig. 1. At first, the initial angular intensity on k angular direction, $I_{0,k}(r_0, E)$ at a source point r_0 is uniformly divided by L azimuthal angle bins (bin l). In multi-medium shielding problem, the unscattered radiation intensity from r_0 to r_n on $\theta_{k,l}$ direction can be approximately calculated by Eq. (1).

$$I_{k,l}(\vec{r_0},\vec{r_n},E) = I_{0,k,l}(\vec{r_0},E)e^{-\sum_{i=1}^{n} N_i\sigma_{ti}(E)|\vec{r_i}-\vec{r_{i-1}}|} \quad (1)$$

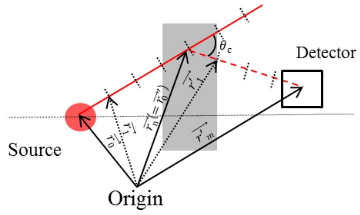

Fig. 1. Geometrical Overview of the Proposed Method

where, N_i is a number density in material of i^{th} bin and $\sigma_{t,i}$ is a total microscopic cross section at the material of i^{th} bin. The radiation at r_n has an angular collision between $|r_{n+1}- r_n|$ shielding material; hence, the intensity ($I^*_{k,l}(\vec{r_n},\theta_c,E)$) on the θ_c angular direction is as given in Eq. (2). By using Eq. (2), the radiation intensity ($I^*_{k,l}(\vec{r_0},\vec{r_n},\vec{r_m}',E)$) of the first scattered radiation from r_0 to detection point $r_m{}'$ with collision at r_n can be approximately calculated by Eq. (3).

$$I^*_{k,l}(\vec{r_n},\theta_c,E) = I_{k,l}(\vec{r_0},\vec{r_n},E)\,|\vec{r_{n+1}}-\vec{r_n}|\,N_i\sigma_c(\theta_c,E) \quad (2)$$

$$I_{k,l}(\vec{r_0},\vec{r_n},\vec{r_m}',E) = \frac{I^*_{k,l}(\vec{r_n},\theta_c,E)}{2\pi|\vec{r_m}'-\vec{r_n}|\sin\theta_c}e^{-\sum_{j=1}^{m} N_j\sigma_{t,j}(E)|\vec{r_j}'-\vec{r_{j-1}}'|} \quad (3)$$

where, $\sigma_c(\theta_c, E)$ is Klein-Nishina angular Compton scattering cross section [3]. Finally, level of contribution on the θ_k angular directional radiation source into the detection point, which is used for the source biased value, is calculated by Eq. (4).

$$SB(\theta_k,E) = \frac{\sum_{l=1}^{L} I_{k,l}(\vec{r_0},\vec{r_n},\vec{r_m}',E)}{\sum_{k=1}^{K}\sum_{l=1}^{L} I_{k,l}(\vec{r_0},\vec{r_n},\vec{r_m}',E)} \quad (4)$$

where, K is the number of the angular direction bin.

2.2 Development of Calculation Module

By using the proposed method in Section 2.1, a source biasing calculation module was developed in this study. C++ program was used. The algorithm of the program is given as shown in Fig. 2. At first, the geometry and source specifications are loaded from MCNP input. Then, the volume source and detector are divided into the unit cubic lattice. The point sources and detectors are located at the centers of the cubic lattices. The angular and azimuthal directions at each source point are divided into the numbers of the K and L, respectively. For the each divided angle of the source, the intensity of the first collision at the detection position is calculated by Eqs. (1) ~ (3). Finally, the source bias value for each angular direction is calculated by Eq. (4). The cross section data, which are used in the calculation, are loaded from ENDF/B-VII cross section library which is ACE format.

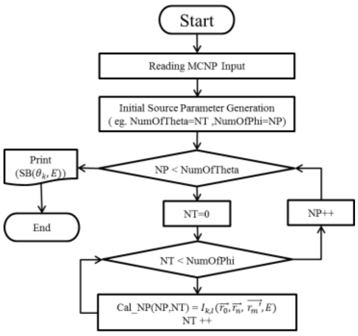

Fig. 2. Flowchart of the Calculation Module with Proposed Method

2.3 Results and Analyses

For the verification of the proposed method, a simple shielding problem was used as shown in Fig. 3. The room has 300 cm x 300 cm x 300 cm cubical shape, and the ordinary concrete wall (2.35 g/cc) with 50 cm thickness is surrounded of the room. A spherical source, which has 0.8 MeV energy and 2.2 cm diameter, is located at the center of the room. The probability of the contribution for each angular direction was calculated by the proposed method. The results are given in Table I.

