British Journal of Applied Science & Technology
16(4): 1-4, 2016, Article no.BJAST.26514
ISSN: 2231-0843, NLM ID: 101664541

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Investigation of Saturation Thickness of Sn Using Backscattering Technique

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Authors' contributions

This work was carried out in collaboration between all authors. Author RS designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Authors JKS and TS managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/26514
Editor(s):
(1) Luigi Maxmilian Caligiuri, Faculty of Science, University of Calabria, Italy AND Foundation of Physics Research Center (Director)- FoPRC, Italy.
Reviewers:
(1) J. G. Fantidis, Eastern Macedonia and Thrace Institute of Technology, Kavala, Greece.
(2) B. S. Sandhu, Punjabi University, India.
Complete Peer review History: http://sciencedomain.org/review-history/14901

Short Research Article

Received 21st April 2016
Accepted 30th May 2016
Published 4th June 2016

ABSTRACT

In this paper, the energy dependence of saturation thickness for Sn target has been investigated at different gamma rays photon energies of 122, 511 and 662 keV using backscattering technique. The back scattered photon spectra for different thicknesses (0.2 – 2.13 cm) of tin ($_{50}$Sn) has been recorded using scintillator detector GAMMA-RAD5 (dimensions 76 mm × 76 mm; energy resolution of 7% at 662 keV) coupled with multi-channel analyzer (MCA) based on Amptek's DP5G Digital Pulse Processor. It has been observed that the intensity of backscattered photon increases with increase in target thickness and saturates beyond a particular value called the saturation thickness; which also varies with incident photon energy. In the energy region of 122-662 keV, the saturation thickness for tin decreases with the increase in incident photon energy. This parameter can be further used to assign effective atomic numbers to composite materials (Compounds/mixtures).

Keywords: Saturation depth; back scattered photons; tin target.

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1. INTRODUCTION

The backscattering of photons of gamma rays from a surface of material is a fundamental importance problem in radiation shielding, radiation absorption, radiation dosimetry and non-destructive testing of samples of medical, industrial and agricultural interest. In case of finite volumes multiple scattering has been a major problem to extract information from scattered flux because during the interaction of gamma photons with material, these photons continue to decrease in energy as the number of scatterings increases in the target. The backscattering technique has the advantage that the sample can be accessed from the same side, imaging is simple and also the depth information of the sample is possible [1-4]. This technique is most dominant process in intermediate energy ranges and in the low Z-elements at near backward angles. In the collision between photons and electrons while dealing with thick targets, there are some higher order processes in addition to single photon Compton backscattering. These higher order processes occur due to large number of secondary radiation produced in the first encounter and are known as backscattered radiations [5-7]. The quantity which characterizes the reflection probability of a material for gamma photon flux called albedo, is defined as the ratio of amount of radiation reflected from the slab in a certain time interval to the amount of radiation incident on the slab during this time. Keeping this in the view, an attempt has been made to find the energy dependence of saturation depth for backscattered photons from Sn target. It has been observed that the intensity of backscattered gamma photons depends on thickness of the material and the energy of incident photon. Initially, the numbers of backscattered events increases with the increase in target thickness and saturates thereafter for all the selected energies.

2. MATERIALS AND METHODS

The experimental set-up was shown in Fig. 1 which is used for performing the present measurements. It is designed to generate maximum number of backscattered photons in direction of the detector. The detector is placed at angle of 180^o relative to the incident gamma ray beam. The experimental analysis has been achieved with the help of different gamma rays radioactive isotopes ^{57}Co (122 keV), ^{22}Na (522 keV) and ^{137}Cs (662 keV). The backscattered photon spectra were recorded using scintillator detector GAMMA-RAD5 of dimensions 76 mm x 76 mm having energy resolution of 7% at 662 keV coupled with multi-channel analyzer (MCA) based on Amptek's DP5G Digital Pulse Processor procured from Amptek Co., USA and lead housing/collimators to minimize the noise (unwanted pulses). The distance between the Sn target and scintillation detector is kept at 9.5 cm. The axes of cylindrical scintillator detector collimator and the disc shaped radioactive source are aligned to pass through the centre of rectangular Sn target. In order to calibrate the detector on energy scale, different spectra were recorded using calibration sources ^{57}Co (122 keV), ^{133}Ba (81 keV, 302 keV and 356 keV), ^{22}Na (511 keV), ^{137}Cs (662 keV), ^{60}Co (1173 keV and 1332 keV) placed at the source position. After calibration of the detector, a beam of gamma photons from the different radioactive sources (^{57}Co, ^{22}Na and ^{137}Cs) is made to impinge on rectangular Sn target and all the spectra were recorded with increasing thickness of selected metal ^{50}Sn by placing the metallic sheets behind the sources for the time of 600 second, so as to have sufficient number of counts (more than 10,000) under the area of backscattered peak which appears at 82.5 keV for ^{57}Co, 170.33 keV for ^{22}Na and 200.91 keV for ^{137}Cs. The schematic of experimental set up is shown in the Fig. 1.

