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"Experimental study on backscattering photons in some materials at,59.54 keV gamma rays".

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Abstract:

In this experimental study, the effect of the atomic number, thickness, and density of the materials such as tin, aluminium, and carbon, on the multiple backscattering photons using gamma radiations with 59.54 keV energy from ^{241}Am radioactive source with activity 300 mCi was studied. The scattered rays were then detected by using a 3″ × 3″ NaI(Tl) detector placed at an angle of 60 ˚to the incident beam. The variation of the count rate and the signal- to-noise ratio with the thickness of the samples were studied. It was observed that the count rate increases with the thickness linearly and then becomes constant, called the saturation thickness of the material. This saturation thickness decreases with the atomic number of the samples. Further, it was observed that the signal-to-noise ratio decreases with the thickness of the sample and also with the increase in atomic number of the samples. By measuring gamma backscattering photons,the thickness of the samples can be estimated using the calibration method.

Key words: Back scattering, NaI(Tl) detector, Saturation thickness, Signal-to-noise ratio, Atomic number.

1. Introduction:

In the study of gamma-ray interaction with matter, the rays get scattered in the direction opposite to their incident direction at an angle greater than 90̊,is called gamma-ray back scattering.It is a non-destructive method broadly used in research and industry to find the physical parameters such as thickness, density, composition of the samples, and shape of the backscattering samples.The Backscattering method has applications in the areas of fiber optics, radiation dosimetry, astronomy, X-ray imaging, photography, X-ray and neutron spectroscopy, radar system, medical sonography, etc. [1].Further, when the ultrasonic method fails to work, the backscattering is used to find the thickness of the hot objects, corroded and uncleaned surfaces. This method isalso used to determine the parameters such as saturation thickness, albedo factors, and effective atomic number.The count rate changes with the thickness of the target material according to the relation

$$C = K\{1 - \exp[-(\mu + \mu')t]\}$$

Where C represents the count rate, μ and μ′ are the linear attenuation coefficients of the incident and scattered gamma radiation, K is a constant, and the thickness of the target is t. The count rate increases up to a certain thickness of the target called saturation thickness. The backscattering theory is difficult in nature [2].

Rohit et al. [3] have measured the thickness (gauge) of metallic and wooden wardrobes using back scattering of gamma photons using a 3″× 3″ NaI (Tl) scintillation detector and ^{137}Cs gamma ray source at a back scattered angle of 180 ̊. They found that the thickness of the wooden wardrobe and the gauging of the metallic wardrobe are in good agreement with the experimental value, with the error less than 3%. Samir Abdul-Majid and Zuhair Tayyeb[4] used the gamma-ray back scattering method for the inspection of corrosion in insulated pipes using ^{137}Cs, ^{22}Na and ^{60}Co. B. A. Almayahi[5] studied the effect of the thickness of the pure concrete from 2 cm to 30 cm on the backscattering factor F_b using NaI(Tl) scintillation detector for 0.088, 0.129, 0.28, 0.662, 0.76, 0.835, 0.893, and 1.253 MeV gamma-rays. It was observed that $F_b \rightarrow 1$ for the thickness → 0, and F_b reaches a saturated value for large thickness of the sample. Inderjeet Singh et al.[6] have evaluated the effective atomic number of some composite materials such as nylon, Bakelite, Perspex, Teflon, and glass for 662 keV gamma rays using 3″ × 3″ NaI (Tl) scintillation detector by backscattering method, and the results were supported by Monte Carlo simulations. S Y Minh Tan Hoang et al.[7] studied the backscattering effects on aluminium alloy targets using a 661.6 keV^{137}Cs gamma source at the scattering angle $60° - 120°$ to determine the contribution of single scattering, and the results were compared with MCNP5 simulations. It was observed that the single and multiple backscattered photons increase with the thickness of the sample and saturated at 20 mm thickness of the sample. This method is used to investigate the electron densities or the thickness of the samples to determine the defects.Chikkappa Udagani[8] has studied the gamma ray backscattering using ^{137}Cs gamma source for granite and glass at 180° scattering angle. Then he studied the gamma ray backscattering for water, kerosene, petrol, and admixture of kerosene and petrol, and he concluded that this is a sensitive technique for qualitative analysis of the samples.

