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KEK Preprint 97-79
June 1997
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SCAN-0005114

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** To be published in J. Nucl. Sci. Technol.*

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Comparison of Line Beam Response Function for Gamma-ray Skyshine Analysis based on Single Scattering Method with the Monte Carlo Calculations

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Abstract

A simple calculation method for estimating gamma-ray skyshine dose rates has been developed on the basis of the line beam response function (LBRF). The new data of LBRFs were generated by the single scattering with point kernel technique (single-scattering method). These resulting LBRFs were compared with the EGS4 and MCNP Monte Carlo calculations. The values of the new LBRFs for the large emitted angle become smaller than the LBRFs obtained with the Monte Carlo calculations with an increase of the distance from the source. This discrepancy increases with an increase of the photon energy.

I INTRODUCTION

Lynch et al.⁽¹⁾ calculated the air-scattered flux (or dose rate) for gamma rays with the Monte Carlo method. The calculations were performed at source-detector separation distances of from 5 to 100 feet, for source energies from 0.6 to 12 MeV and for beam angles with respect to the source-detector axis from 1 to 180 degrees. Their results were used as the first line beam response function (LBRF). Lately, the LBRFs for distances greater than 100 feet have been calculated using the COHORT Monte Carlo code⁽²⁾ up to 3750 feet for 17 beam angles, and for source energies of 0.6, 1.0, 3.0 and 6.2 MeV. Both results were utilized to obtain Skyshine dose rates for source-detector distances at between 40 and 500 feet.⁽³⁾

Bernard⁽⁴⁾ has suggested that a single-scattered flux or dose with exponential attenuation and without buildup factor is a good approximation for evaluating the scattered flux or dose in air. Trubey⁽⁵⁾ proposed an elementary single-scattering approximation ignored both the contribution of the exponential attenuation and buildup of photons in the air, and compared his technique with the results of Lynch et al..

Kitazume's approximation⁽⁶⁾ was based on the single-scattering formula by incorporating exponential attenuation and a Taylor-type buildup factor for the energy of scattered gamma rays. His approximation reproduced the results of Lynch et al. better than those by Trubey at large distances for all source energies.

The success of their work had led to a further development of the single-scattering method for applications to more complicated skyshine geometries.⁽⁷⁾ Specific applications of this single-scattering method to the skyshine have been exemplified by the work of Rosenberry and Shultis,⁽⁸⁾ Chou et al.⁽⁹⁾ and George.⁽¹⁰⁾ Shultis et al.^(11,12,13) calculated the LBRF by the single-scattering method, and new coefficients for an empirical fit to them were provided, which made the LBRF continuous in energy and emission direction.

The use of buildup factors derived for isotropical sources, however, includes approximations. It is supposed that a simplification affects especially at large distances. It is important to check the limit of the single-scattering method from a wide use of this method in the skyshine calculation.

In this paper, the LBRFs obtained with single-scattering method are compared with those calculated by exact transport code such as the Monte Carlo method. Going through comparisons of calculation methods of the LBRF for gamma-rays skyshine analysis, it is discussed whether the single-scattering method is suitable or not.

II Approximations of the Single-Scattering Method

In the single-scattering method photons emitted from the source reach a scattering point with exponential attenuation after that those reach at a detector with exponential attenuation, including a buildup factor for the scattering energy.

A calculation by this method differs from the real situation regarding the following points.

First, photons are not scattered isotropically from the scattering point, but are mostly scattered in the forward direction. Fig. 1 shows the angular distribution of Compton-scattered photons as the ratio of the yield at $\Phi = 0^\circ$ for 0.662, 1.25 and 6.2 MeV with spherical coordinates. The photons emitted normally and reaching the detector must be scattered with a scatter-angle of more than 90° at a point on the line-beam. From this figure it is clear that the use of photons directly scattered to a detector with attenuation,

including a point isotropic buildup factor for representing the contributions of scattered photons to the various directions, underestimates the photon flux or dose. This tendency increases with an increase in the photon energy.

