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Research Article

AN INTEGRATED GAMMA RAY SPECTROMETER SYSTEM FOR NON-DESTRUCTIVE TESTING OF MATERIALS AND MULTIPLE SCATTERING OF THICK SAMPLES

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ABSTRACT
An experimental setup for angular distribution and measurement for scattered γ rays was designed and constructed. This is composed of a well-collimated photon beam from a 214 MBq ^{137}Cs source. The scattered photons from the samples are detected by a properly shielded 76 mm × 76 mm NaI (Tl) scintillation detector, integrated with the digital signal processing based MCA system for the spectrometric analysis of samples. The spectroscopic software programs using winTMCA32 evaluates Compton backscattered photons and transfers data into spread sheets. The sample size was optimised by conducting area effect experiment for aluminium, glass and iron samples. The backscattering experiment conducted for few metals and composite materials. The gamma ray photons continue to soften in energy as the number of scatterings increases in thick target, and results in the generation of singly and multiply scattered events. The numbers of multiply backscattered events are found to be increasing with target thickness, and saturate for a particular thickness known as saturation thickness.

Key Words: *Saturation Thickness, Nai (Tl) Detector, Signal to Noise Ratio, Gamma Radiation Source, Compton Backscattering.*

INTRODUCTION
Gamma rays interact with matter mainly through three processes viz., photoelectric effect, Compton scattering and pair production. 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, a process predominating in intermediate energy range, is a powerful tool for applications such as: determining electron momentum distribution (Compton profile) in an atom, non-destructive testing of samples and reactor shielding. The Compton profile can be obtained directly from the spectral distribution of photons emitted by a monochromatic radiation source and scattered at a fixed angle from a sample (Singh *et al.*, 2007). The scattering of gamma photons backward from the bulk of a material is called backscattering of gamma photons. As the number of interactions increases in the target, multiple backscattered photons continue to lose their energy and get registered in the spectrum along with the singly backscattered events. The energy spectrum is broad and is never completely separated from the distribution of singly backscattered events. This makes it cumbersome to measure both qualitatively and quantitatively the exact contribution of multiple backscattered photons in the lower energy region near the backscattered peak. Singh *et al.* (2007) have studied different approaches to account for the study of multiple scattering of gamma rays in a material, which are based on the geometrical arrangement of the radioactive source and detector, scatterer dimensions and interaction probability of radiation in a particular energy range.
Paramesh *et al.* (1983) have reported Z-dependence of saturation thickness of 0.662 MeV multiply scattered gamma ray at 120^0 for aluminium, iron, copper and lead. Singh *et al.* (2008) have experimentally verified the multiple scattering of 0.662 MeV gamma photons in metals and binary alloys and compared the experimental results with Monte Carlo simulations. It has been observed that the numbers of multiply backscattered photons increase with an increase in target thickness and becomes almost a constant for a particular target thickness called saturation thickness. This parameter

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is highly dependent on the incident photon energy, the backscattering angle and the density of the specimen. Saturation thickness can be used to find the effective atomic number (Z_{eff}) of a composite material.

Experimental Setup

Figure 1 shows the schematic diagram of the experimental setup for angular distribution and measurement of scattered γ-rays. The source shielding, collimation, detector shielding and collimation are obtained using cylindrical lead rings of 50 mm thickness. The actual experimental setup is shown in Figure 2 For the present measurements, 661.66 keV gamma photons are obtained from the radioactive source of ^{137}Cs of strength 214 MBq (5.8 mCi). This source is in the form of capsule sealed in an aluminium tube of diameter 20 mm and length 115 mm. The active portion of the source is 10 mm in diameter and 6 mm in length.