2. Materials and methods:

In this study, the saturation thickness and the signal-to-noise ratio are evaluated for the different thickness of the materials such as tin (Sn),aluminium (13Al), and carbon (C) of atomic number 50, 13, and 6, and of density 7.31 g cm^{-3}, 2.7 g cm^{-3}, and 2.26 g cm^{-3} respectively,at 59.54 keV gamma radiations at the back scattering angle of 60° to the incident beam. The scatterers of dimension 10 cm × 10 cm × 0.2 cm are used for the study.The experiment on backscattering photons was conducted using 3″ × 3″NaI(Tl) detector at CARRT (Centre for Application of Radioisotope and Radiation Technology), Mangalore University, Mangalore.

3. Experimental set up:

An experimental setup of a gamma-ray spectrometer used for the study of backscattering photons is as shown in Fig. 1. The gamma-ray source ^{241}Am of energy 59.54 keV is placed inside the seven cylindrical lead rings of 5 cm thickness with a collimator of diameter 2cm. The fine beam of gamma rays from the source is allowed to incident on the target material placed on the target stand with the support of polystyrene of density 0.006 kg m^{-3}at an angle of 120° to the incident beam, and then the backscattered photons were received at an angle of 60° from the incident path using 3″× 3″NaI(Tl) scintillation detector coupled with a photomultiplier tube and MCA covered with the five cylindrical lead rings of thickness 3.5 cm, of inner diameter 9cm, of outer diameter 16 cm, and is having a collimator of diameter 8cm.

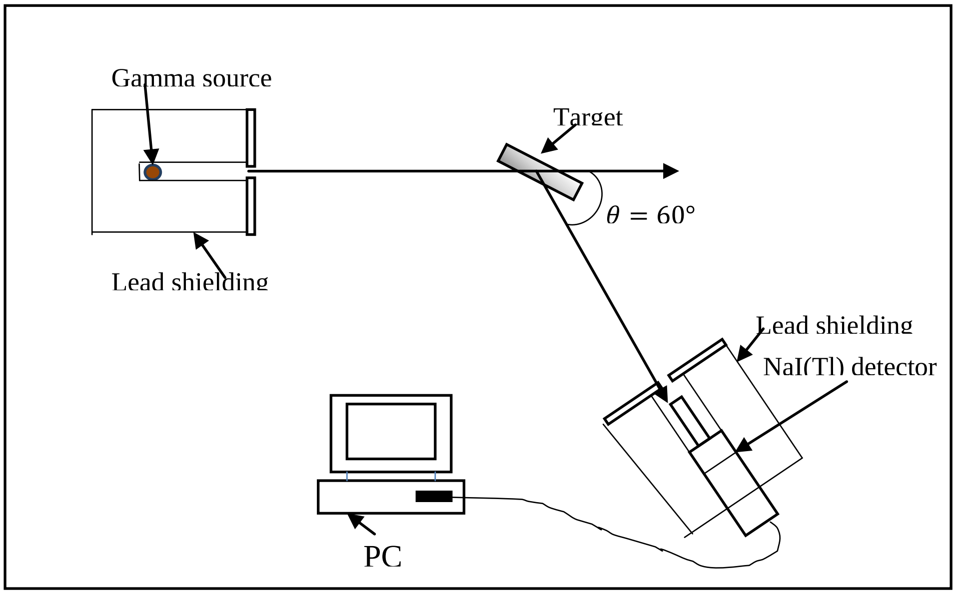

Fig. 1: Schematic diagram of backscattering experimental set up

The sample is placed at a distance of 26 cm from the source collimator and 30 cm from the detector collimator. Because of the good attenuation ability of the lead, it is used to cover both the source and the detector in the form of cylindrical rings, and these rings are coated with 3 mm thick aluminium and 2cm thick iron in order to avoid the effect of K X-rays at 20-100 keV energy produced by lead. The entire experimental set up is placed on the strong wooden table at the center of the room such that the centers of the detector collimator, target and the source collimator must be at the same level.

