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Experimental Observation of Energy Dependence of Saturation Thickness of Gamma Photons in Iron

Eshwarappa K M, Ravindraswami K, Kiran K U and Somashekarappa H M*

Abstract— Multiple scattering of gamma photons scattered backwards from iron targets is studied to estimate energy dependence of saturation thickness. Collimated beam, obtained from ^{203}Hg, ^{133}Ba, ^{22}Na, ^{137}Cs, ^{65}Zn and ^{60}Co gamma sources is allowed to impinge on rectangular iron targets of dimension 100 mm × 100 mm. The scattered photons from the samples are detected by a 3″ × 3″ NaI (Tl) scintillation detector placed at a backscattering angle of 180°. We observed that the multiple scattered photons increase with an increase of target thickness and then saturates. The measured saturation thickness for multiple backscattering of gamma photons is found to be increasing with increase in energy of incident gamma photons. The experimental results are compared with results obtained by Monte Carlo N-Particle (MCNP) simulation code.

Index Terms— NaI(Tl) detector, single scattering, multiple scattering, gamma sources, simulation.

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1 Introduction

In Compton backscattering experiments, the energy and intensity of backscattered radiation vary with the angle between primary and scattered radiation. The gamma rays backscattered from a thick absorber will show absorption and multiple scattering effects. Gamma-ray backscattering is very important to get useful information about shielding, dosimetry and non-destructive testing. 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. The multiply scattered photons continuously decrease in energy as the number of scatterings increases in the sample. These multiply scattered photons get registered in the spectrum along with singly scattered events. The energy spectrum of such photons is broad and never completely separate from the singly scattered distribution. Thus, an accurate measurement of the intensity and energy distributions of multiply scattered photons is required in various materials as a function of the target thickness to correct the data for multiple scattering contaminations (Singh et al., 2007).

Paramesh et al., (1983) measured the saturation depth of multiple scattered gamma rays by subtracting the analytically calculated contribution of single scattered gamma rays at 120° for aluminium, iron, copper and lead. Singh et al., (2008) experimentally measured energy and intensity distributions of multiple scattered gamma rays from copper targets of various thicknesses at 90^0. The present measurements provide saturation thickness of gamma rays of various energies from iron targets. We observe that the saturation thickness for multiply backscattering of gamma photons increases with increase in incident gamma photon energy. Monte Carlo calculation supports the present experimental results.

Eshwarappa K M &Kiran K U.*Government Science College, Hassan – 573 201, Karnataka, India.*
Ravindraswami K .*St Aloysius College (Autonomous), Mangalore – 575 001, Karnataka, India.*
Somashekarappa H M*.*University Science Instrumentation Center (USIC), Mangalore University, Mangalagangothri – 574 199 (D K), Karnataka, India.*
**carrtmu@gmail.com*

2 EXPERIMENTAL DETAILS

The experimental setup to measure the backscattered radiation is shown in Fig. 1. In the present experiment gamma photons are obtained using radioactive sources ^{203}Hg (1.126 MBq), ^{133}Ba (0.823 MBq), ^{22}Na (0.355 MBq), ^{137}Cs (0.555 MBq), ^{65}Zn (0.492 MBq) and ^{60}Co (0.340 MBq).The sources are of disc type with 25 mm diameter × 5 mm thick and an active portion of 6 mm diameter. The gamma ray spectrometer consists of 76 mm × 76 mm NaI (Tl) scintillation detector. 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 of 35 mm and internal diameter of 90 mm. The distance of the scatterer from the detector is kept 175 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 (Singh et al., 2006).

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 are done through this application software. These configuration settings can be stored and retrieved from the computer system. A software program using winTMCA32 software package was written for the present experimental setup to evaluate parameters like multiple scattering events and single scattering events.

