Angular dependence of 662 keV multiple backscattered gamma photons in Aluminium

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Abstract

In Compton backscattering experiments, the energy and intensity of backscattered radiation vary with the angle between primary and scattered radiation. When gamma rays are allowed to interact with thick targets, they undergo number of scatterings within the dimensions of the target before they escape from it, and thus resulting in multiple scattering of gamma-ray photons. Gamma-ray backscattering is very important to get useful information about shielding, dosimetry and non-destructive testing.In the present study, multiple scattering of 662 keV incident photons from ^{137}Cs (214 MBq) gamma source is measured as a function of target thickness for aluminium target. The backscattered photons from the samples are detected by a NaI (Tl) scintillation detector placed at backscattering angles of 35°, 45°, 55°, 65°, 75°, 85°, 95°, 105°, 115°, 125° and 135°. The singly scattered events are reconstructed analytically to get multiple scattering photons. We found multiple scattering increases with increase in sample thickness and saturates after a particular value called saturation thickness. The saturation thickness behaves differently in the two hemispheres and shows symmetry around 90°. The optimum thickness at which the multiply scattered events saturate is also evaluated. Experimental results are compared with Monte Carlo N Particle code and are in good agreement.

Keywords: Scintillation detector, saturation thickness, multiple scattering, MCNP simulation.

1. Introduction

The photons interact with matter by a number of ways depending upon their energy. Among various processes of interaction of gamma rays with matter, photoelectric effect, Compton scattering and pair production are the dominant processes in the energy range from 10 keV to 10MeV. Photoelectric effect predominates in the low energy region in high atomic number elements, while the pair production is possible only when the energy of incident photon is greater than 1.02MeV.Compton scattering predominates in intermediate energy range, is a powerful tool to study electron momentum distribution in an atom, non- destructive testing of samples, effective atomic number etc.

The Compton profile can be obtained directly from the spectrum of photons emitted by a gamma source, scattered at a fixed angle from a target. A correct measurement of the Compton profile is possible only when photons scattered from the sample should undergo only one Compton collision. But in practice, the scattered beam invariably contains photons scattered more than once (multiple), when the scatterer is of finite dimensions both in depth and lateral extension. Hence an accurate measurement of intensity, angular and spectral distribution of multiply scattered photons accompanying singly scattered ones is essential for correct evaluation of Compton profiles, Compton cross sections and saturation thickness.

In Compton scattering experiments involving thin targets, the generation of multiply backscattered photons is less as compared to singly backscattered events, with increase in target thickness, the flux of multiply backscattered photons gets enhanced and more backscattered photons are detected. So, along with the singly backscattered events, these multiply backscattered events also get registered. The numbers of multiply backscattered photons also depend upon the atomic number of the target used in the experiment(Singh et al., 2006).Experimental measurements of multiple scattering have been reported by(Singh et al., 2007a)(Singh et al., 2007b). (Paramesh et al., 1983)measured the saturation depth of multiply scattered gamma rays by subtracting the analytically evaluated contribution of singly scattered gamma rays at 120° for aluminium, iron, cooper, and lead.

In the present experiment, measurements on multiple scattering are performed in Aluminium as a function of thickness and scattering angle, from 35° to 135°for 662 keV incident photons at various possible scattering angles. The optimum thickness at which the multiply scattered events saturate (saturation thickness) is also evaluated.

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2. Experimental setup:

The experimental setup to measure angular distribution backscattered radiation is shown in Fig. 1. In the present measurements, gamma photons are obtained using ^{137}Cs of strength 5.8 mCi. To minimize the background and biological effects of radiation, the active portion of source is shielded using a cylindrical lead ring of thickness 50 mm and a diameter of 160 mm. The source shielding, detector shielding and collimation are obtained using cylindrical lead rings of 50 mm thickness. In addition to this, 4 cylindrical lead rings (120 mm diameter and 50 mm thickness) were specially prepared to enclose the source both from the back and the front sides.