Next, the energy of scattered photons differs together with the scattering angle, following the well-known Compton formula. The ratio of the single-scattering energies to source energies of 0.662, 1.25 and 6.2 MeV are shown in Fig. 2 with spherical coordinates. The energies of 90° single-scattering photons are 0.288, 0.363 and 0.472 MeV, for 0.662, 1.25 and 6.2 MeV, respectively. The way to use the buildup factors for the photon energy directly scattered to the detector is not correct, especially for a large scattering angle, due to the large differences in the energy from the photons scattered in the forward direction.

III Comparisons Between the Single-Scattering Method and the Monte Carlo method

The results of LBRF obtained by the single-scattering method were compared with those calculated by the Monte Carlo method in order to examine the problems mentioned in the previous section.

1 Comparison between COHORT, EGS4 and the single-scattering method

The original SKYSHINE code⁽³⁾ directly used the results calculated by the COHORT Monte Carlo code.⁽²⁾ The responses were calculated up to 3750 feet for source energies of 0.6, 1.0, 3.0, and 6.2 MeV and for 17 beam angles.

Fig. 3 shows comparison between the LBRFs obtained with COHORT, EGS4⁽¹⁴⁾ and the single-scattering method for source energies of 0.6, 1.0, and 6.2 MeV and for Φ of 2.5° , 40° , 90° , and 140° . Where Φ is the angle between a photon beam emitted from a point source and the source-detector axis. The results with the single-scattering method were calculated with a 3-parameter empirical formula by Shultis et al.,⁽¹²⁾ where the values of 3 parameters were fitted to the results calculated by the single-scattering method. The COHORT and EGS4 codes calculated the LBRF under the geometry that a point source and a point detector are located in an infinite air medium.

The results of COHORT and EGS4 agree well for all Φ at 1 MeV. In the case of 0.6 and 6.2 MeV, they are in good agreement at distances between 0.1 and 0.3 km. On the other hand, the results of COHORT are smaller than those of EGS4 beyond 0.3 km, except for $\Phi = 2.5^\circ$. This tendency is supposed to be a statistical problem due to a limitation of the CPU power at that time.

The results with single-scattering are slightly larger than those with the Monte Carlo code for $\Phi = 2.5^\circ$. For larger Φ , the results with the single-scattering method are smaller than those of the EGS4 method, especially at large distances, due to the reasons explained in the previous section.

2 Comparison between EGS4, MCNP and G33-GP

Under the same condition as for EGS4, comparisons of the LBRF at $\Phi = 90^\circ$ for 1.25 and 6.2 MeV between EGS4, MCNP⁽¹⁵⁾ and G33-GP2,⁽¹⁶⁾ which uses the single-scattering method, are shown in Fig. 4. The results of EGS4 and MCNP are good agreement for both energies, and those of G33-GP2 clearly underestimate, especially at large distances.

The effects of air-ground interface geometries around the detector, which are an infinite air medium, air-ground, and an air-vacuum (no reflection), were studied with the MCNP code. The results are shown in Figs. 5 and 6 together with the LBRF calculated by G33-GP2.

The results obtained with the G33-GP2 code for 1.25 MeV are larger than all cases using the MCNP code for $\Phi = 5^\circ$, and agree well with those of MCNP air-black absorber for $\Phi = 90^\circ$ on the whole. For 6.2 MeV, although the slight overestimate tendency for $\Phi = 5^\circ$ is the same, the results using the G33-GP2 code are smaller than those of the air-black absorber using the MCNP code for $\Phi = 90^\circ$.

IV Summary

The values of LBRF calculated by the single-scattering method are slightly larger at a small beam angle (Φ) from the source-to-detector axis, and are smaller at a large beam angle than the results using the Monte Carlo method as the distance increases, especially for a higher source energy.

The agreement between the calculations using the LBRF by the single-scattering method and benchmark experiments of open silo for 1.25 MeV in Fig.9 of Ref.11 is due to the compensation of the above contrary tendency caused by the integration of the LBRF over a wide angle of Φ .

The single-scattering method is based on a simplification in the estimation of the total dose used for the represented energy by the specified photon energy directly scattered to the detector from each scattering point.

The LBRF, however, should be accurate for use as basic data for the skyshine calculation. It is therefore better to calculate the LBRF with accurate calculations such as the Monte Carlo code.