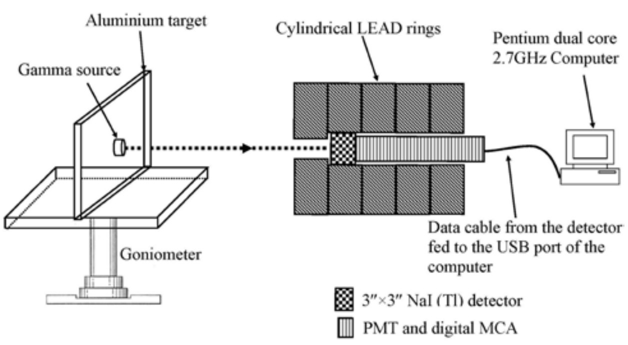

Fig. 1. Schematic diagram of the experimental setup.

The pulse height distribution obtained during experimental study contains both single and multiple scattered photons. The methodology employed in the present measurements to determine multiple Compton scattered events, having same energy as in single Compton scattering, is based upon reconstruction of single scattered spectrum using experimentally determined parameters such as full width at half maximum (FWHM) and detector efficiency of gamma detector. The number of multiple scattered photons is obtained by subtracting counts due to analytically reconstructed distribution of single scatter events from measured experimental composite spectrum (Paramesh et al., 1983).

3 RESULTS AND DISCUSSION

Measurements of the scattered photons are carried out as a function of sample thickness for rectangular iron targets of 100 mm × 100 mm using eight sources of various energies. A typical spectrum obtained by irradiating an iron sample of 20 mm thickness using ^{137}Cs source for 1000 seconds is presented in Fig. 2 (curve-a), consists of both single and multiple scattered events. Subtraction of reconstructed single scattered spectrum (curve-b of Fig. 2) from experimental spectrum in the range 163-230 keV results in only multiple scattered photons. This procedure is repeated for different thicknesses of iron samples. For the sources ^{203}Hg, ^{133}Ba, ^{137}Cs, ^{65}Zn and ^{60}Co backscattered counts were measured in the range 111-155, 128-172, 163-207, 148 - 193, 190-234 keV respectively.
Multiple scattering increases with increase in sample thickness and saturates after a particular value called saturation thickness. 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 present experimental results show that saturation thickness increases with increase in incident energy of gamma photons (Fig. 6).The saturation thickness of gamma rays for 279, 360, 511, 662, 1115 and 1250 keV energies is found to be 5, 9, 23, 33, 68, 76 mm respectively.

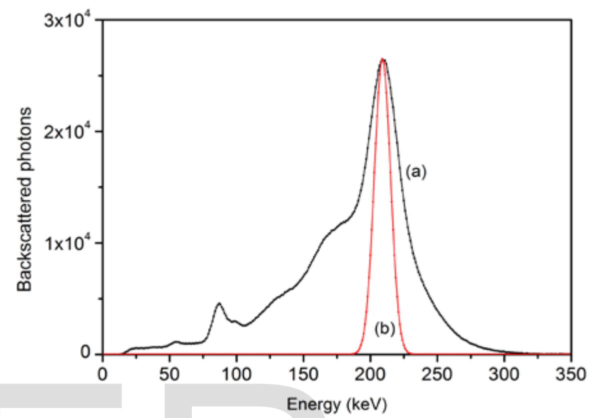

Fig. 2. Curve-a is a typical experimentally observed noise subtracted spectrum for 662 keV source with 20 mm thick iron target at a scattering angle of 180°. Curve-b is the normalized analytically reconstructed single scattered full energy peak spectrum.

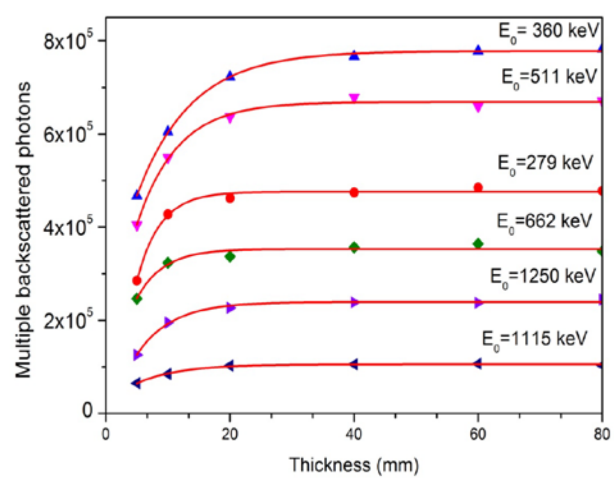

Fig. 3. A plot of saturation thicknesses versus thickness for different gamma sources.

