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Evaluation of Multiple Backscattering and Saturation Thickness of Gamma Rays

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A Monte Carlo code was written to determine the saturation thickness for multiply scattered gamma rays from aluminium targets. Interactions of incident gamma rays with the energies of 123, 279, 360, 511, 662, 1115, and 1250 keV were simulated. This work aims to design a convenient code which can be used in investigations on gamma backscattering. Obtained results for saturation thickness values have been compared with experimental ones and the Monte Carlo N-particle (MCNP) code results, and showed good agreement. Also, based on the similar behavior of number of multiple scattered photons between these three methods, the expected spectrum of singly or multiply scattered photons which is not possible to observe with experiment has been presented.

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1. Introduction

The backscattering of gamma rays from the surface of a material is of fundamental importance in radiation shielding, radiation absorption and non-destructive testing of finite samples of industrial, medical and agricultural interest [1]. When gamma rays are allowed to interact with thick targets, they undergo multiple scattering incidents within the dimensions of the target before they escape from it [2]. These gamma photons continue to decrease in energy as the number of scatterings increases in the target. These low energy photons get registered in the spectrum along with the singly scattered events. Therefore, the energy spectrum of such photons is broad and never completely separates from the singly scattered distribution [1, 3].

The backscattering of gamma rays from various materials has been the subject of experimental investigation by many studies [1–10]. Because of the large number of experimental parameters that must be followed by Monte Carlo simulations, these become both unwieldy and time consuming, in addition to the unavoidable increase in statistical errors that follow this type of correction procedure [5]. Monte Carlo based codes have proved to be a valuable tool in experimental design because they allow the testing of experimental conditions which would be difficult or expensive to perform otherwise. A number of Monte Carlo codes are available that simulate in detail photon and electron transport [7].

In this work, a Monte Carlo code was written to provide insight into the gamma ray backscattering, and simulation results for saturation thickness of gamma rays with various energies multiply backscattered from aluminium target have been presented. Also, the results of the written code may provide useful information about the energy distributions of gamma rays backscattered from aluminium as a function of primary gamma radiation energy.

2. Materials and method

A Monte Carlo was written to simulate the gamma ray transport. This code allows us to obtain saturation thickness of gamma rays with various energies and the true spectrum of backscattered photons. In the code, an isotropic point source was placed on the rectangular target of aluminium having 10×10 cm^2 surface area and the thickness of target had been varied. The incident energies of the gamma ray photons were defined at 123, 279, 360, 511, 662, 1115, and 1250 keV. The complete setup is schematically represented in Fig. 1. The algorithm of the code has been detailed in our previous studies [11, 12]. Especially, for this work incoherent and photoelectric attenuation coefficients of aluminium were obtained using the NIST XCOM database [13] and a fit relation, as used in our previous studies [11, 12], was obtained for aluminium in the energy range of 10–2000 keV. For runs 10^7 or 10^8 photons were followed.

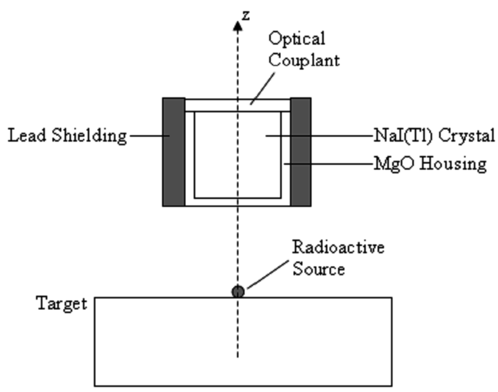

Fig. 1. A schematic presentation of Monte Carlo simulated geometry (not to scale).

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3. Results and discussion

In the first step of the work, to show the usefulness of the written code for reliable estimation, response function of a NaI(Tl) detector of 5.08 cm in diameter by 5.08 cm length (i.e. 2 inch $\times$ 2 inch) for 511 keV photons followed in the geometry of Fig. 1 has been obtained and compared (Fig. 2) by experimentally one observed by Eshwarappa et al. [2].

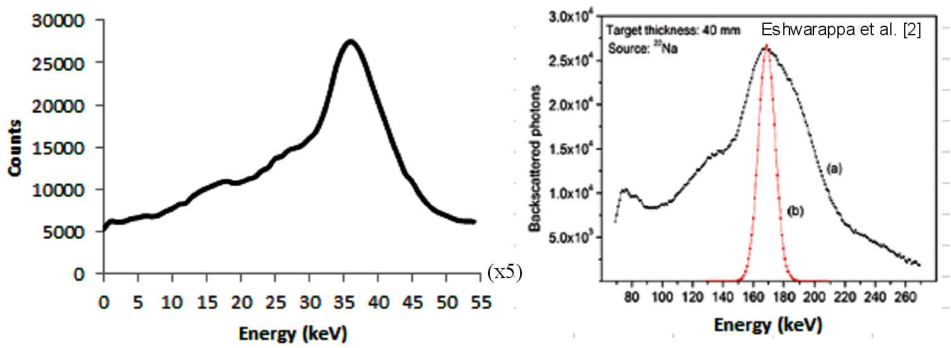

Fig. 2. A part of simulated detector response function (comprise backscattering peak) for 511 keV photons scattered from a 40 mm thick aluminium target at a scattering angle of 180° (for 10^8 primary photons).