References

- [1] Lynch, R. E., Benoit, J. W., Johnson, W. P. and Zerby, C. D.: "A Monte Carlo Calculation of Air-Scattered Gamma Rays," ORNL-2292, Oak Ridge National Laboratory (1958).
- [2] Soffer, L. and Clemons, Jr., L. C.: "COHORT-II: A Monte Carlo General Purpose Shielding Computer Code," NASA-TN-D-6170, National Aeronautics and Space Administration (1971).
- [3] Price, J. H., Collins, D. G., and Wells, M. B.: "Utilization Instructions for SKYSHINE," RRA-N-7608, Radiation Research Associates (1976).
- [4] Bernard, C. H.: "Air Scattering of Gamma Rays from a ^{60}Co Source," CVAC-171 (1953).
- [5] Trubey, D. K.: *Nucl. Sci. Eng.*, **10**, 102 (1961).
- [6] Kitazume, M., *J. Nucl. Sci. Technol.*, **5**, 464 (1968).
- [7] Malefant, R. E.: "G³: A General Purpose Gamma-Ray Scattering Program," LA-5176, Los Alamos Scientific Laboratory (1973).
- [8] Roseberry, M. L. and Shultis, J. K., *Nucl. Sci. Eng.*, **80**, 334 (1982).
- [9] Chou, D. -P., Hsiao, T. -P., and Lai, G. -H.: "SKYSHINE-P, A Point Kernel Computer Program for Calculating Skyshine Exposure Rates," INER-0498, Institute of Nuclear Energy Research, Taiwan (1983).
- [10] George, D. L.: "Computational Techniques in Gamma-Ray Skyshine Analysis," Report 204, Engineering Experiment Section, Kansas State University (1988).
- [11] Shultis, J. K., Faw, R. E., and Bassett, M. S., *Nucl. Sci. Eng.*, **107**, 228 (1991).
- [12] Shultis, J. K., Faw, R. E., and Deng, X.: "Improved Response Functions for Gamma-Ray Skyshine Analyses," SAND-92-7296, Sandia National Laboratory, Albuquerque, NM (1992).
- [13] Shultis, J. K. and Faw, R. K.: "Extensions to the Integral Line-Beam Method for Gamma-Ray Skyshine Analyses," SAND-94-2019, Sandia National Laboratory, Albuquerque, NM (1995).
- [14] Nelson, W. R., Hirayama, H. and Rogers, D. W. O., "EGS4 code system," SLAC-265, (1985).
- [15] Briesmeister, J. I.: "MCNP-A General Monte Carlo Code for Neutron and Photon Transport, Version 4.2," LA-7396, Los Alamos National Laboratory (1990).
- [16] Sakamoto, Y.: "QAD-CGGP2 and GP2," JAERI-M-90-116 (1990); "G33-GP: Kernel Integration Code System-Multigroup Gamma-Ray Scattering Using the GP Buildup Factor," RSIC CCC-494, Oak Ridge National Laboratory, Radiation Shielding Information Center (1986).

Fig. 1 Angular distribution of Compton scattered photons as the ratio of the yield at $\Phi = 0^\circ$ for 0.662, 1.25 and 6.2 MeV.

Fig. 2 Ratio of single Compton-scattered photon energies to source energies of 0.662, 1.25 and 6.2 MeV.

Fig. 3 Comparison of the LBRFs obtained from COHORT, EGS4 and the single-scattering method for source energies of 0.6, 1.0, and 6.2 MeV and Φ of 2.5° , 40° , 90° , and 140° .

Fig. 4 Comparison of the LBRFs obtained from EGS4, MCNP and G33-GP at $\Phi = 90^\circ$ for 1.25 and 6.2 MeV.

Fig. 5 Comparison of the LBRFs obtained from G33-GP2 and MCNP of an air-ground interface for an infinite air medium, air-ground, and an air-vacuum (no reflection) for a source energy of 1.25 MeV and Φ of 5° and 90° .

Fig. 6 Comparison of the LBRFs obtained from G33-GP2 and MCNP of an air-ground interface for an infinite air medium, air-ground, and an air-vacuum (no reflection) for a source energy of 6.2 MeV and Φ of 5° and 90° .