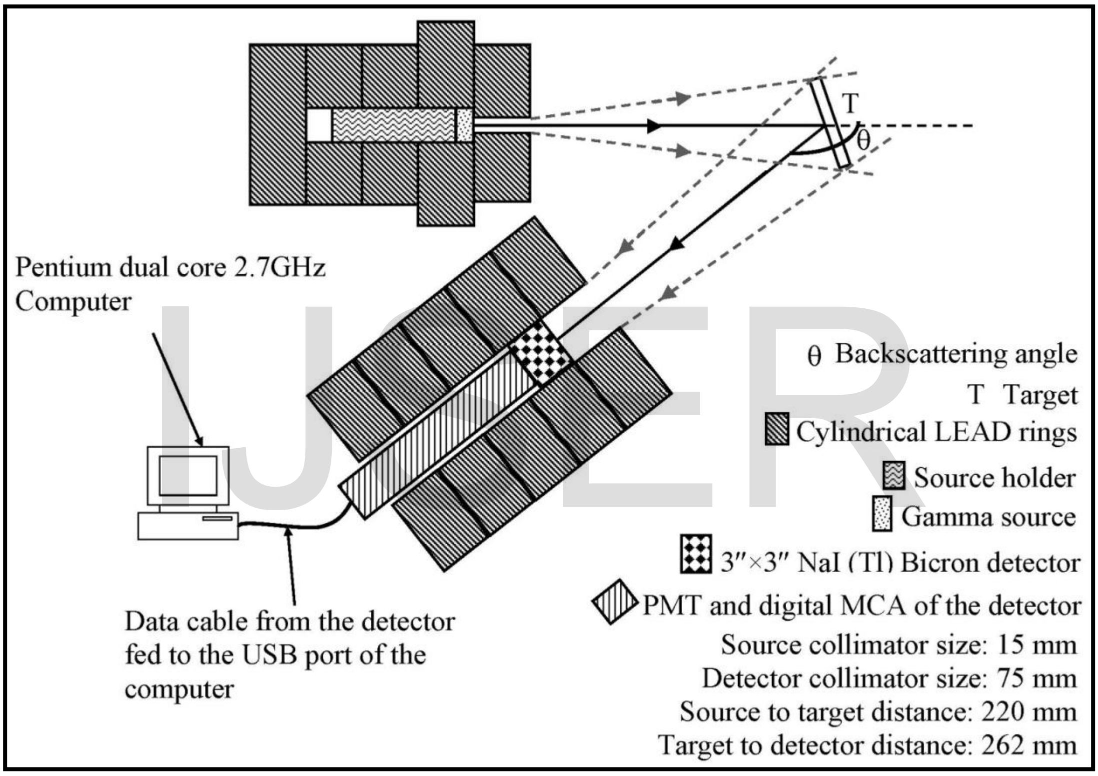

Fig. 1. Schematic diagram of experimental setup.

The gamma ray spectrometer consists of 76 mm × 76 mm NaI (Tl) scintillation detector. The distance of scatterer from source collimator is kept 220 mm so that angular spread due to source collimator (15 mm) on the target is ±1.9°. The distance of source can be varied up to 430 mm from the scatterer center.

The detector crystal is covered with an aluminium window of 0.8 mm thick and optically coupled to photo-multiplier tube. To avoid the contribution due to background radiations the detector is shielded by cylindrical lead shielding of length 200 mm, thickness 35 mm and internal diameter of 90 mm. The distance of source can be varied up to 400 mm and the distance of detector can be varied up to 270 mm from the scatterer center. The distance of the scatterer from the detector is kept 262 mm so that the angular spread due to the detector collimator (60 mm) on the target is ±5.8°. The entire experimental setup was placed at a height of 340 mm on a sturdy wooden table. This table was placed in the center of the room to minimize scattering from the walls of the room. The source-detector assembly is arranged in such a way that the centers of source collimator and gamma ray detector pass through the center of scatterer.

