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Investigations of Energy Dependence of Saturation Thickness of Multiply Backscattered Gamma Photons in Carbon

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In Compton scattering experiments employing thick targets one observes that the numbers of multiply backscattered photons increases with increase in target thickness and then saturate at a particular target thickness called saturation thickness. In present experiment the measured saturation thickness for multiply backscattering of gamma photons is found to be decreasing with increase in energy of incident gamma photons.

Key Words: Multiply backscattered events, Saturation thickness, Energy dependence

INTRODUCTION

The backscattering (or reflection) 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. Multiple backscattering in finite volumes has been a major drawback in the extraction of information from scattered photon flux because during the interaction of gamma photons with material, these photons continue to decrease in energy as the number of scatterings increases in the target. These low energy gamma photons get registered in the spectrum along with the singly scattered events. So, the energy spectrum of such photons is broad and never completely separate from the singly scattered distribution. The problem is to quantitatively calculate the numbers of multiply backscattered gamma photons from the finite slabs of carbon. Our recent measurements[1] provide Z-dependence of saturation thickness along with the survey of analytical and Monte Carlo simulation approaches to study the multiple backscattering, and available experimental data on these processes. The reported experimental data provide useful information about intensity and energy distributions of gamma rays experimentally backscattered from various materials as a function of primary gamma radiation energy. Yuk *et al.*[2] developed a land mine detection system based on backscatter X-ray principle which relates the different backscattering X-ray characteristics of materials with different densities. The present measurements provide saturation thickness of gamma rays of various energies multiply backscattered from the targets of carbon. The response function of NaI(Tl) detector obtained in our earlier work[3] employs the use of an inverse matrix approach, and it does the required spectrum unfolding.

EXPERIMENTAL SET-UP

The principle of present measurements of multiply backscattered photons is based upon detection of all the backscattered photons originating from interactions of primary gamma beam photons with the targets under study by placing a gamma ray detector at an angle of 180^o to the incident beam. The present measurements are performed for 279, 320, 511 and 662 keV incident gamma photon energies. The experimental set-up used[1] for the present measurements is designed to generate maximum numbers of backscattered photons towards the direction of 51 x 51 mm NaI(Tl) scintillation detector. The carbon targets of 8 x 4 cm^2 surface area and of varying thickness are used as scatterer. The experimental data are accumulated on a PC based ORTEC Mastreo-32 Multi channel analyzer (MCA).

RESULTS AND DISCUSSION

A typical observed pulse-height distribution (curve-a) from the carbon target (thickness 30 mm) at scattering angle of 180°, exposed to 279 keV incident gamma photons is given in Fig. 1. The pulse-height distribution corresponds to events originating from the interaction of primary gamma photons with the target material and subsequent events such as multiple Compton scattering, bremsstrahlung, Rayleigh scattering etc. The target related observed spectrum consists of intensity distribution of singly as well as multiplies backscattered photons. The singly scattered events under the backscattered peak, details provided in measurements[3], are obtained by reconstructing analytically the singly backscattered peak using the experimental determined parameters, such as counts at the photo-peak and FWHM and the detector efficiency of the detector corresponding to the backscattered energy. The curve-b provides analytically reconstructed backscattered peak due to singly scattered events. The experimental pulse-height distribution (curve-a) is converted to a photon energy spectrum with the help of an experimentally constructed (Sabharwal *et al.*[3]) inverse response matrix. The solid curve-c is the resulting calculated histogram obtained from the curve-a. The response matrix enables the low pulse-height counts resulting from partial absorption of higher energy photons to shift to the backscattered peak energy region. The events under the histogram in the Compton continuum accounts for photons of reduced energy (less than that of backscattered peak) originating from multiple interactions in the target and finally escaping in the direction of gamma detector. The events under the calculated histogram corresponding to end points energies of the backscattered peak accounts for singly and multiply scattered radiations having energy equal to that of backscattered ones. The events under curve-b of Fig. 1 are divided by peak-to-total ratio, $\varepsilon_p(E)$, of the gamma ray detector and then their subtraction from the events under the calculated histogram (curve-c) in the specified energy range results in events originating from multiple backscattering but having the same energy as in singly Compton scattering process. The intensity of photons, corresponding to respective end points energies of the backscattered peak (selected bin meshes in which the singly scattered Compton peak distribution lies), emerging from carbon targets when these are exposed to 320 keV gamma photons from ^{51}Cr, 511 keV gamma photons from ^{22}Na, and 662 keV gamma photons from ^{137}Cs is also calculated in a similar manner. The plots of