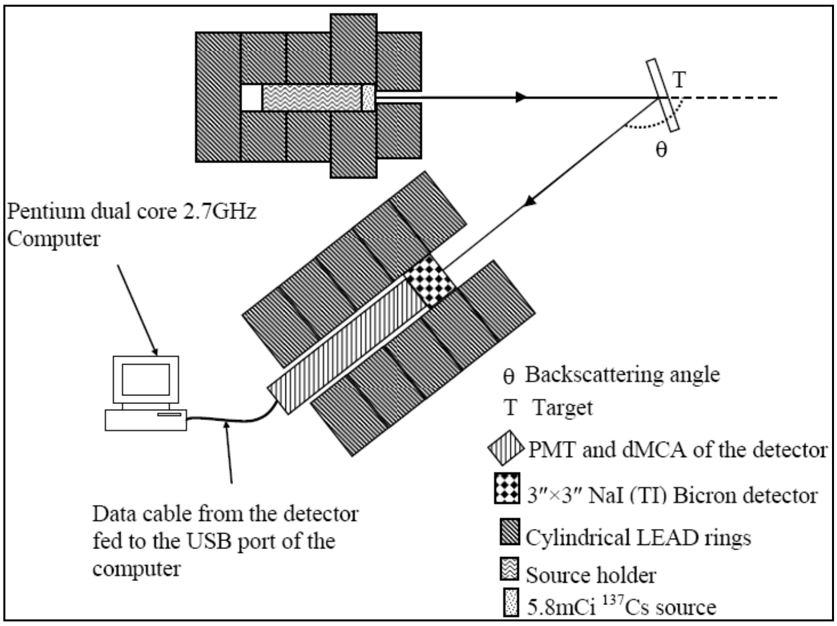

Figure 1: Schematic diagram of the experimental setup.

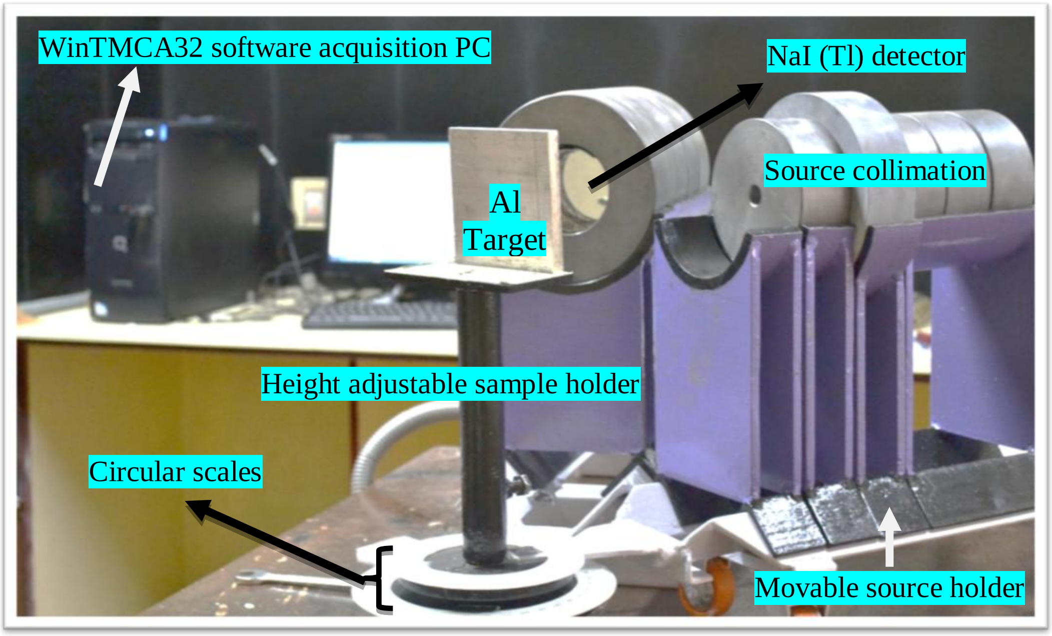

Figure 2: Photograph of the experimental setup.