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To validate the results obtained, the experimental setup has been simulated using Monte Carlo N-Particle (MCNP) code (J.F. Briesmeister, 1993). As many as 1.5 lakh histories were run in order to produce reliable confidence intervals. The pictorial representation of MCNP simulation of the set up is shown in Fig. 5. The F1 tally is used to estimate the number of photons crossing front surface of the detector. The dotted curves are the best-fitted curves to the simulated data (hollow symbols). The simulated data of multiple scattered intensity increases with increase in target thickness and attains saturation (Fig. 4). This behavior supports the present experimental data.

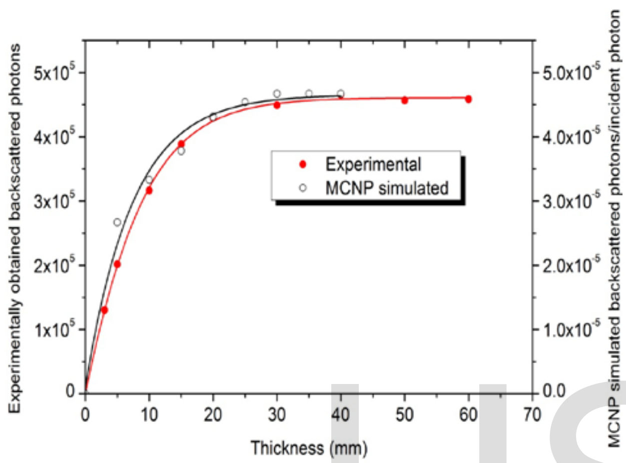

Fig. 4. Comparison of experimental and MCNP simulated saturation thickness

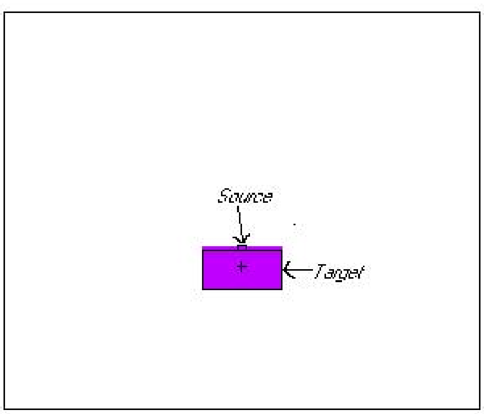

Fig. 5. MCNP plot of target geometry.

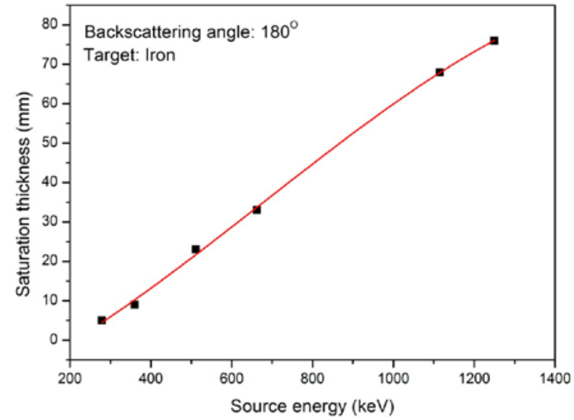

Fig. 6. A plot of saturation thicknesses versus source energy.

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. The experimental measured saturation thicknesses increase with increase in incident photon energy, caused by increasing penetration of gamma photons in matter with increasing energy. The experimentally obtained saturation thicknesses are in good agreement with simulated data using MCNP code.

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