In the second step, to extract useful information about multiple backscattering processes, number of multiply backscattered events for 123, 279, 360, 511, 662, 1115, and 1250 keV incident gamma rays as a function of target thickness has been obtained. As shown in Fig. 3, the number of multiply scattered events increases with increase in target thickness and saturates beyond a particular thickness, called the saturation thickness. On the other hand, number of multiply scattered events decreases with increasing energy of incident photons because the penetration of gamma ray photons increases with increase in incident energy. This behaviour is in agreement with experimental results obtained from the works of Sabharwal et al. [1, 3, 6, 14]. The values of the saturation thicknesses, being compared with experiment and MCNP [2], are presented in Table I.

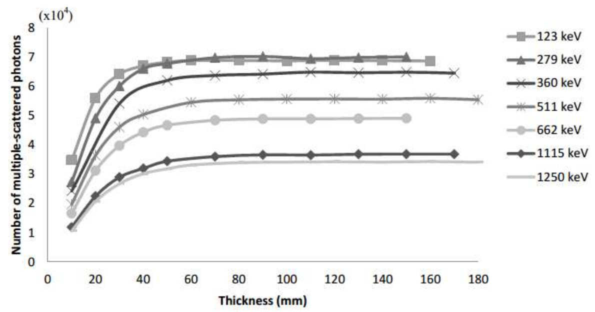

Fig. 3. Monte Carlo simulated numbers of multiple backscattered events for 123, 279, 360, 511, 662, 1115, and 1250 keV incident gamma rays as a function of aluminium target (for 10^7 primary photons).

TABLE I

Comparison of saturation thicknesses for different gamma ray energies.

Gamma ray energy	Saturation thickness [mm]		
	this study	exp. [2]	MCNP [2]
123	52.70	43.13	43.77
279	73.85	63.32	64.26
360	97.75	67.28	66.61
511	77.57	78.12	76.56
662	89.63	91.78	92.69
1115	119.84	120.38	121.58
1250	128.62	127.92	129.19

Differences at low energies observed in Table I between results of this study and experimental and MCNP calculated ones [2] can be arisen due to utilization of fit function of cross-sections for aluminium in the written code. The similarity between the experimental and the simulated response functions, and the compatible results for saturation thicknesses demonstrate that the simulation code offers a reliable estimate of the true spectrum of backscattered photons from the target and analysis of this spectrum. Fig. 4 shows simulated spectra of backscattered photons from 40 mm thick aluminium target for the various incident energies.

The code has also been used to determine the contributions of singly and multiply scattered photons to the backscattering spectrum. The energy distributions of photons scattered once (Fig. 5a) or multiple times (Fig. 5b) were obtained separately for a 40 mm thick aluminium target for all studied photon energies. The analysis of the backscattering peak shows that the maximum intensity in the spectrum is associated with singly scattered photons. This result is in good agreement with those of other authors [15, 16] and ours previously presented [11, 12]. On the other hand, the energy of the primary photons affects the total number of photons in the

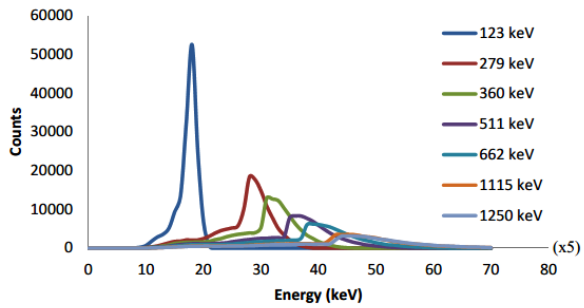

Fig. 4. Simulated spectra of backscattered photons from 40 mm thick aluminium target for the various incident energies (for 10^7 primary photons).

distribution and the location of the distribution's peak. However, the shape of the distribution is not very sensitive to the incident energy.

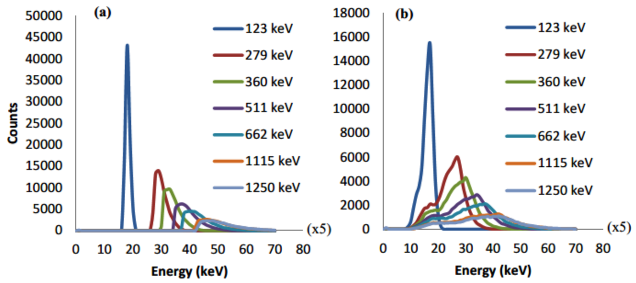

Fig. 5. Energy distributions of (a) singly, (b) multiply backscattered photons for different primary photon energies (for 10^7 primary photons).

It is clear that from Fig. 5a and b, the energy distribution in the multiply scattered spectrum is broader than for singly scattered line shapes, as previously reported by Singh et al. [5].

4. Conclusion

This work on backscattering of gamma rays has the following conclusions:

- The code written for the present investigation is useful for the studies on gamma ray interactions. Code provides quick calculations and results not possible to observe through experiment.
- There is a significant contribution of multiply backscattered photons to backscattered photon spectrum while the maximum contribution is provided by singly scattered photons emerging from the target.
- Energy distribution in the multiply scattered spectrum is broader than for singly scattered line shapes.
- Number of multiply scattered events decreases with increasing energy of incident photons.

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