Experimental evaluation of saturation thickness for 662 keV in Lead at scattering angle 120^o.

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Abstract: For sample having finite dimensions both in depth and lateral dimensions, the incident photons undergo a number of scatterings within the sample before finally emerging out. The multiple scatterings of photons act as a background in Compton scattering measurements and should be minimized for correct evaluation of Compton profile, The study of multiple scattering of photons is considered as a tool for the correct determination of electronic momentum distribution in an atom, non-destructive testing, effective atomic number of composite materials, reactor shielding etc. In the present work, intensity and energy distribution of multiply scattered photons originating from interactions of 662 keV photons in thick targets of lead is determined with the help of an inverse response matrix that converts the pulse-height distribution to a photon energy spectrum. A collimated beam from 137Cs radioactive source of strength 222GBq is allowed to impinge on rectangular targets of lead with varying thickness. The scattered photons are detected by a properly shielded NaI (Tl) scintillation detector having dimensions 51mm x 51mm diameter and thickness placed at low scattering angle to the incident beam. The singly scattered Compton peak is analytically reconstructed and is subtracted from the observed pulse height distribution to obtain multiply scattered events. It is observed that the number of multiply scattered events increases with increase in target thickness and saturate for a particular thickness called saturation thickness. This saturation thickness for 662 keV photons in lead target at 120o scattering angle comes out to be 16 mm. The signal-to-noise ratio is found to be decreasing with the increase in target thickness. The self-absorption correction in the target is also applied and found that the number of multiply scattered photons increases, but the saturation thickness remains the same. The same experiment repeated with an HPGe gamma detector and found same saturation thickness. The Monte Carlo calculations based upon the package developed by Bauer and Pattison (1981) supports the present experimental results.

Keywords: Scintillation detector response unfolding; energy and intensity distribution, multiple Compton scattering, HPGe gamma detector, Saturation thickness and signal - to - noise ratio

Introduction

In Compton profiles, the interactions of photons with the target may result in significant fraction of multiply scattered photons in addition to singly scattered ones. The energy spectrum of such photons is broad and never completely separate from the singly scattered distribution in real measurements. This leads to the smearing of information associated with the intensity change of scattered photons. Photons continue to soften in energy as the number of scatterings increases in the sample. Thus for correct evaluation of Compton profile, an accurate measurement of the intensity and energy distributions of multiply scattered photons is required to correct the data for multiple contamination.

Our previous measurement [1] provides a complete survey of analytical and Monte Carlo simulation approaches to study the multiple scattering. A survey of experimental measurements of multiple scattering reported so far has been provided in measurements [2]. The survey reveals that the measurements are carried out to correct the Compton profile data for multiple contaminations but are confined to few incident photon energies (60, 159 and 662 keV) in a number of targets of different atomic

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numbers. Our measurement [1] investigates the effect of the detector collimator and the sample thickness on 662 keV multiply Compton scattered photons from cylindrical samples of aluminium, and confirmed that in order to increase the signal-to-noise ratio, multiple scattering background should be minimised and can be achieved by using a narrow detector collimation. The measurements [2] provides the intensity and energy distributions of 662 keV gamma rays multiply scattered from a Lead target of various thicknesses at a scattering angle of 90° with the scattered photons being detected by an HPGe gamma detector. Owing to the use of an HPGe detector, the measurements provide a more faithful reproduction of the spectral distribution. The saturation depth and multiply scattered fraction saturates as expected.

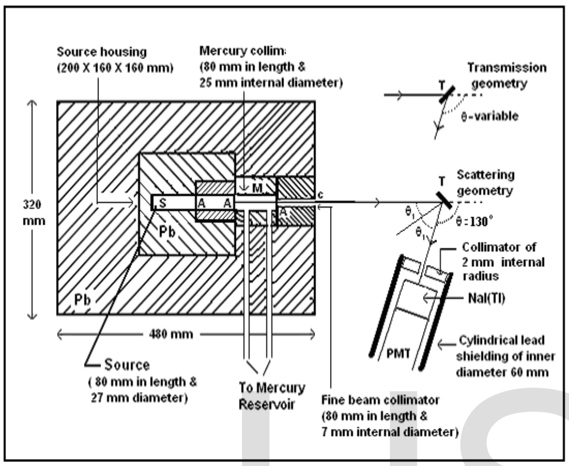

Fig 1

For alloys, Barnea et al [3] have measured the distribution of multiply scattered photons at 662 keV for samples of brass at 90° and 120°, and compared the experimental results with the Monte Carlo simulations (ACCEPT code in ETRAN model) developed according to the geometry of the experiment. Shengli et al [4] have performed multiple scattering experiments to detect an iron object embedded in the large concrete wall at 662 keV using NaI(Tl) scintillation detector. By simulating their experiment with the Monte Carlo simulation in the EGS4 package, they concluded that the presence of multiple Compton scattering impairs the contrast between the background and the object. So the present measurements are undertaken to investigate the multiple scattering of 662 keV photons in soldering material (an alloy) target of various thicknesses.

