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Multiple scattering of gamma rays in water, concrete and sand

G S BHANDAL, VIJAY KUMAR, RAMA RANI, KAWALDEEP and K SINGH*
Radiation Physics Lab., Department of Physics, Guru Nanak Dev University, Amritsar 143 005, India
*Author for correspondence

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Abstract. The transmitted photon spectra of ^{133}Ba, ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co point sources are measured through different thicknesses of water, concrete and sand. The multiple-scatter peaks observed in these materials at 60, 90 and 100 keV energies respectively are found to be independent of incident photon energy and thickness of the medium.

Keywords. Multiple-scatter peak; transmitted photon spectra; radioisotopes

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1. Introduction

The investigation of the transmitted photon spectra through a medium has led to better understanding of the process of transport and energy degradation of a primary photon. Swarup and Peshori [1] showed that, in energy degradation of a gamma ray photon in a medium of low effective atomic number, a multiple-scatter peak, irrespective of the energy of primary photon entering the medium, is observed at an energy between 100 keV, at which Compton interactions are not very effective in energy degradation of the photon, and a lower energy above which the photoelectric cross-section for the medium is negligible.

The multiple-scatter peak has been studied in nuclear graphite, water and air by Swarup and Peshori [1, 2] and Swarup [3]. They reported this peak at 50, 60 and 72 keV respectively. Smith and Scofield [4] also reported similar peak in aluminium at 92 keV. Swarup and Peshori [2] concluded that a higher energy primary photon produces a greater number of multiple scattered photons for the same thickness of the medium that does a lower energy primary photon. Singh [5] has also studied the transmitted photons spectra of ^{133}Ba, ^{137}Cs and ^{60}Co through different thicknesses of a soil medium and a multiple-scatter peak was observed at an energy of 100 keV. Thye also observed a linear relationship between the effective atomic number and the multiple-scatter peak energy. Brust [6] has shown that for media of different atomic numbers, the multiple scatter peak is at different energies in the soft part of the spectrum and Mintato [7] has concluded that, as a first approximation its energy varies directly with the atomic number of the medium.

We extend the study here to transmitted photon spectra of ^{133}Ba, ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co gamma ray sources through different thicknesses of water, concrete and sand.

2. Experimental set-up

The experimental system (figure 1) consists of a aluminium drum (90 cm high, 60 cm diameter and 0·2 cm wall thickness) kept on a plywood stand with a circular hole of 8 cm diameter in its centre below which a detector assembly is placed. A NaI(Tl) (2″∗2″) detector is housed in a cylindrical lead shield which is lined on the inside with brass and aluminium sheets. The axis of the drum is placed co-linear with the extended axis of the crystal. The pulse height spectra were recorded with PC/XT AC–4 K plug in card multichannel analyzer.

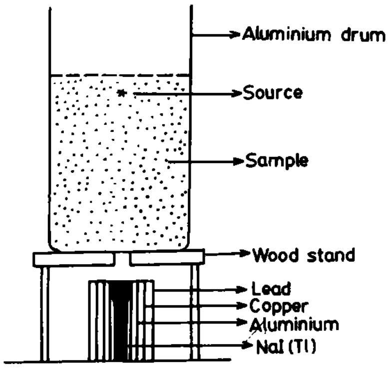

Figure 1. Experimental set-up.

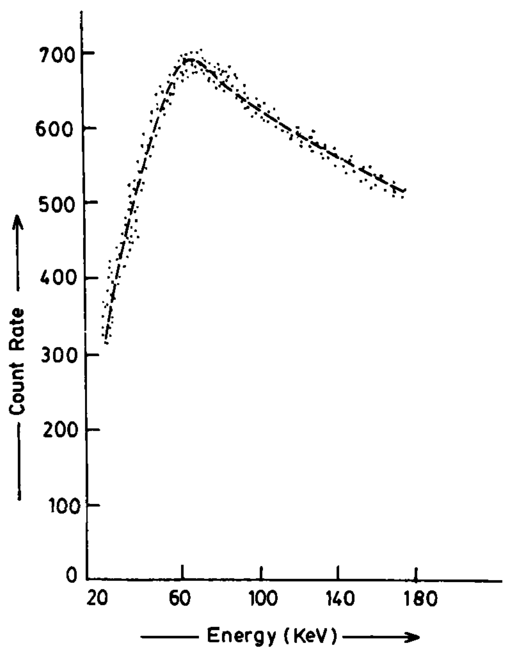

Figure 2. Transmitted photon spectra of ^{137}Cs through water medium.

