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Short communication

Investigations of effect of target thickness and detector collimation on 662 keV multiply backscattered gamma photons

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ABSTRACT

The present studies aimed to investigate the effects of detector collimation and target thickness on multiply backscattered gamma photons. The numbers of multiply backscattered events, having energy the same as in singly scattered distribution, are found to be increasing with target thickness, and saturate for a particular thickness known as saturation thickness. The saturation thickness is not altered by the variation in the collimator opening. The number and energy albedos, characterizing the reflection probability of a material, are also evaluated. Monte Carlo calculations support the present experimental work.

1. Introduction

The interaction processes of gamma rays in various media result in complete absorption, elastic scattering and inelastic scattering of incident photons. Compton backscattering is a most dominant process in the intermediate energy range and in low *Z*-elements at near backward angles. In the collision between photons and electrons while dealing with thick targets, some higher order processes occur due to a large number of secondary radiation produced in the first encounter, also known as multiply backscattered radiations. These multiply backscattered photons have a noticeable effect in the lower energy region of Compton continuum because these radiations also reach the detector and get counted. Therefore, multiple scattering is one of the principle difficulties for interpreting data, which is present within an energy range of single scattering.

Our measurements (Sabharwal et al., 2008 and references therein) provide in brief the results of various experiments on multiple backscattering along with analytical and Monte Carlo simulation approaches to study these processes. The quantities characterizing the reflection probability of a material for gamma photon flux are called albedos. The simplest of these albedos is the number albedo that refers to the fraction of incident radiations, which actually emerged from the target (Hayward and Hubbell, 1954). The energy albedo refers to the fraction of incident energy that escapes the target. These albedos are required in the calculations of radiation shielding problems to estimate the contribution of radiation backscattered by the shield (Pozdneyev, 1967). Hayward and Hubbell (1954) developed a Monte Carlo method to determine the albedo factor at 1 MeV photons scattered from semi-infinite slabs of water, aluminium, copper, tin and lead at various angles of incidence. Bulatov and Garusov (1960) had calculated the absolute values of energy albedo of various materials for 1.17, 1.33 and 0.410 MeV gamma photons. Hyodo (1962) experimentally calculated the energy and number albedos, and the angular distributions of scattered energy from semi-infinite media.

In a previous work, our group (Singh et al., 2006) has observed the effects of detector collimator and target thickness on 0.662 MeV multiply scattered gamma photons experimentally at scattering angle of 90°. Our recent measurements (Sabharwal et al., 2008, 2009) have confirmed that the saturation thickness for multiply backscattered events decreases with an increase in incident gamma photon energy and atomic number (*Z*), and the detector response unfolding converting the observed pulse-height distributions to a true photon energy spectrum is quite satisfactory.

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There has been no work for the investigations of effects of detector collimator and target thickness on multiply backscattered gamma photon intensity except that of Singh et al. (2006) at 90. In the present work, multiple backscattering of 662 keV gamma photons from thick aluminium targets has been investigated. The dual effect of detector collimator and target thickness on multiply backscattered gamma photon intensity, number and energy albedos, and signal-to-noise ratio have also been investigated.

2. Experimental set-up and measurements

An intense beam of gamma rays incident on a thick target results in multiply backscattered events in addition to singly scattered ones. The principle of the present measurements is to record these events using a gamma detector placed at 180° to the incident beam. In the present work, ^{137}Cs radioactive source, sealed in a plastic disk of diameter 25 mm and length 5 mm, is placed adjacent to the center of the surface (facing toward detector) of aluminium target as shown in Fig. 1. The distance between the aluminium target and the NaI(Tl) detector is 75 mm. The beam of gamma photons from the source is made to impinge on rectangular aluminium targets, 80 mm in length and 40 mm in breadth, of varying thickness. The radiations backscattered from the target are detected by a NaI(Tl) scintillation detector having dimensions 51 × 51 mm. The backscattered radiations are collimated by a cylindrical collimator (hole-size of different radii) made of lead, lined with aluminium having a thickness of 17 mm placed at a distance of 10 mm in front of the detector, to check the effect of detector collimation on numbers of multiply backscattered events. The experimental details along with the procedure for measurements are provided in our recent measurements (Sabharwal et al., 2009).

The gamma ray detector detects the primary photons emitted from the source as well as the photons that are scattered by the target. The subtraction of recorded spectra without target from those recorded with target results in events originating from interactions of primary gamma beam with the target and followed by multiply scattered events occurring in the target. The evaluation of numbers of multiply backscattered events in the present measurements is carried out using the photon intensity incident on the target, collimator opening (hole-size) and spectral distribution of multiply backscattered events for a given thickness of aluminium target and geometry (the overall set-up condition), by reconstructing singly scattered distribution and using the response function of NaI(TI) scintillation detector (Sabharwal et al., 2008).