2. Experimental set-up

In the present measurements, a 137-Cs source of strength 222 GBq (=6Ci) emitting 662 keV gamma rays is used. This radioactive source is in the form of pellets of CsCl sealed in an aluminium can of diameter 27 mm and length 80 mm. The source is placed in the cavity of a rectangular lead container of dimensions 200 mm x 160 mm x 160 mm especially prepared to enclose the source (Fig. 1). Bearing in mind the biological effects of radiation, a cylindrical beam collimator consisting of a brass pipe (80mm in length and 28mm internal diameter) and having aluminium windows on both ends is fitted in a rectangular block of lead. This collimator could be filled with a column of mercury and is used to close the beam incident on the target when desired. The fine beam collimator (length 80 mm, internal diameter 7 mm) provides a well collimated beam of 662 keV gamma photons. The source housing, cylindrical and fine beam collimators are placed adjacent to each other so that the three are coaxial. This arrangement is further shielded by additional lead bricks and the complete source assembly, rectangular in shape having dimensions 480 mm x 320 mm x 320 mm, is placed at a height of 380 mm on an aluminium table fixed to

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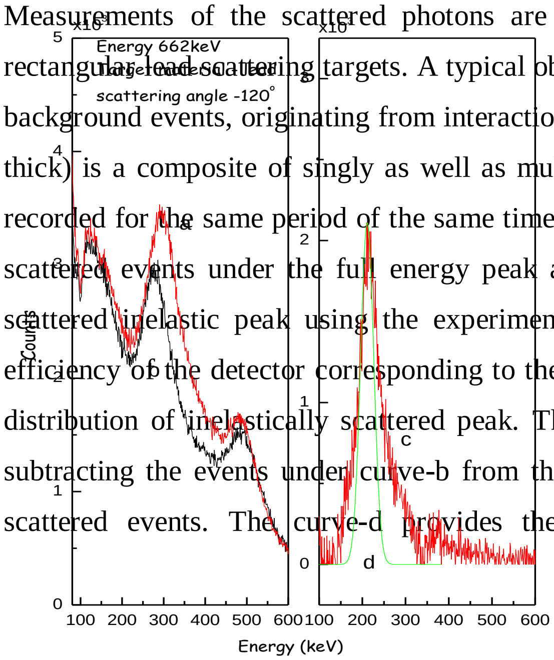
one side of the scattering table to avoid scattering of radiation from the scattering table. This table is placed in the centre of the room to minimize the scattering from the walls of the room. When the cylindrical beam collimator is filled with a column of mercury, the background near the assembly comes to natural background level, thus confirming the proper shielding of the radioactive source, an essential requirement in nuclear spectroscopy. An intense collimated beam of gamma photons from the radioactive source is allowed to impinge on the target of given material. The source-target assembly is aligned in such a way that the incident photon beam is confined to the target only. The distance between the fine beam collimator and the front face of the target is kept at 320 mm. An integrated gamma detector assembly supplied by Electronics Corporation of India Limited (ECIL) Hyderabad, India, is used to detect the scattered photons originating from interaction of incident radiation with the target electrons. It consists of 51 mm diameter x 51 mm thick NaI(Tl) scintillation crystal, having 0.38 mm thick aluminium window and optically coupled to RCA-8053 photomultiplier tube. The gamma detector is shielded by cylindrical lead shielding (140 mm in length and 27.5 mm thick) of inner diameter 60 mm. The inner side of this shielding is covered with 2 mm thick iron and 1 mm thick aluminium with iron facing towards lead to absorb the lead K X-rays emitted by lead shielding. It is also checked experimentally that there is no shift in peak position or change in energy resolution of the detector at the different angular positions. The detector is placed on a movable arm, which can rotate around the target mount on the scattering table. The scattered beam is further collimated by a cylindrical collimator (internal radius 2 mm and thickness 17 mm) of lead lined with aluminum, placed at a distance of 25 mm in front of the gamma detector. The detector assembly is arranged in such a way that the axes of source collimator and gamma detector pass through the centre of the front face of the target. Owing to the radius of the cylindrical lead shielding of the gamma detector, the singly scattered photons from the target followed by scattering from the detector shielding have energy lower than corresponding to observed inelastic scattered peak's energy in the direction of gamma detector.

3. Measurements and Results

Measurements of the scattered photons are carried out as a function of sample thickness, for the rectangular lead scattering targets. A typical observed scattered spectrum (curve-a of Fig. 2) corrected for background events, originating from interactions of 662 keV incident photons with the lead target (3 mm thick) is a composite of singly as well as multiply scattered photons. Also the background spectrum is recorded for the same period of the same time to permit registration of events under curve -b The singly scattered events under the full energy peak are obtained by reconstructing analytically [1] the singly scattered inelastic peak using the experimental determined parameter, such as FWHM and detector efficiency of the detector corresponding to the singly scattered energy, counts at the peak and Gaussian distribution of inelastically scattered peak. The observed experimental spectrum curve –c obtained by subtracting the events under curve-b from those under curve –a, consists of both singly and multiply scattered events. The curve-d provides the analytically reconstructed singly scattered peak. The



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subtraction of reconstructed singly scattered spectrum from this observed experimental spectrum results in multiply scattered photons only. This procedure is then repeated for different thicknesses of the lead target. The plot of observed number function of target thickness is shown in Fig. 3. The saturation of multiply scattered photons is due the fact that as the thickness of target increases, the number of scattered events also increases but the number of photons coming out of the target decreases. So a stage is reached when the thickness of the target becomes sufficient to compensate the above increase and decrease of the number of photons known as saturation thickness. The response technique of NaI(Tl) detector only increase the intensity of the multiply scattered photons but not the saturation thickness (fig.3) The thickness for which the number of multiply scattered events saturates in lead at 120^o is 19.2 mm for 662 keV incident photons. The Monte Carlo calculations based upon the package developed by Bauer and Pattison (1981) supports the present experimental results

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