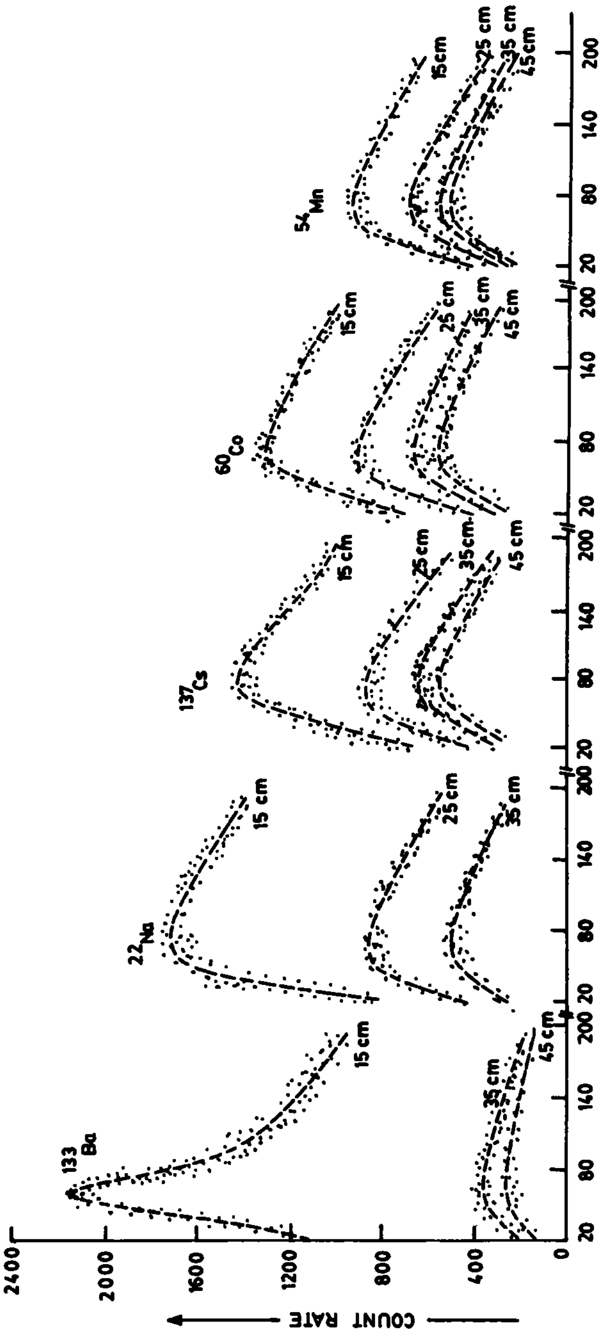

Figure 3. Transmitted photon spectra of different sources through different thicknesses of water.