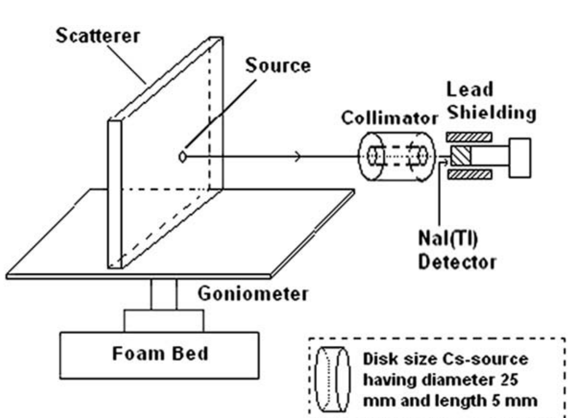

Fig. 1. Experimental set-up of present measurements.

3. Results and discussions

In Compton scattering experiments, as the collimator opening (hole-size) and target thickness are increased, the probability of multiply backscattered photons to reach the detector increases. So, along with the singly scattered events, the multiply backscattered photons are also measured. This is because firstly with an increase in target thickness, more numbers of backscattered photons is generated and secondly with an increase in collimator opening (aperture hole-size) the detector is exposed more to the backscattered radiations. With the increase in target thickness, the generation of multiply backscattered photons increases. Measurements of the backscattered photons are carried out both as a function of target thickness and detector collimator opening.

Fig. 2 shows a typical observed pulse-height distribution (curve-a) with a target of aluminium at a scattering angle of 180°. Curve-b of Fig. 2 gives spectrum with the target out of the primary gamma beam. The subtraction of events under curve-b from those under curve-a results in scattered spectrum (curve-c) corresponding to events originating from the interaction of primary gamma photons with the target material and subsequent events such as multiple Compton scattering, bremsstrahlung, Rayleigh scattering, etc. The curve-d is the analytically reconstructed singly backscattered distribution (Sabharwal et al., 2008) originating from the aluminium target. The experimental pulse-height distribution (curve-c) is converted to a photon energy spectrum with the help of an inverse response matrix (Sabharwal et al., 2008). The solid curve-e is the

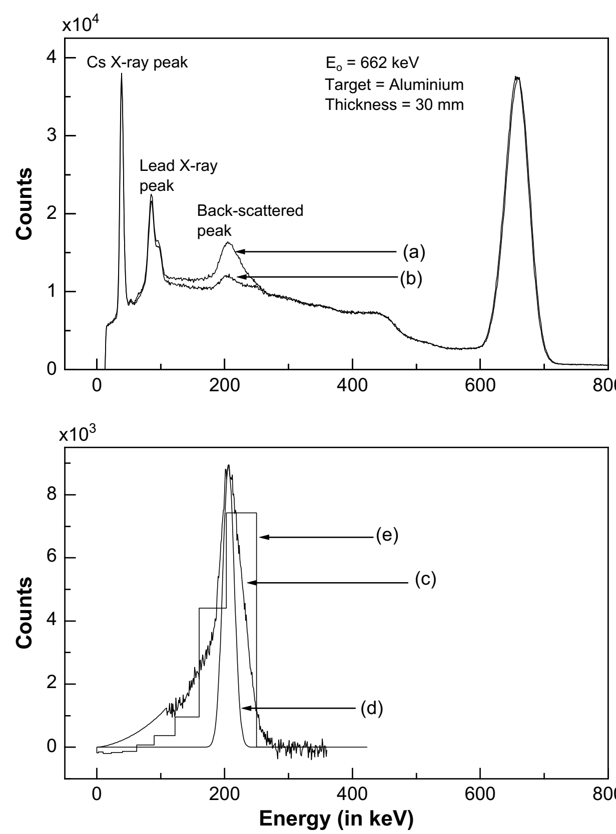

Fig. 2. A typically observed pulse-height distributions with (curve-a) and without (curve-b) an aluminium target (detector collimator opening of 40 mm), recorded for time duration of 10,000 s. Experimentally observed pulse-height distribution (curve-c) obtained after subtracting events unrelated to target. Normalised analytically reconstructed singly scattered full energy peak (curve-d) and resulting calculated histogram (curve-e) of N(E) converting pulse-height distribution to a true photon spectrum.