To minimize the background and biological effects of radiation, the active portion of the source was shielded using a cylindrical lead ring of thickness 50 mm and a diameter of 160 mm. In addition to this, 4 cylindrical lead rings of 120 mm diameter and 50 mm thickness were specially prepared to enclose the source both from the back and the front sides. The distance of the scatterer from the source collimator is kept 220 mm so that the angular spread due to the source collimator (radius 15 mm) on the target is ±4.2°. The distance of source can be varied up to 430 mm from the scatterer center. The gamma ray detector is a NaI (Tl) scintillation detector having dimensions of 76 mm diameter × 76 mm thickness. This crystal is covered with an aluminium window of 1 mm thick and optically coupled to photo-multiplier tube. To avoid the contribution due to background radiations (like cosmic rays, radiations from week radioactive sources present in the laboratory) the detector is shielded by cylindrical lead shielding of length 200 mm, thickness 35 mm and internal diameter of 90 mm. The inner side of the shielding is covered with 1 mm thick aluminium. The experimental measurements and verification shows that there is no shift in peak position or change in energy resolution of the detector at different angular positions. The distance of the detector can be varied up to 400 mm from the scatterer center. The distance of the source 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 source collimator (radius 74 mm) on the target is ±4°.
The backscattering setup was placed at a height of 340 mm on a wooden table. This table was placed in the center of the room to minimize the scattering from the walls of the room The source-detector assembly is arranged in such a way that the center of the source collimator and gamma ray detector pass through the center of the scatterer. The goodness of the shielding was tested using a Thermo-scientific survey meter. It showed a dose rate of 1.35 μSv/h on the lead shielding and a dose rate 0.5 μSv/h at a distance of 30 cm from setup which is almost equal to background radiation.

Methods of Measurements

In the present measurements, the data is accumulated on a PC based gamma spectrometer consisting 76 mm × 76 mm NaI(Tl) detector with fully integrated dMCA (digital-Multi-Channel Analyzer, Make: Thermo scientific, Germany). A Windows XP based spectroscopic application software winTMCA32 acts as user interface for system setup and display. All gamma ray spectral and functional adjustments (e.g. noise level, dead time, fine gain, EHT etc.,) are done through this application software. These configuration settings can be stored and retrieved from the computer system. WinTMCA32 is used to write program/batch-file to acquire the counts, maximum counts, FWHM and then calculate single and multiple scattering events.
The geometrical setup calculation shows that the source must illuminate the target area of 53.42 square cm. To optimize the sample area, an experiment is carried out for iron, aluminium and glass.

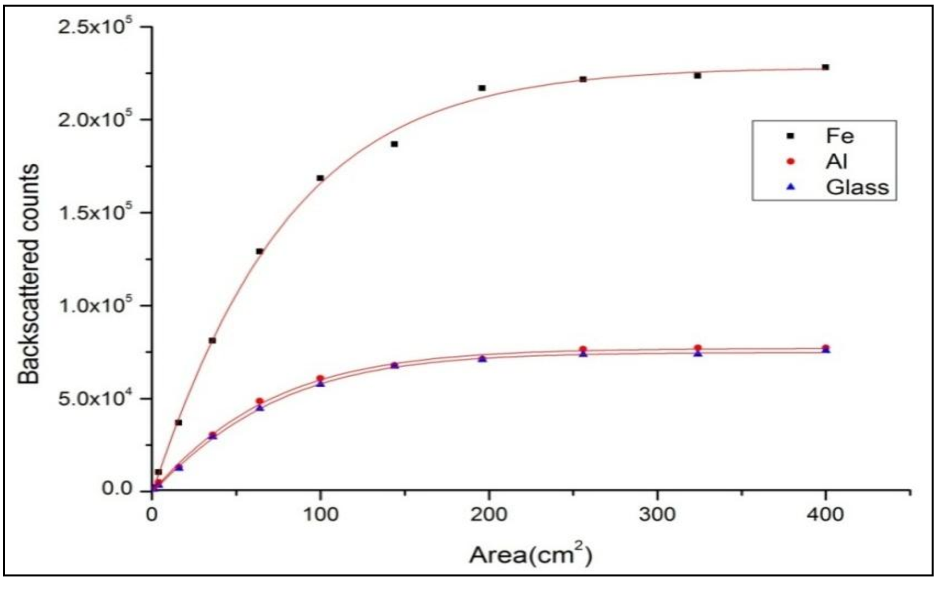

Figure 3: Backscattered counts versus target area.