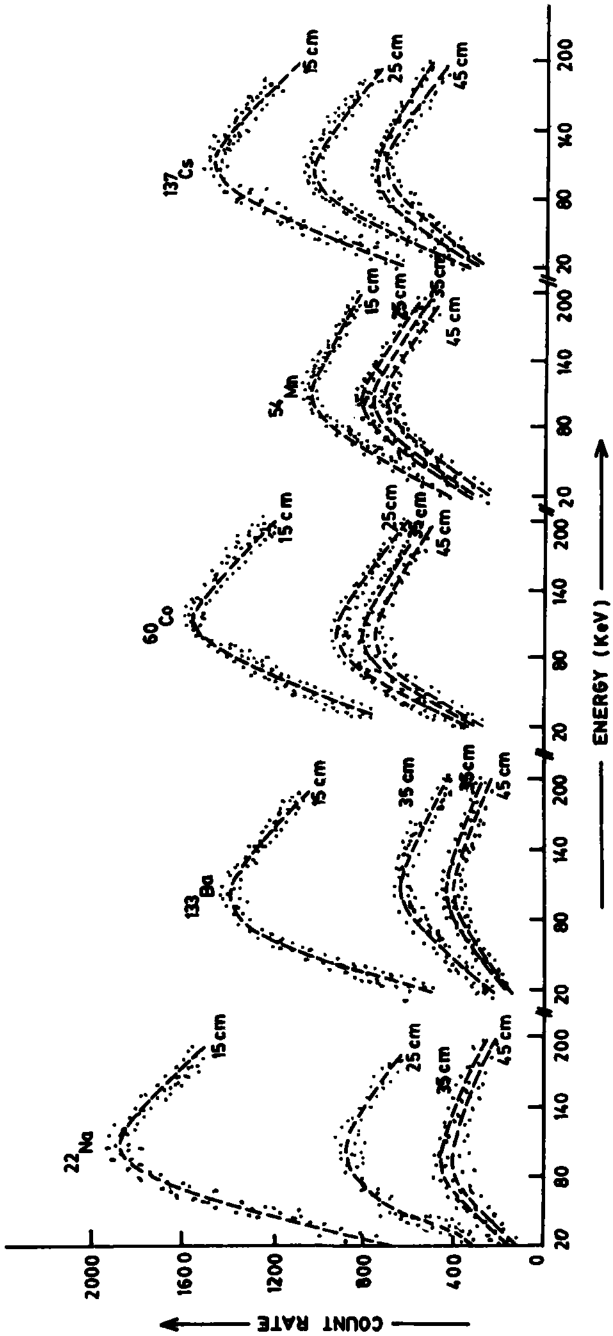

Figure 4. Transmitted photon spectra of different sources through different thicknesses of sand.

3. Measurements

After calibration of the spectrometer in the low energy region with X-rays and gamma ray photons from ^{57}Co, ^{241}Am and ^{133}Ba, the following five sets of observations were recorded.

i) In the first set, experimental set-up was checked with incident energy of 662 keV from ^{137}Cs through water where a multiple scatter peak of 60 keV (figure 2) was observed. This value is in good agreement with the value reported in [2].
ii) In the second set, the sources were placed in a thin plastic cup glued on a thermocole float (2 cm thick) and the level of water in the drum was changed from 15 cm to 45 cm in four steps. The recorded spectrum is shown in figure 3.
iii) In the third set, the sealed sources were placed 3 cm below the sand medium at the axis of the drum. Different transmitted photon spectra were recorded for four different thicknesses of the sand medium. The spectra are shown in figure 4.
iv) In the fourth set, to determine the effect of backscattering due to different thicknesses of the sand on the transmitted spectra, the distance of the ^{137}Cs source was fixed at 10 cm in sand medium and spectra were recorded for different thicknesses of sand above the source. The spectra are shown in figure 5.
v) In the last set, the sand medium was replaced by concrete and observations were recorded with different sources as in step (iii). The spectra are shown in figure 6.

4. Results and discussion

In all the transmitted photon spectra shown in figures 2–4 and 6 and for all the thicknesses of the media, broad peaks at 60, 90 and 100 keV are observed in water, concrete and sand respectively. These peaks are the properties of the scattering media through which primary gamma rays pass to the detector. These peaks are due to multiple scattering in the media. It was checked that the multiple-scatter peaks are not due to electronic artifacts. Minato [7] with his Monte Carlo calculations has concluded that in different media shapes of multiple-scatter peaks in transmission

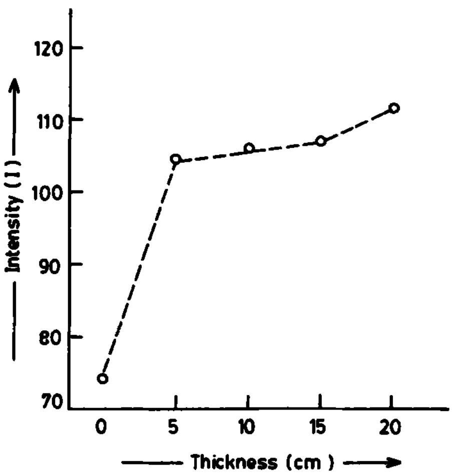

Figure 5. Variation in intensity of multiple scatter peak with thickness of sand above source (10 cm).

