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Number albedo measurements for backscattered 1250 keV photons from stratified lead layers

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Abstract : A new treatment of the stratified combination of lead with other radiation shielding materials for the measurement of number albedo for backscattered 1250 keV photons has been carried out. The stratified combination has been found to attain higher shielding property as well as to acquire a virtual homogeneous entity with a definite effective atomic number. Number albedo measurements have been carried out with indigenously designed Uniform Sensitivity Photon Counter which avoids tedious response correction by inverse matrix method. The results when compared with the theoretically obtained values were found to have better agreement than those obtained experimentally by other workers. The measurements of number albedo values and the angular distribution of backscattered 1250 keV photons for iron, aluminium and concrete stratified with lead have been reported.

Keywords : Number albedo, stratified combination, backscattered photon, angular distribution, photon counter.

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1. Introduction

Albedo measurements for backscattered γ-rays from semi-infinite single layer scatterers were initiated by Hayward and Hubbell (1954). Considering albedo as an useful parameter for the design of γ-ray shields, these investigations for isotropic incidence of γ-rays from semi-infinite scattering media were augmented by Hyodo (1962), Pozdneyev (1967) and Steyn and Andrews (1967). Bulatov and Garusov (1960) and Elias *et al* (1973) carried out albedo measurements for collimated beam of γ-rays incident on semi-infinite media at fixed angles. Most of these authors carried out albedo measurements using a NaI(Tl) detector coupled with a multichannel analyser. The spectrum obtained in such measurements needed response correction by tedious inverse matrix method. The application of indigeneously designed Uniform Sensitivity Photon Counter (USPC) in the albedo measurements for backscattered γ-rays from semi-infinite media were reported by Biswas *et al* (1979, 1980), Sinha *et al* (1983), Bhattacharjee and Sinha (1989). This counter had the advantage that its efficiency was independent of the energy of the incident γ-rays and required no correction factor. Results obtained with USPC were straight forward and agreed better with theoretical Monte Carlo values than experimental results obtained by other workers. Literature on the albedo measurements from stratified layers is almost nil. Nakamura and Hyodo (1968) carried out measurements from stratified layers of aluminium and tin. Nakata (1961) investigated the effect of lead sheet placed in front of semi-infinite concrete slabs. Systematic investigations on albedo measurements from stratified layers were reported by Sinha and Bhattacharjee (1987), Bhattacharjee and Sinha (1988a, 1988b) by extending the application of USPC. Because of high photoelectric absorption of lead, the saturation thickness of radiation shielding materials when stratified with lead was expected to decrease and the shielding property to increase appreciably. In the present investigation the differential as well as total albedo values for backscattered 1250 keV photons from semi-infinite scatterers of iron, aluminium and concrete stratified with lead have been reported. It has been observed during the course of the present investigation that the stratified slabs of alternate heterogeneous layers have attained virtually homogeneous property with a definite effective atomic number.

2. Uniform sensitivity photon counter

The efficiency of a NaI(Tl) detector has high values for low energy photons and decreases rapidly with the increase in photon energy. It was shown by Ghose (1965) that a filter of suitable material and thickness when placed before a NaI(Tl) crystal detector, the efficiency of the filter-crystal combination may be made constant for paraxially incident γ-rays. The intrinsic efficiency of the filter-crystal combination expressed in counts per photon is given by the equation :

$$\epsilon=[1-\exp(-a\mu)]\exp(-b\phi), \tag{1}$$

where a and b are the thicknesses of the crystal and the filter and μ and ϕ are their respective non-coherent and total absorption coefficients. To push the efficiency of the above counter further in the lower energy range, the filter is placed before the crystal for a certain fraction of time f and then the filter is kept removed for the remaining interval of $(1-f)$. The count is taken in both the intervals f and $(1-f)$ and the total count is the sum of the above two counts. The efficiency of the detector assembly under the condition is represented by the equation :

$$\epsilon\simeq[1-\exp(-a\mu)][(1-f)+f\exp(-b\phi)] \tag{2}$$

For a particular value of γ-ray energy and for definite values of a and b the above equation is linear with f. Keeping the values of a and b same and changing the values of γ-ray energy in succession a set of linear graphs with varying slopes will be obtained. For an ideal counter the above set of linear graphs should intersect at a point which is considered as the optimum value of f. The system should have constant efficiency for this value of f for the whole energy range under consideration. However in practice the point of intersection of the straight lines is found to have a spread, the centre of which is taken as the optimum value of f as shown in Figure 1. For a definite thickness a of the NaI(Tl) crystal and substituting the values of μ and ϕ from Hubbell's Table (NBS circular 29) along with the optimum value of f in eq. (2), the efficiency of the combination in each case is calculated by varying in steps the values of b in g/cm^2. It will be observed that the efficiency of the combination remains constant for the energy range under consideration for an optimum thickness of b as shown in Figure 2. In the present investigation the

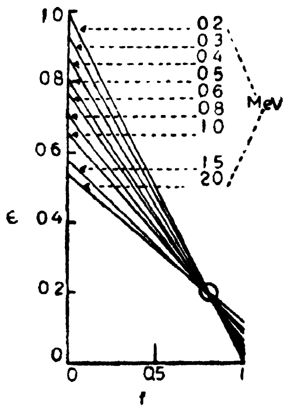

Figure I. Variation of efficiency with time fraction f for different energies.

