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

Evaluation of Geometric Progression (GP) Buildup Factors Using MCNPX 2.7.0

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1. Introduction

Codes based on the point kernel method have been widely used to analyze the radiation shielding and gamma-ray field around radioactive sources. Particularly, QAD-CGGP [1] is a three dimensional point kernel code employed using a double precision Combinatorial Geometry (CG) scheme and a more accurate Geometric Progression (GP) fitting function for the ANS-6.4.3 gamma-ray buildup factor [2]. However, ANS standard data are only included with single-material buildup factors which were evaluated about 20 years ago. Hence, it is necessary to update existing data and supplement buildup factors for compound materials widely used in radiation shielding.

In this study, MCNPX 2.7.0 code [3] is used to derive gamma-ray buildup factors that cover an energy range of 0.015-15 MeV and an iron thickness of 0.5-40 Mean Free Path (MFP). These new data are compared with ANS standard data equipped with QAD-CGGP. In addition, a simple benchmark calculation was performed to compare the QAD-CGGP results applied with new and existing buildup factors, on the basis of MCNPX 2.7.0.

2. Methods and Materials

The data for buildup factors are generally fitted to various curves (e.g., Taylor and polynomial functions) to estimate the values between a series of data points. The Geometric Progression (GP) fitting function was first introduced to QAD-CGGP for providing a better fit for gamma-ray buildup factors, and this function is defined as follows:

$$B(E,x) = 1 + (b-1)(K^x - 1)/(K-1) \quad for \;\; K \neq 1$$
$$= 1 + (b-1)x \quad for \;\; K = 1$$

$$K(E,x) = cx^a + d[\tanh(\frac{x}{X_k} - 2) - \tanh(-2)]/[1 - \tanh(-2)]$$

where, E is the gamma-ray source energy, x is the source-detector distance in the unit of MFP, b is the buildup factor at 1 MFP, and K is the geometric ratio. The variation of parameter K according to the penetration depth represents the dose rate multiplication and change in the shape of the gamma-ray spectrum at 1 MFP. These GP parameters from 0.5 to 40 MFP were previously established from ANS-6.4.3 gamma-ray buildup factors, and the rest of the K values (< 60 MFP) are extrapolated from those data using this formula;

$$K(x) = 1 + [K(x_i) - 1] \times \exp\left[\frac{1 - (x/x_i)^{\frac{1}{n}}}{1 - (x_j/x_i)^{\frac{1}{n}}} \ln \frac{K(x_j) - 1}{K(x_i) - 1} \right]$$

where x_i = 35 MFP, x_j = 40 MFP, and n=10.

This study derives gamma-ray buildup factors of single iron material which cover an energy range of 0.015-15 MeV and penetration depth of 0.5-40 MFP. New data derived from MCNPX 2.7.0 are also fitted to the above-mentioned functions to analyze the GP parameters. Finally, the simple benchmark simulation shown in **Figure 1** is performed to compare the accuracy of two buildup factors on the basis of the reference calculation.

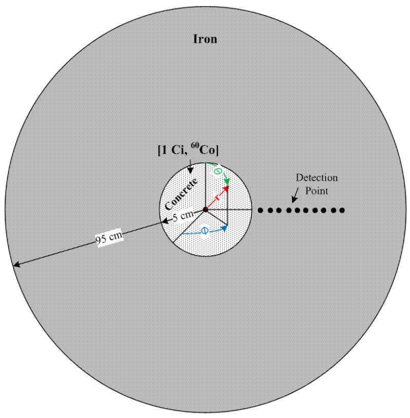


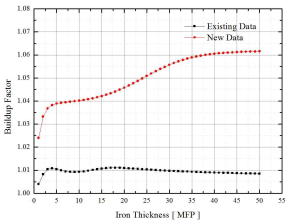
Figure 1. Benchmark Simulation for the Change of Gamma-ray Dose Rate according to Penetration Depth

3. Results and Discussions

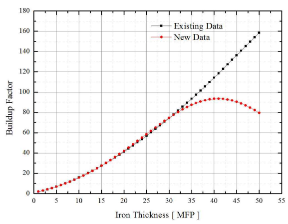
This work has evaluated the gamma-ray buildup factors of single iron material using MCNPX 2.7.0 and ENDF/B-VI.8 photoatomic data. These data were fitted to the GP function for applying QAD-CGGP, and new GP parameters derived from this procedure were compared with the existing parameters, as shown in **Table 1**. **Figure 2** represents the buildup factors for low (0.015 MeV), medium (1 MeV), and high (10 MeV) energy gamma-ray source, respectively. In the case of a low-energy gamma-ray, new data are evaluated to be about 5% as higher as the existing one. In other cases, two data present a similar trend based on the specific penetration depth, while existing data in contrast with the other data are continuously increased after that depth.