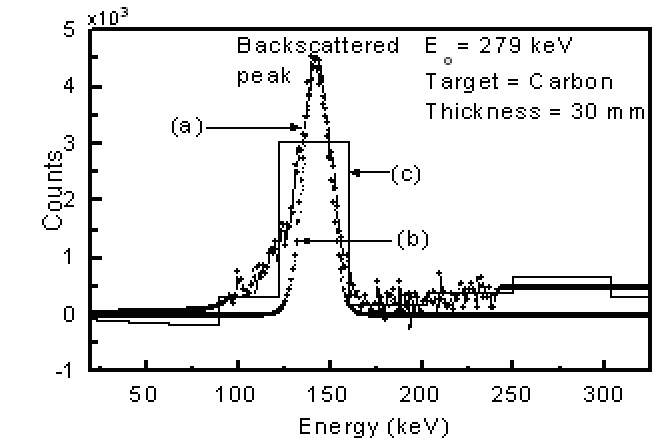

Fig. 1: An Experimentally observed pulse-height distribution (curve-a) with carbon target after subtracting background events (unrelated to target). Normalized analytically reconstructed singly scattered full energy peak (curve-b) and resulting calculated histogram (curve-c) of N(E) converting pulse-height distribution to a photon spectrum.

observed number of multiply backscattered events (having energy equal to singly scattered ones) for different incident photon energies as a function of target thickness are shown in Fig. 2.

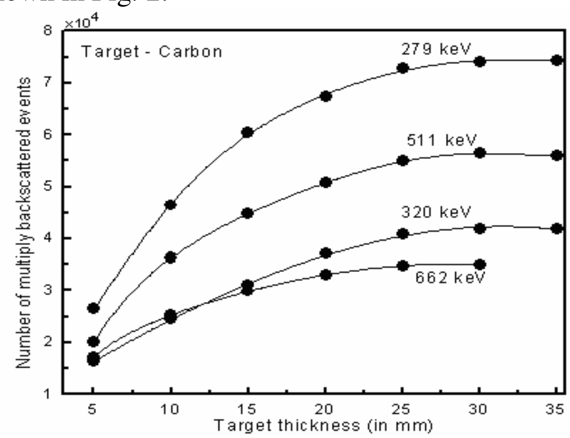

Fig.2: Variation of observed numbers of multiply scattered events as function of thickness of the carbon target for different incident photon energies

The solid curves provide best-fitted curves to the present experimental data. The present experimental results show that for each of the incident photon energy, the numbers of multiply backscattered events increases with increase in target thickness and then saturate after a particular value of target thickness, called saturation thickness. The saturation of multiply backscattered photons is due to the fact that as the thickness of target increases, the number of scattered events also increases but on the other hand enhanced self- absorption results in decrease of the number of photons coming out of the target. So a stage is reached when the thickness of the target becomes sufficient to compensate the above increase and decrease of the number of photons. The measured saturation thickness (Table 1) for multiply backscattering of gamma ray photons is found to be decreasing with increase in incident gamma photons energy. This is because the penetration of gamma ray photons increases with increase in incident gamma ray energy, so the backscattered radiation has to propagate through a large thickness and the flux of multiply backscattered photons having energy equal to the singly backscattered photons reduces.

Table 1: Experimentally measured values of saturation thickness in carbon for different incident gamma photon energies

Incident gamma energy (keV)	Backscattered gamma energy (keV)	1 mean free path in Carbon (in mm)	Measured saturation thickness	
			in mm	in mean free path
279	133.4	90.90	31.0	0.34
320	142.1	96.15	29.0	0.30
511	170.3	115.74	27.0	0.23
662	184.3	129.53	25.0	0.19

Conculsions

Our experimental results have confirmed that for thick targets, there is significant contribution of multiply backscattered radiation emerging from the target, having energy equal to that of a singly scattered Compton process. The intensity of multiply backscattering increases with increase in target thickness and saturates beyond a particular value, called the saturation thickness, thus supporting the work reported in references[1, 3-4]. It has also been concluded that the saturation thickness decreases with increase in incident gamma photon energy. It is further required to perform the experiment using HPGe detector, which provides a more faithful reproduction of the shape of distribution under the observed spectra owing to its better resolution in comparison to scintillation detectors, for better understanding of the process of multiply backscattered photons. There is also a need to simulate the experiment with some suitable

Monte Carlo code. The work on multiple backscattering is further in progress for the elemental targets of different atomic numbers.

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