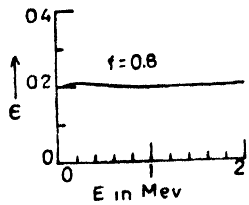

Figure 2. Variation of calculated efficiency with energy for $f = 0.8$.

material of the filter is aluminium of thickness 35 g/cm^2, the crystal is a 18.63 g/cm^2 thick NaI(Tl) scintillator of diameter 5 cm and the optimum value of f is 0.8.

3. Experimental arrangement and method

Aluminium, iron and lead scatterers of 99.9% quoted purity have been used. Each concrete slab is made by mixing 25% of portland cement with 25% of gravel and 50% of sand and is provided with an iron net inside. The dimension of each of the scattering slabs has been made either equal to or greater than 3 to 4 mean free paths to satisfy the semi-infinite condition of the scattering medium. Moreover, to ensure the semi-infinite condition of the medium, the source to slab distance was made much smaller in comparison with the scattering surface of each medium. The semi-infinite dimension of the slabs ensured full emergence of backscattered photons from the scattering surface and minimised their escape from the edges. The thickness and latera of each semi-infinite scatterer is given in Table 1. The ^{60}Co source of 30 μCi strength used in the present investigation is having a diameter of 3 mm and is considered as a point source. For isotropic incidence the source is placed at the centre of the front layer

Table I. Thickess and latera of each scatterer.

Scatterer	Thickness (cm)	Latera (cm^2)	Symbol used in a configuration
Aluminium	0.3	40 × 40	A
Iron	0.3	40 × 40	I
Concrete	2.0	40 × 40	C
Lead	0.1	40 × 40	L

at the point of intersection of its surface and the detector axis as shown in Figure 3. The front face of the first layer has been kept at a distance of 100 cm from the scintillation detector and 80 cm from the front face of the

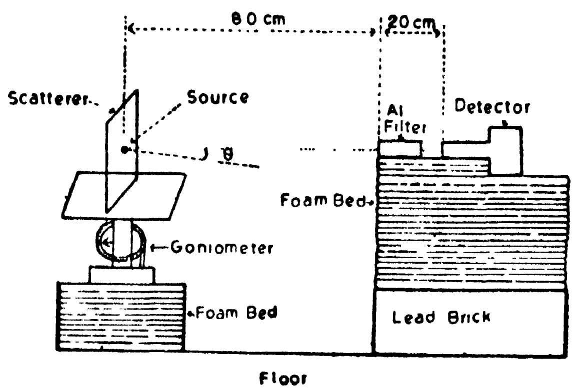

Figure 3. Schematic diagram ot the experimental arrangement.

filter. The alternate scattering slabs were placed on a goniometer calibrated in degrees. The angle θ as shown in Figure 3 is the angle between the normal to the front scatterer of the configuration and the detector axis. The angle is changed for measurement from 0° to 90° in steps of 10°. If θ_s is the angle of Compton scattering of a photon then $\theta = 180° - \theta_s$. To eliminate forward scattered radiation at 90° position, the goniometer is placed close to 90°. The whole assembly is placed on a foam-bed at a height of one meter from the floor and about 4 and 5 meter from the walls and ceiling respectively to avoid scattering from there. Moreover foam has negligible scattering effect.

For the measurement of differential as well as total albedo, different stratified configurations of scatterers have been arranged. The subscript in a configuration shows the total number of plate (s) of the material present in each configuration. In L_1A_1 configuration one plate of lead is followed by one plate of aluminium and the arrangement is repeated. Similarly in L_3C_1 configuration three plates of lead have been placed before one plate of concrete and the arrangement has been repeated. The same procedure has been followed in all other configurations.

The differential number albedo $N_d(\theta, x)$ for a particular angle θ and slab thickness x is defined as the fraction of a photon emerging at the angle θ per steradian and for one primary photon incident on the scatterer. The total number albedo $N(x)$ for a particular thickness x is obtained by numerical integration of differential values. The number of backscattered photons were obtained by subtracting integral counts without the scatterer from those with the scatterer. Measurement for differential values were done for three different analyser bias settings and the total number albedo value was determined by extrapolation to zero bias. This ensured the elimination of error in the albedo values due to noise at zero bias.