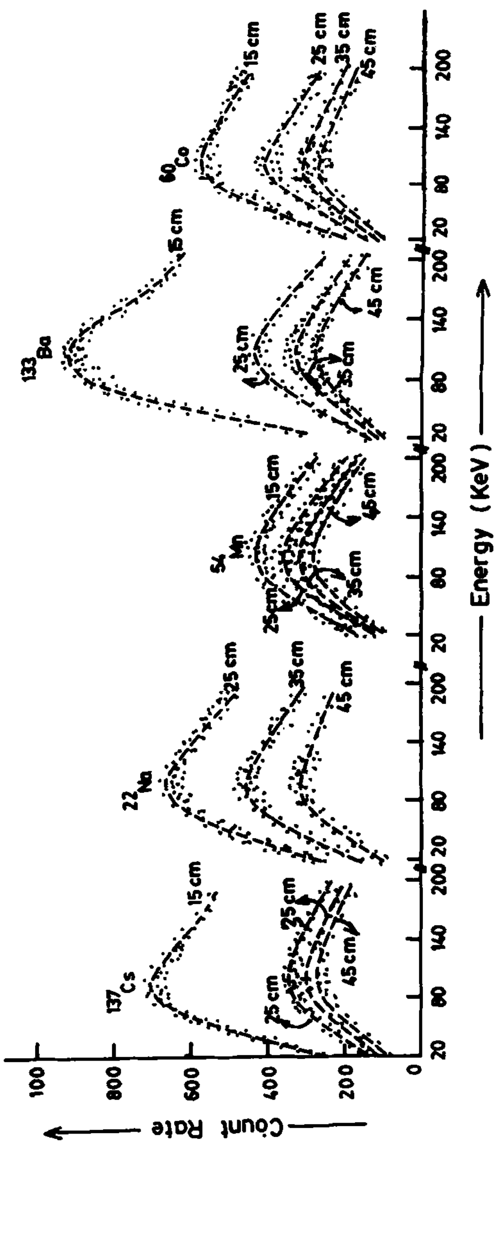

Figure 6. Transmitted photon spectra of different sources through different thicknesses of concrete.

spectra are quite similar to each other. According to him multiple-scatter energy is a characteristic constant of the medium. From these figures it is clear that multiple-scatter peak is independent of primary incident photon energy and thickness of the medium. Similar results are reported in [1,2].

In the experimental setting (iv) above, it is found that the intensity of scattered peak changes with the thickness of the medium beyond 10 cm behind the source. Above a certain thickness the change in intensity is very small (figure 5). Transmitted flux increases with increase in thickness above the medium due to backscattering. It is also evident from figure 7 that energy of multiple-scatter peak is independent of the thickness of a medium above the source.

From figure 8, it is clear that transmitted intensity of multiple-scatter peak decreases exponentially with increase in thickness of medium whereas the multiple-scatter peak energy is independent of thickness of medium. The log of normalized counts of the multiple-scatter peaks is plotted against thickness of the medium (figure 9). It is to be noted that energy spectra in figures 8 and 9 are corrected for detector efficiency and transmission through aluminium drum wall and detector window. From this it is seen that the logarithm of the intensity decreases linearly with increase in thickness of the medium. This shows that the intensity I of the multiple-scattered photons can be expressed by

$$I = I_0 e^{-ax} \quad (1)$$

where a, the slope, is called the multiple-scatter coefficient and x is the thickness of the medium. It is observed that a values decrease with increase in incident photon