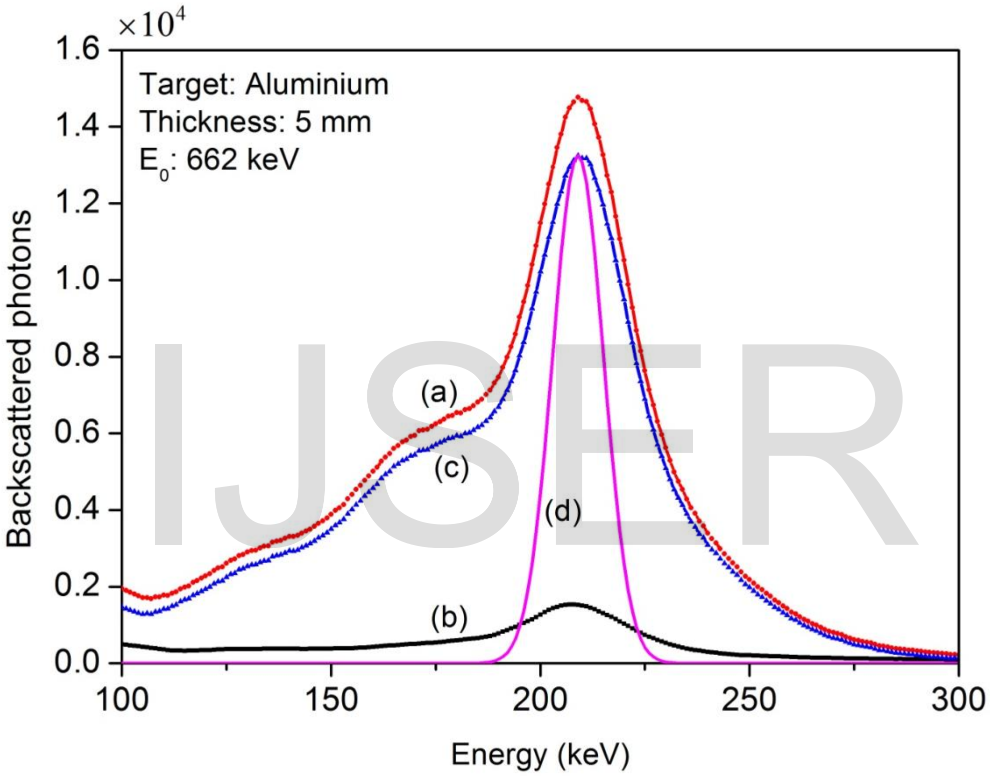

Fig. 2. A typical experimentally observed spectrum (Curve-a) with 5 mm thick aluminium target at a scattering angle of 125°. An observed background spectrum (Curve-b) without target in the primary beam. Background subtracted events (Curve-c). Normalized analytically reconstructed single scattered full energy peak (Curve-d).

Experimental data are accumulated on a PC based gamma spectrometer with fully integrated dMCA (Make: Thermo scientific, Germany). A Window-XP based spectroscopic application software winTMCA32 acts as user interface for system setup and display. All gamma ray spectral functional adjustments (e.g. noise level, dead time, fine gain, EHT etc.) are done through this application software. A software program using winTMCA32 software package was written for the present experimental setup to find to backscattered counts, multiple scattering events and single scattering events.

The incident gamma photons of energy E_0 scattered at several points of the target contribute to scattered energy that continuously decreases, requiring different values of the detector efficiency and FWHM of the gamma detector corresponding to the scattered energy (E). The scintillation detector output will be a Gaussian distribution

$$Y(E) = Y_0 e^{-4ln2\left(\frac{E - E_0}{\Delta E}\right)^2}$$

corresponding to each energy E is calculated using values of Y_0 (number of counts at peak position of the distribution). *Y(E)* is numerically integrated to obtain total number of photons at desired energy. The resulting distribution is an analytically estimated single scatter profile as detected by gamma detector. This is normalized at full-energy peak to obtain contribution of single scattered photons. Total intensity of the single scattered photons is then obtained by dividing normalized peak area by peak to total ratio corresponding to peak energy. The number of multiple scattered photons is obtained by subtracting of counts due to an analytically reconstructed distribution of single scatter events from measured experimental composite spectrum.

3. Results and discussions:

Measurements of the scattered photons are carried out as a function of sample thickness for rectangular aluminium targets of 100 mm × 100 mm using eight sources of various energies. A typical spectrum obtained by irradiating an aluminium sample of 5 mm thickness using ^{137}Cs source for 1000 seconds is presented in Fig. 2 (curve-a). Background spectrum is also recorded for same period of time to permit registration of events unrelated to target (curve-b of Fig. 2). Observed experimental spectrum obtained by subtracting events under curve-b from those under curve-a, consists of both single and multiple scattered events (curve-c of Fig. 2). Subtraction of reconstructed single scattered spectrum (curve-d of Fig. 2) from experimental spectrum in range the range 183 to 229 keV results in only multiple scattered photons. This procedure is repeated for different thicknesses of aluminium samples. Figure 3 shows the multiple scattering counts as a function of scattering angle for four different sample thickness.