Table 1. Comparison of New and Existing GP Parameters

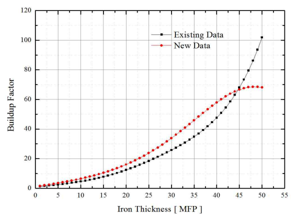
	Energy [MeV]	*b*	*c*	*a*	x_k	*d*
Existing Data	0.015	1.004	1.561	-0.554	5.60	0.352
	0.05	1.099	0.366	0.232	14.01	-0.135
	0.10	1.389	0.557	0.144	14.11	-0.079
	0.50	1.957	1.261	-0.046	24.77	0.008
	1.00	1.841	1.250	-0.048	19.49	0.014
	5.00	1.483	1.009	0.012	13.12	-0.026
	10.00	-0.292	1.297	0.949	0.042	13.97
New Data	0.015	1.024	0.383	0.000	10.90	0.229
	0.05	1.076	0.333	0.248	28.97	-0.913
	0.10	1.353	0.520	0.152	32.97	-0.507
	0.50	2.038	1.182	-0.024	31.55	-0.145
	1.00	1.910	1.166	-0.024	31.22	-0.135
	5.00	1.613	0.966	0.022	23.53	-0.057
	10.00	1.521	0.910	0.047	37.10	-0.292



(a) 0.015 MeV



(b) 1 MeV



(c) 10 MeV

Figure 2. Change of Buildup Factors as a Function of Gamma-ray Source Energy

Table 2 shows the calculation results for the simple benchmark simulation shown in **Figure 1**. The two codes were used for the calculation, and the calculation using QAD-CGGP was applied with new and existing buildup factors. The calculation employed using the existing data are being gradually overestimated in comparison of the reference data at a deep penetration depth. On the other hand, the other case is being stabilized with an increasing penetration depth, in spite of a slight overestimation at a shallow penetration depth. From these results, it was confirmed that gamma-ray buildup factors are sufficiently evaluated from the MCNPX code with the latest cross-section library.

Table 2. Dose Rate Distribution as a Function of Penetration Depth [Unit: μSv/hr]

Iron Thickness [cm]	QAD-CGGP Existing (Value/Ref.)	QAD-CGGP New (Value/Ref.)	MCNPX* [Rel. Error]
10	2.72E+04 (1.02)	2.82E+04 (1.05)	2.68E+04 (1.61%)
20	2.87E+02 (1.02)	2.94E+02 (1.04)	2.82E+02 (3.82%)
30	3.60E+00 (1.01)	3.69E+00 (1.03)	3.57E+00 (1.52%)
40	4.87E-02 (0.96)	5.02E-02 (0.99)	5.08E-02 (2.31%)
50	6.91E-04 (0.95)	7.13E-04 (0.98)	7.27E-04 (3.41%)
60	1.01E-05 (0.93)	1.04E-05 (0.95)	1.09E-05 (4.64%)
70	1.53E-07 (0.94)	1.52E-07 (0.93)	1.63E-07 (5.77%)
80	2.36E-09 (1.03)	2.22E-09 (0.96)	2.30E-09 (5.58%)
90	3.70E-11 (1.05)	3.21E-11 (0.91)	3.54E-11 (6.83%)
95	4.65E-12 (1.14)	3.84E-12 (0.95)	4.06E-12 (7.89%)

**MCNPX calculation is assumed to be reference data.*

4. Conclusions

In this study, the gamma-ray buildup factors of single iron material were derived using MCNPX 2.7.0 and ENDF/B-VI.8. From the calculation results, it was confirmed that existing data cause an overestimation in the results with increasing the penetration depth, while new data draw stable results overall, except for a slight overestimation at a shallow penetration depth. Therefore, gamma-ray buildup factors for existing and new compound materials were sufficiently re-evaluated from the MCNPX code with the latest cross-section library.

REFERENCES

[1] K.A. Litwin, I.C. Gauld, and G.R. Penner, Improvements to the Point Kernel Code QAD-CGGP: A Code Validation and User's Manual, COG-94-65, AECL, 1994.

[2] D.K. Trubey, New Gamma-Ray Buildup Factor Data for Point Kernel Calculations: ANS-6.4.3 Standard Reference Data, NUREG/CR-5740, 1991.

[3] D.B. Pelowitz (Ed.), MCNPX User's Manual Version 2.7.0, LA-CP-11-00438, LANL, 2011.