A PC based gamma-ray spectrometer with the win TMCA 32 application software program is used for the experimental setup in order to evaluate parameters such as single and multiple scattering events.

4. Results and discussion:

4.1 Saturation thickness:

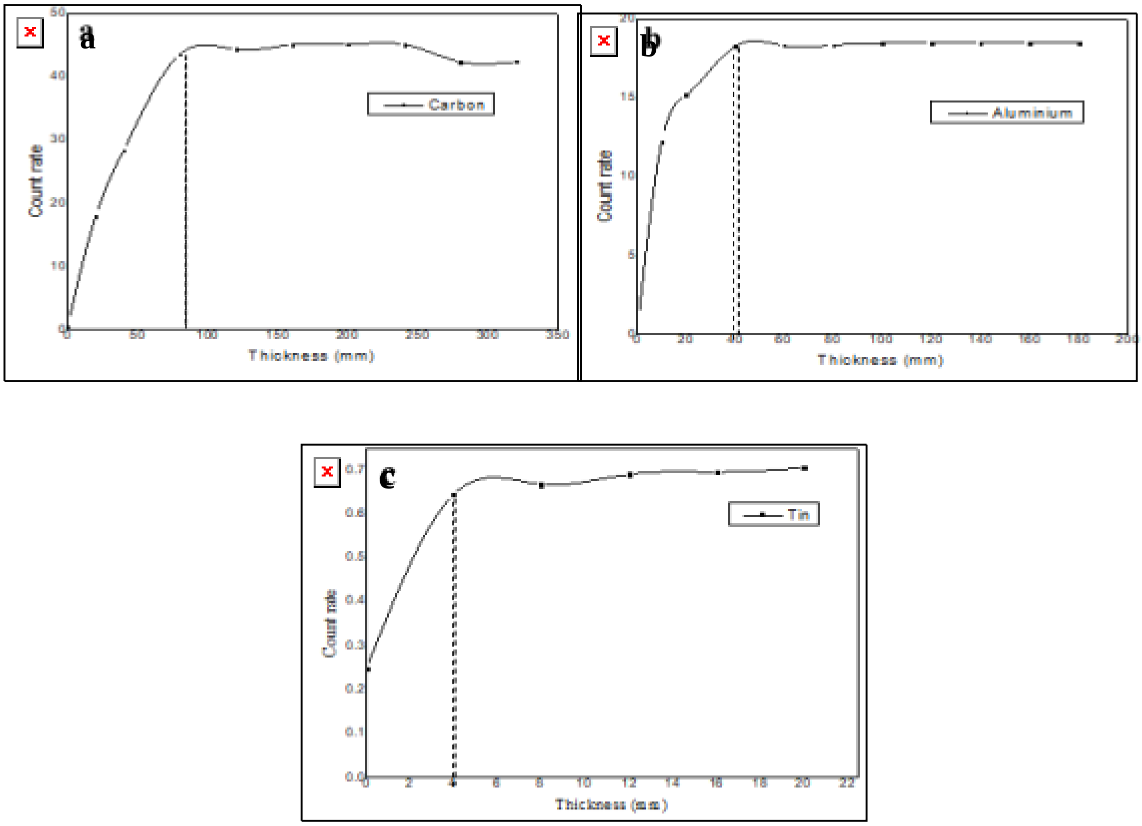

Fig. 2: Variation of count rate with the thickness of the samples a) Carbon

b) Aluminium and c) Tin

Fig. 2 shows the variation of the count rate with the thickness of the samples. The count rate increases sharply for the smaller thickness, and then becomes constant for a certain thickness of the sample called saturation thickness. It was observed that, the saturation thickness of tin (4 mm) is very much less than aluminium (40 mm) and carbon (80 mm). i.e., the saturation thickness increases as the atomic number, and the density of the sample decreases. This is due to the fact that the attenuation is dominant in higher atomic number and higher density samples, and hence the backscattering effect suppresses. By knowing the saturation thickness of the material, the thickness and the density of the material can be estimated using a calibration method. The backscattering method is used to detect inaccessible corrosion, bridges, voids, aircrafts, storage tanks etc [5].