Multiple scattering increases with increase in sample thickness and saturates after a particular value called saturation thickness and shown in figure 4. This increase is due to availability of greater scattering centres for interaction of incident gamma rays with sample material. However, after reaching saturation thickness, the number of photons coming out of scatterer does not increase further with increase in sample thickness as probability for absorption within a target sample gets enhanced. So, a stage is reached when thickness of sample becomes sufficient to compensate the increase and decrease of multiple scattered photons. Hence, the number of multiple scattered photons coming out of scatterer saturates. The saturation thickness for 35°, 45°, 55°, 65°, 75°, 85°, 95°, 105°, 115°, 125° and 135° is obtained from the graph is 81, 76, 78, 80, 90, 87, 80, 85, 89, 84 and 81 mm respectively.

To validate the results obtained, the experimental setup has been simulated using Monte Carlo N-Particle (MCNP) code. The mean free path for 662 keV gamma photons is 49.83 mm. The simulated data of multiple scattered intensity increases with increase in target thickness and attains saturation (Fig. 5). This behavior supports the present experimental data

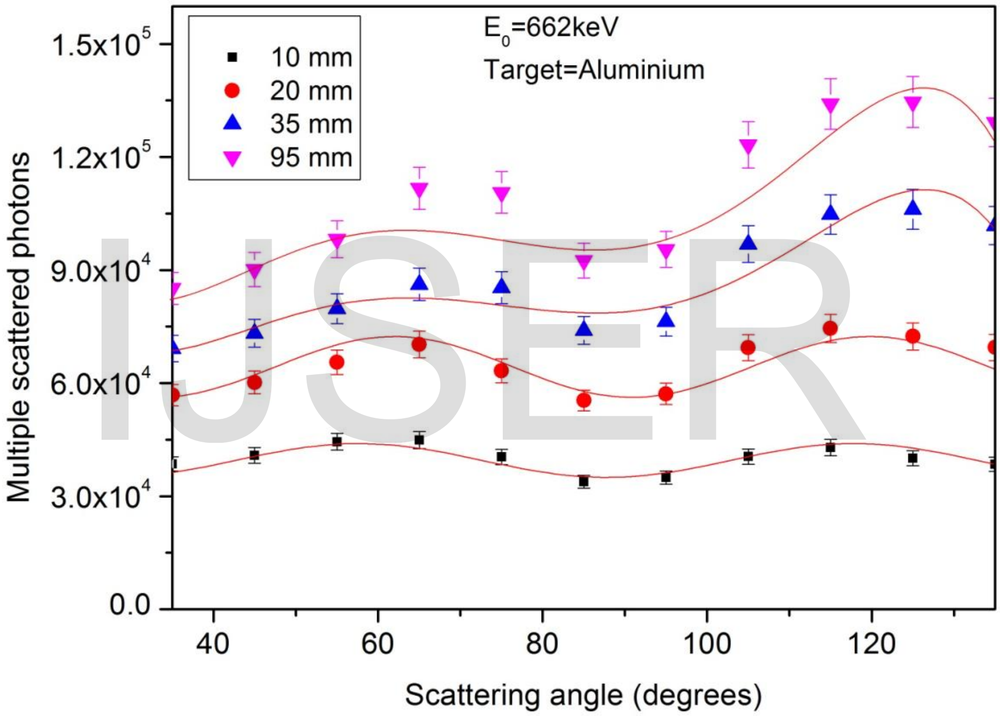

Fig. 3. Multiple scattered photons as a function of scattering angle.

4. Conclusions:

Present measurements also confirm that the number of multiple scattered events, having energy equal to single scattered events, saturates with increasing sample thickness. It is observed that the intensity of multiply scattered photons goes on decreasing from 35^0 to 85^0, reaching a minimum at 90◦ and again increases from 95° to 135°. The dip in the curves nearly at 90° occurs due to the fact, that at this particular scattering angle, the active thickness of the scatterer does not change along the direction normal to the primary beam with increase in the thickness of the scatterer.

