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Angular dependence of multiple scattered photons and saturation thickness for certain elements by gamma scattering method

K.U. Kiran [a,*], K. Ravindraswami [b], K.M. Eshwarappa [a], H.M. Somashekarappa [c]

[a] Government Science College, Hassan 573 201, Karnataka, India
[b] St Aloysius College (Autonomous), Mangalore 575 003, Karnataka, India
[c] University Science Instrumentation Centre, Mangalore University, Mangalagangothri 574 199 (D K), Karnataka, India

HIGHLIGHTS

- Angular dependence of multiple scattered photons was studied.
- Variation of saturation thicknesses as a function of scattering angle was studied.
- The experimental and MCNP simulated results are compared.

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ABSTRACT

Multiple scattering of gamma photons obtained from 0.215 GBq ^{137}Cs source in both forward and backward hemisphere for 4 elements viz., carbon, aluminium, iron and copper are detected by a 76 mm × 76 mm NaI(Tl) scintillation detector. The variation of saturation thicknesses of 4 elements are studied experimentally at 60°, 80°, 90°, 100°, 120° and 135°. Monte Carlo N-Particle (MCNP) simulation of multiple scattering and variation in saturation thicknesses is carried out for 40°, 60°, 80°, 90°, 100°, 120°, 135°, 160° and 180° for four elements. The variation of the intensity of multiple scattered photons in different scattering angles is found to be different in forward and backward hemispheres. The intensity of multiple scattered photons is found to be minimum at around 90°. Saturation thicknesses for 40° and 60° are found to be less than saturation thicknesses for 80°, 90°, 100°, 120°, 135°, 160° and 180° in spite of the fact that the scattered energy is more for lower scattering angles. The behaviour of variation of saturation thicknesses as a function of scattering angles obtained from MCNP simulation agrees well with experimentally obtained values.

1. Introduction

Multiple scattering of gamma photons is the process in which gamma photons interact with thick targets in a substantial number along with single scattered photons. This results in softening of gamma photons which acts as noise if differential Compton cross section has to be measured. This is taken into account in radiation shielding calculation (Gopinath and Santhanam, 1971). In majority of gamma scattering experiments, multiple scattering is considered as one of the principal difficulties for interpreting accurate results. In order to minimize the effect of undesired multiple scattering, researchers choose very thin target materials under study (Latha et al., 2012; Manjunathaguru and Umesh, 2006). On the other hand, multiple scattering of gamma photons provides very useful information regarding properties of materials like density, effective atomic number, that are very important for shielding purposes. Because of larger interacting area, multiple scattering photons increase for an increase in target thickness. Paramesh and Venkataramaiah (1998) and Paramesh et al. (1983) work on 662 keV and 835 keV photons interacting with aluminium, iron, copper, tin and lead showed that multiple scattered photons increase for an increase in target thickness and then become almost a constant after a thickness called "saturation thickness". Their work established a logarithmic relationship between the atomic number "Z" and saturation thicknesses of the materials. This relationship of atomic number and saturation thickness of multiple scattered photons was successfully used to assign "effective atomic number" to certain composite materials (Singh et al., 2006, 2008). Our previously published work also shows that

* Corresponding author.
E-mail address: kirangsch@gmail.com (K.U. Kiran).

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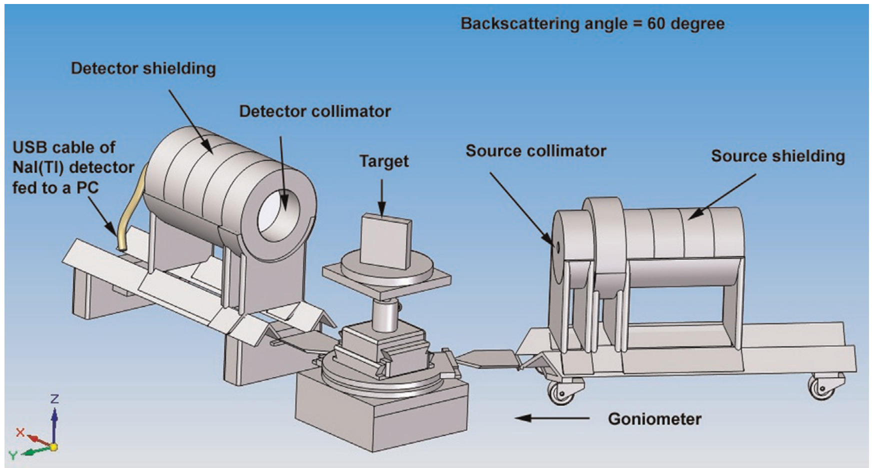