The signal to noise ratio (numbers of singly to multiply scattered events) were also estimated for the same targets. The saturation thickness of iron, aluminium, copper and glass was estimated by measuring the backscattered counts at 135°. The samples of 100 cm^2 and of various thicknesses, rectangular parallelepiped were selected for the study. The spectra of the scattered radiation are recorded for a period of 180 seconds by placing different samples. The average of four trials was taken for the same sample to reduce the statistical error by a factor of 0.5, Knoll (1988).

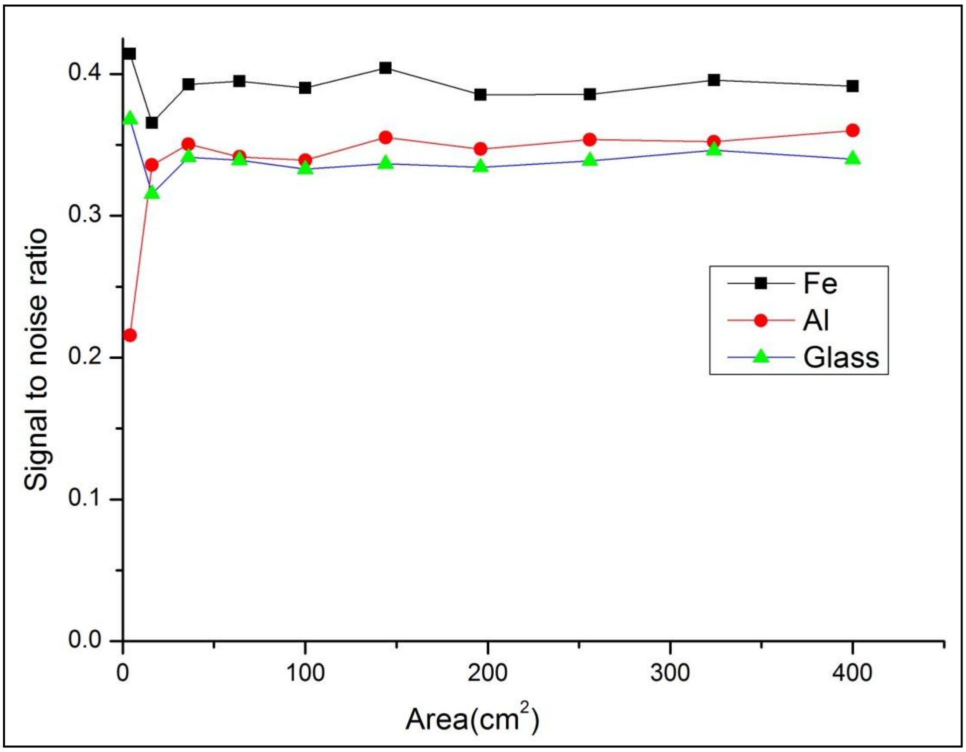

Figure 4: Signal to noise ratio as a function of target area.