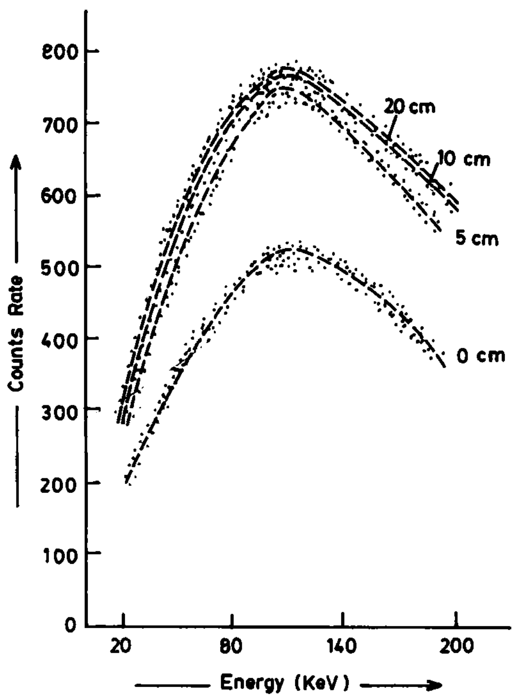

Figure 7. Plot of energy of multiple scatter peak for different thicknesses of sand above source at 662 keV.