Table I. Probability of Contribution for Each Cosine Bin

Cosine Bin (Min.)	-1	-0.8	-0.6	-0.4	-0.2	0	0.2	0.4	0.6	0.8
Cosine Bin (Max.)	-0.8	-0.6	-0.4	-0.2	0	0.2	0.4	0.6	0.8	1
Probability of Contribution	1.2×10^{-4}	2.8×10^{-4}	6.2×10^{-4}	6.2×10^{-3}	2.2×10^{-2}	4.3×10^{-2}	4.5×10^{-2}	6.0×10^{-2}	1.9×10^{-1}	6.4×10^{-1}

For the verification of the proposed method, the radiation shielding calculations were performed with the proposed bias method and without the source angular bias. Also, to compare the source biasing efficiency, a reference set of the angular bias was decided by calculating the contribution ratio of each angular direction with MCNPX code. The results of the gamma intensities and relative errors are given in Fig. 3 and 4. With the proposed method, the history to get < 1% relative error of the intensity was 3×10^7 while the history without the source bias was 2×10^8. The result shows that the radiation shielding with the proposed method can increase the calculation efficiency over 6 times than that without the source bias.

3. Conclusions

In this study, a method for obtaining the parameter of the angular source bias was proposed for the large gamma radiation generation facility. A calculation program with the proposed method was developed for the automatic calculation of the source angular bias value from MCNP input. For the verification of the proposed method, a simple shielding problem was evaluated by MCNPX code. The results show that the radiation transport result with the proposed method give a good calculation efficiency over 6 times than that without the source angular bias. It is expected that the proposed method can contribute increasing the calculation efficiency and accuracy for the radiation shielding problem in using Monte Carlo method.

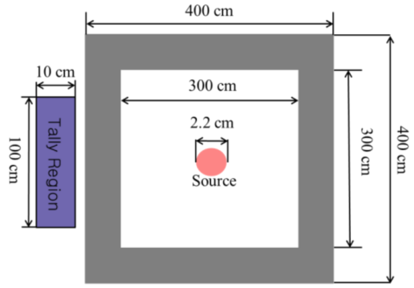

Fig. 3. Overview of Shielding Problem Geometry

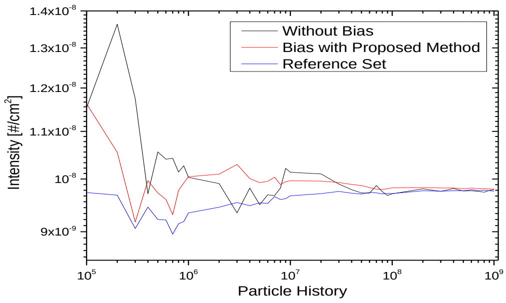

Fig.3 Results of Gamma Intensities at Tally Region

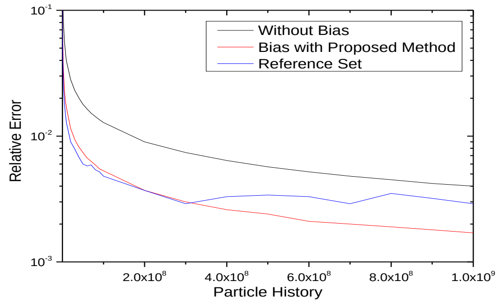

Fig.4 Results of Relative Errors at Tally Region

Acknowledgement

This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by Korea government Ministry of Knowledge Economy (2012T100100477), and Innovative Technology Center for Radiation Safety (iTRS).

REFERENCES

[1] H. Alireza, and J. C. Wagner., Monte Carlo Variance Reduction with Deterministic Importance Functions, Progress in Nuclear Energy, 42.1, p. 25-53, 2003.

[2] D.B Pelowitz, editor, MCNPXTM User's Manual, Version 2.7.0, LA-CP -11-00438, Los Alamos National Laboratory, April, 2011.

[3] O. Klein and Y. Nishina, Uber Die Streuung Von Strahlung Durch Freielektronen Nach Der Neuen Relativistischen Quantendynamik Von Dirac, Z. Physik ,52, p. 853-68, 1928.