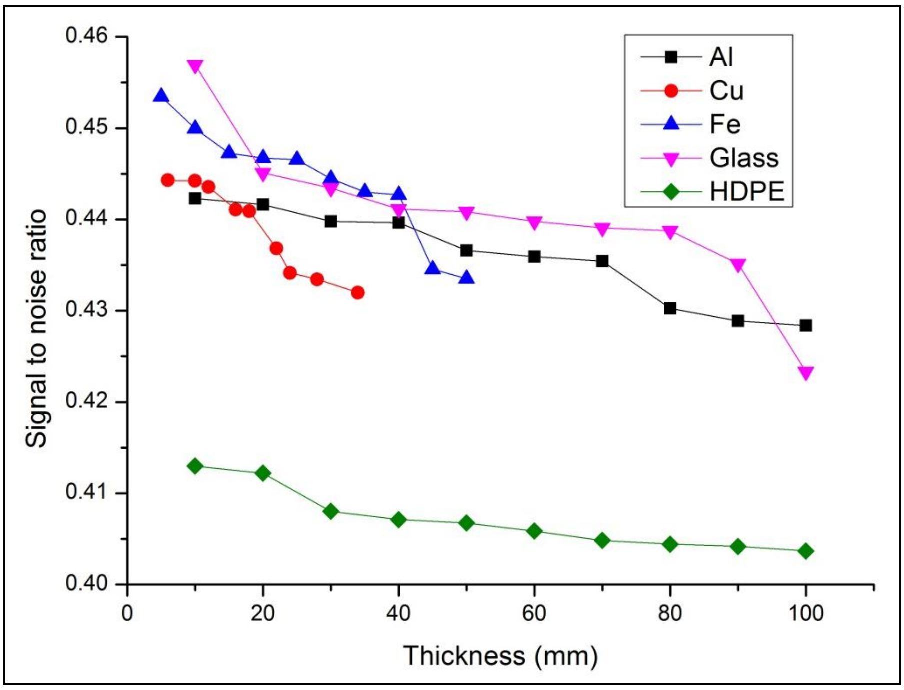

Figure 5: Signal to noise ratio for different materials.

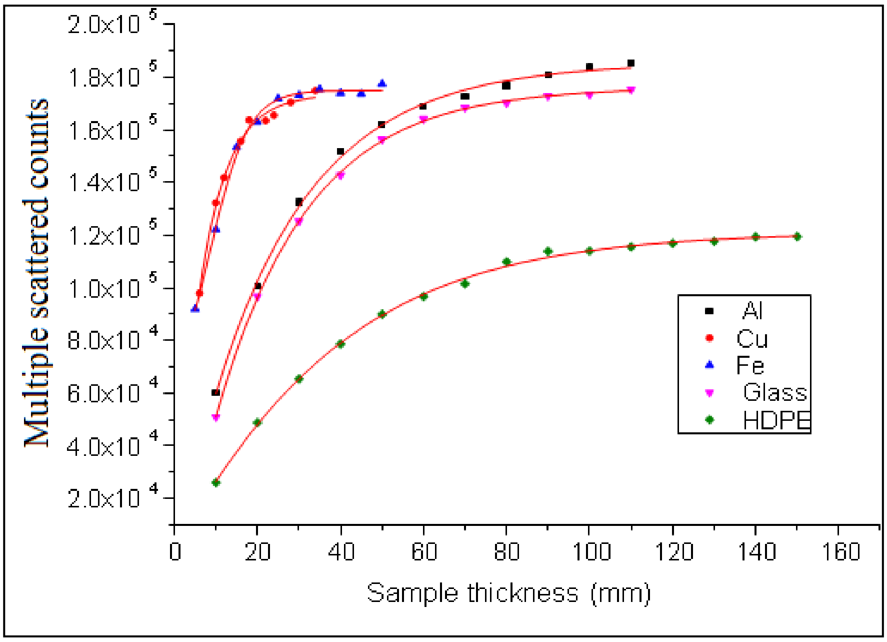

Figure 6: Saturation thickness for different materials.

CONCLUSION

The plot of the number of backscattered events as a function of target area (Figure 3) indicates that the scattered intensity increases with the target area and saturates beyond 100 cm^2. As shown in Figure 4, the signal to noise ratio remains almost a constant with increase in the target area. The plot of signal to noise ratio as function of target thickness (scattering angle of 135°) for Al, Fe, Cu, glass and HDPE (High Density Polyethylene) is shown in Figure 5. The signal to noise ratio is found to decrease with an increase in target thickness. This is because of the fact that, an increase in target thickness increases the number of multiply scattered events.

The intensity of the multiply scattered photons as a function of thickness is shown in figure 6 for Al, Fe, Cu, glass and HDPE. It can be seen that multiple scattering in the backward direction increases with the sample thickness and saturates after a particular value depending upon the material. The saturation thickness is found to be 83.79 mm, 30.67 mm, 26.44 mm, 85.86 mm and 125 mm for Aluminium, Iron, Copper, glass and HDPE respectively. Saturation thickness is more for elements having lower atomic number. The saturation of multiply scattered photons is due to the fact that as the thickness of the target increases the number of scattered events also increases, but on the other hand an 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 increase and decrease of the number of photons.

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