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4.2 Signal to noise ratio:

In Compton backscattering experiments, for low atomic number target materials and for thin targets, the single scattered event (One interaction) is more than the multiple scattered events. The ratio of single scattered photons to the multiple scattered photons is called Signal-to-Noise ratio. As the thickness of the target increases, the number of scattering centers increases, and hence the multiple scattered events increases and thus the signal-to-noise ratio decreases. For the targets of higher atomic numbers, the importance of multiple scattered radiation diminishes because of the dominance of photoelectric absorption. These multiple scattered photons increase the background noise to the original signal. This ratio decreases as the thickness of the scatterer increases. The signal-to-noise ratio can be increased by decreasing multiple scattered photons. The thin targets and narrow collimators showa high value of signal-to-noise ratio. [9]. Fig. 3 (a) and(b) show the signal-to-noise ratio of carbon is high and further, tin shows,a very low value of signal-to-noise ratio because, atomic number Z of tin (Z=50), is more than aluminium (Z=13) and carbon (Z=6).

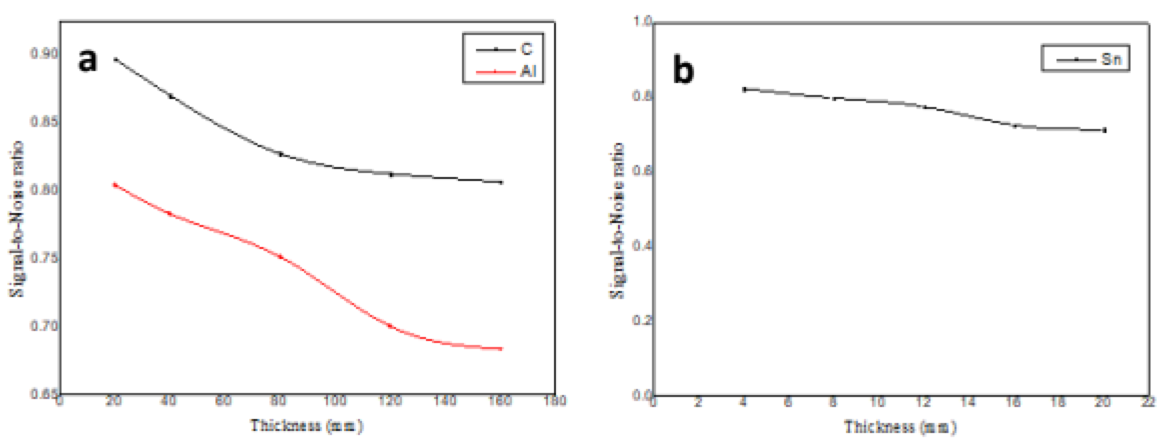

Fig 3: Variation of signal-to-noise ratio with the thickness of the scatterers (a) carbon and aluminium (b) tin.

5. Conclusion:

This study concludes that the gamma source ^{241}Am of energy 59.54 keV is an effective source for the study of backscattering gamma photons from the scattering materials such as tin, aluminium and carbon. Among the three materials used for the study, tin is a high density and high atomic number material, having very less saturation thickness, and carbon has a very low saturation thickness because of its low density and atomic number.The count rate varies linearly with the thickness of the material less than the saturation thickness. Therefore, from the calibration method, the thickness of material of interest can be estimated. This nondestructive and low-cost testing is helpful to study the structural properties like thickness, density, composition of metals, metal alloys and compounds. The increase in the signal-to-noise ratio with the thickness of the materials shows that the increase in the thickness contributes more multiple scattered events, and it was also observed that the signal-to-noise ratio decreases as the atomic number of the scatterer increases. The present experimental work using an integrated NaI(Tl) detector on carbon, aluminium and tin using ^{241}Am gamma-ray source is useful for in-situ measurements.

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