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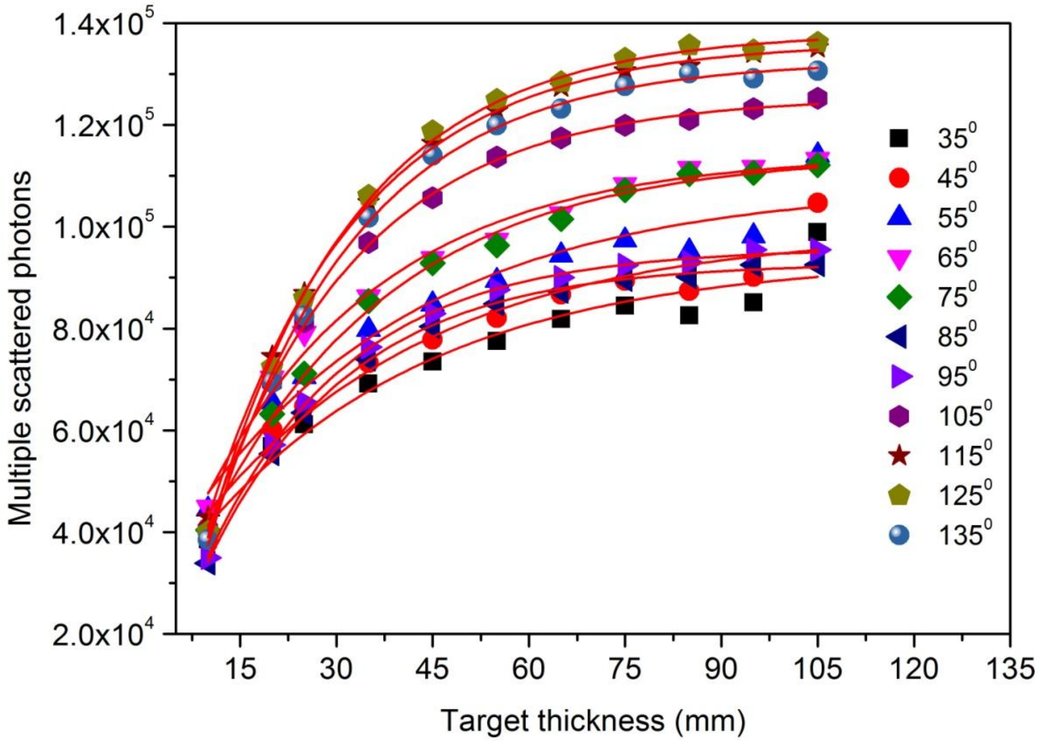

Fig. 4. A plot of saturation thicknesses for different scattering angles.

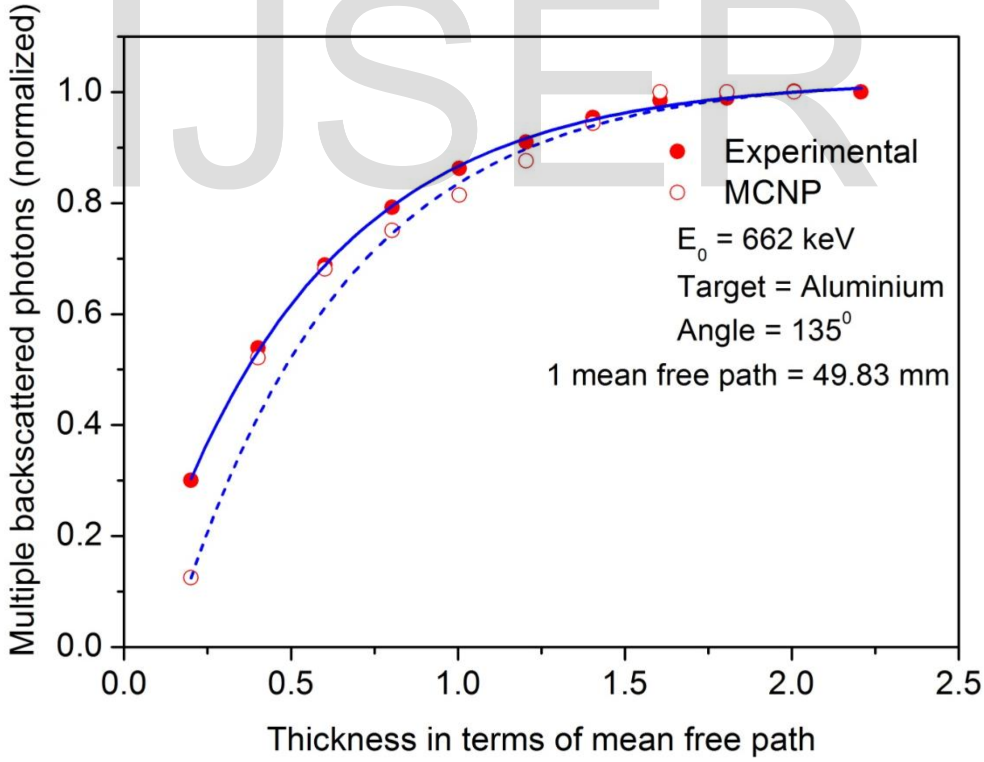

Fig. 5. A function of multiple scattering photons and mean free path.

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