Fig. 1. Experimental set-up for a scattering angle of 60°.

this method of Z dependence of saturation thicknesses of multiple scattered photons can be effectively used to obtain effective atomic numbers of glass and certain polymers (Ravindraswami et al., 2013, 2014). Our work established the energy dependence of saturation thickness for 59.54, 123, 279, 360, 511, 662, 1115 and 1250 keV gamma photons in carbon and aluminium (Kiran et al., 2014; Eshwarappa et al., 2014). The work of Dumond (1930) showed the importance of careful study of multiple scattered X-rays. The work of Tanner and Epstein (1976) showed how multiple scattering varies with optical thickness in a simple model for a Compton-scattering experiment.

It is, therefore, important to accurately estimate the intensity and spectral distribution of multiply scattered photons. The angular distribution of 662 keV multiple scattered photons was experimentally observed using a 2 in × 2 in NaI detector in certain materials (Singh et al., 2007, 2008). Barnea et al. (1995) studied the variation of multiple scattered photons for 45°, 60°, 90° and 120° in aluminium, brass and tin for 662 keV photons. The angular distributions of double scattering for aluminium and nickel have been studied using the relativistic Klein–Nishina cross section (Halonen and Williams, 1979).

The present work made an experimental study of angular dependence of 662 keV multiple scattered photons and saturation thickness for certain elements in gamma scattering method using the response corrected 76 mm × 76 mm NaI(Tl) detector in carbon, aluminium, iron and copper. Literature survey showed the absence of the comparison of experimental work and simulated work for 662 keV photons for carbon, aluminium, iron and copper. Hence the experimentally obtained results are compared with the Monte Carlo N Particle (MCNP) simulation code for 40°, 60°, 80°, 90°, 100°, 120°, 135°, 160° and 180° scattering angles.

2. Experimental setup

The experimental set-up to study the angular dependence of multiple scattered photons and saturation thicknesses is shown in Figs. 1 and 2 for forward and backward hemispheres respectively. Gamma photons are obtained from ^{137}Cs source of strength 0.215 GBq. The 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. In order to minimize the background 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. 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 centre.

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. Because of the low cost, easy availability and good attenuation for gamma photons, lead was used to shield the source and the detector. The use of lead shielding for the source generates K X-rays in the range of 20–100 keV. In order to avoid these background radiations and increase the signal to noise ratio, the inner side of the shielding is covered with 2 mm thick iron and 3 mm thick aluminium with iron facing towards lead (Raghunath et al., 1983). 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 centre. The distance of the scatterer from the detector is kept 262 mm so that the angular spread due to the detector collimator (74 mm) on the target is ± 8.1°. The entire experimental set-up was placed at a height of 340 mm on a sturdy wooden table. This table was placed in the centre of the room to minimize scattering from the walls of the room. The source–detector assembly is arranged in such a way that the centres of source collimator and gamma ray detector pass through the centre of scatterer.

3. Method of measurements

3.1. Data acquisition

Scattered photons at various scattering angles from different target materials are counted using a fully integrated Multi Channel Analyzer (MCA).[1] A Window-XP based spectroscopic application software winTMCA32 acts as user interface for system set-up and display. All gamma ray spectral 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. A software program using

[1] Make: Thermo scientific, Germany.