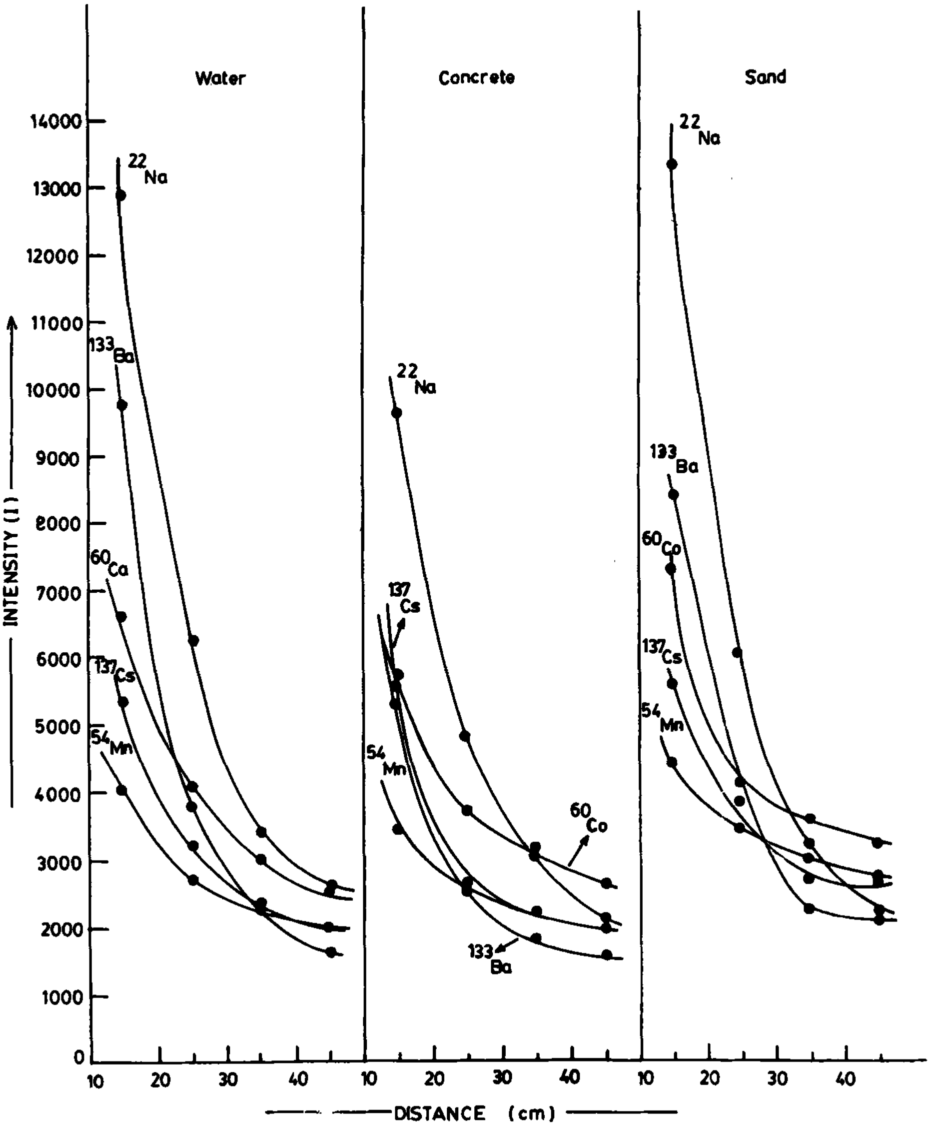

Figure 8. Variation in intensity of multiple scatter peak with thickness in different media.

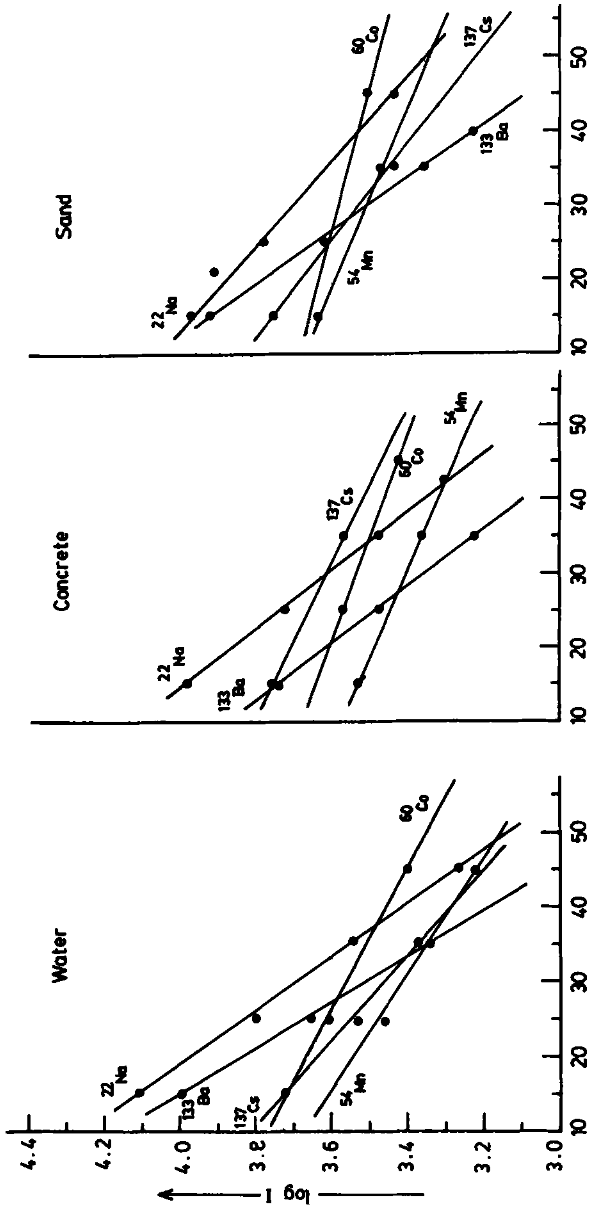

Figure 9. Logarithm of normalized peak counts compared with the thickness of different media.

Table 1. The values of multiple-scatter coefficient a in water, concrete and sand.

Sample	Values of a				
	356 keV	511 keV	662 keV	835 keV	1280 keV
Water	0·0330	0·0285	0·0175	0·0130	0·0105
Concrete	0·026	0·025	0·0095	0·0085	0·0075
Sand	0·028	0·017	0·015	0·0085	0·005

energy. The coefficient a is a characteristic constant of the medium which depends on incident energy, like linear attenuation coefficient. The multiple scatter coefficients obtained from figure 9 are shown in table 1.

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