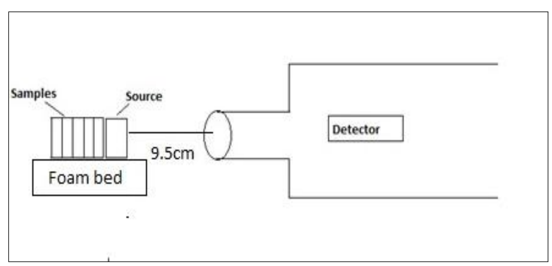

Fig. 1. Experimental setup

3. RESULTS AND DISCUSSION

A typical backscattered peak with sample and without sample from the Sn target (thickness 21.3 mm) using samples of different thickness at scattering angle 180º is given in Fig. 2. We obtain the contribution of backscattered photons after subtracting this observed backscattered peak (with sample) from backscattered peak (without sample). The variation of numbers of backscattered events as a function of target thickness for different gamma rays radioactive isotopes ^{57}Co (122 keV), ^{22}Na (522 keV) and ^{137}Cs (662 keV) is shown in Fig. 3. It has been observed that the numbers of backscattered events increases with increase in target thickness and saturates after a particular value, called the saturation thickness (depth). Up to a certain thickness (prior to the saturation thickness), the numbers of backscattered photons emerging from the target increases with increasing target thickness because higher number of scattering centres were available for the interaction of incident gamma rays with the increase in thickness of target material. However, after saturation thickness, the number of photons emerging out of the target does not increase further with increase in target thickness because it may provide sufficient thickness where the probability for self-absorption within the target sample is enhanced.

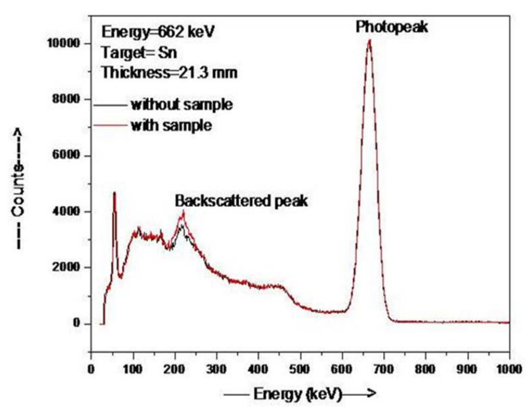

Fig. 2. The recorded photon spectra of ^{137}Cs for Sn sample showing photo peak (662 keV) and backscattered peak (200.9 keV)

Thus a stage is reached when thickness of the target becomes sufficient to compensate for the above increase of the backscattered photons and hence the number of backscattered photons coming out of the target saturates. It has been also observed that the saturation thickness for the rectangular targets of Sn is altered by the variation in incident photon energy. The measured saturation thickness value (in cm as well as mean free path; mfp) as shown in Table 1 differs slightly from the earlier findings [8], which reported the saturation thickness for Sn as 1.25 cm (at 511 keV) and 1.00 cm (at 662 keV). It may be due to the presence of slight impurities/dust particles/air voids while preparing the metallic sheets using melt-quench technique. The intensity of backscattered photon increases with increase in target thickness and saturates beyond a particular value, called the saturation thickness. Further, the saturation thickness for the rectangular targets of Sn decreases with increase in energy. It may be due to the reason that cross-section for photoelectric absorption is very high in lower energy region as compared to cross-section values for Compton scattering in the intermediate energy region; which contributes in the total photon interaction cross-section values. In other words, smaller thickness of an element at lower energy provides similar interaction probability as provided by large thickness of the same element at intermediate energies.

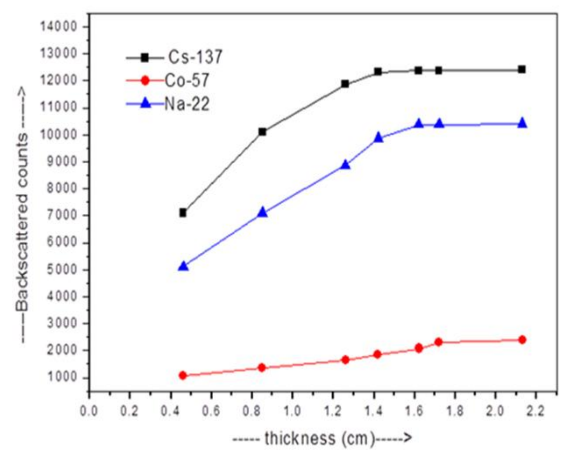

Fig. 3. Variation of backscattered counts with thickness of Sn material at different energies (122, 511 and 662 keV)

Table 1. Experimentally measured saturation thickness for Sn

Experimental results				
Sample	**Incident photon energy (keV)**	**Back scattered photon energy (keV)**	**Saturation thickness (cm)**	**Saturation thickness (mfp)**
	122	82.5	1.73	12.73
$_{50}Sn$	511	170.3	1.62	1.09
	662	200.9	1.40	0.77

4. CONCLUSION

The intensity of multiply backscattering increases with increase in target thickness and saturates beyond a particular value called the saturation thickness. Further, the saturation thickness decreases with the increase in incident gamma rays photon energy, which can be explained on the basis of cross-section values for various photon interaction processes (specially, photoelectric absorption and Compton scattering in the present work) in different energy regions.

ACKNOWLEDGEMENT

One of the author (Tejbir Singh) is thankful to SERB, India for providing financial grant (SR/FTP/PS-081) to carry out the present investigations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/14901