The effective atomic number of the heterogeneous layer of a configuration is computed following the procedure of Berger and Raso (1960). The weight fractions of the constituent elements in a configuration is determined and the effective atomic number of the configuration is computed as reported by Bhattacharjee and Sinha (1988b).

The conventional electronic circuitry consists of a pulse amplifier, a single channel analyser and a decade scalar.

4. Results

The ratio of the thickness of constituent scatterers in a stratified combination, their weight fractions and the computed effective atomic number of each configuration have been shown in Table 2. It is observed from this table that the effective atomic number of stratified combination lies between the atomic number of constituent elements. The total number albedo values for the stratified combinations of lead-iron and lead-aluminium have been shown in Figure 4 and those of lead-concrete combination have been shown in Figure 5. The total number albedo values as well as saturation thickness of aluminium, iron, concrete, lead and their stratified configurations have been shown in Table 3. It is observed in Figures 4 and 5 and in Table 3 that the saturation thickness reduced appreciably when lead scatterers are alternately placed between scatterers of lower atomic number. The total number albedo values of constituent elements and the average values of total albedo for stratified combinations (L_1C_1, C_1L_1), (L_1I_1, I_1L_1) and (L_1A_1, A_1L_1) denoted by LC, LI and LA have been shown as a function of atomic number in Figure 6. It is observed both in Figure 6 and Table 3 that the total

Table 2. Weight fraction of constituent scatterers and the effective number of each configuration.

Configuration or element	Ratio of the thickness of constituent scatterers	Weight fraction		Computed Z_{eff}
L	—	W_L	W_A	82.00
L_1A_1	0.1 : 0.3	0.583	0.417	68.11
L_2A_1	0.2 : 0.3	0.737	0.263	74.97
L_3A_1	0.3 : 0.3	0.808	0.192	76.88
A	-	W_L	W_C	13.00
L_1C_1	0.1 : 2	0.171	0.829	46.36
L_2C_1	0.2 : 2	0.292	0.708	53.24
L_3C_1	0.3 : 2	0.382	0.618	57.72
C	—	W_L	W_I	13.53
L_1I_1	0.1 : 0.3	0.325	0.675	56.54
L_2I_1	0.2 : 0.3	0.490	0.510	57.33
L_3I_1	0.3 : 0.3	0.591	0.409	69.48
I	—	—	—	26.00

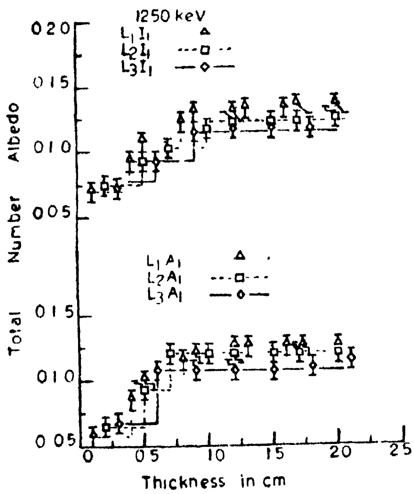

Figure 4. Total number albedo as a function of thickness for lead-iron and lead-aluminium combination.

number albedo values as well as the saturation thickness decrease with increasing Z_{eff}. The results are in good agreement with the values obtained by Hyodo (1962), Biswas et *al* (1979) and Bhattacharjee and Sinha (1988a, 1988b), for elements and stratified configurations.

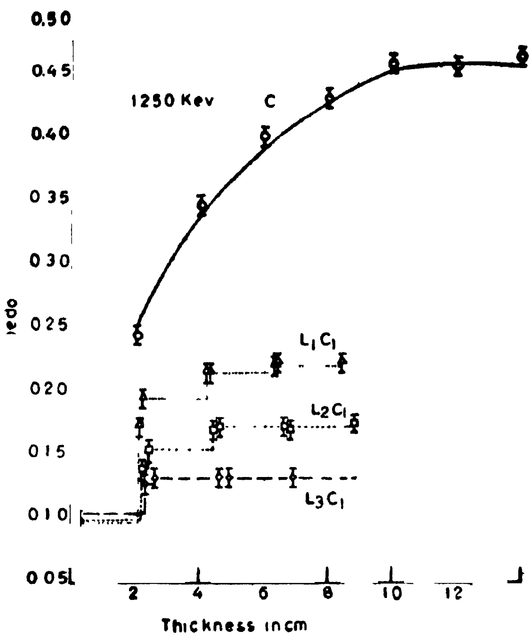

Figure 5. Total number albedo as a function of thickness for concrete and stratified configuration of concrete and lead.

Table 3. Extrapolated values of total number albedo and saturation thickness of scatterers and their stratified combination at 1250 keV energy.

Element or configuration	Z or Z_{eff}	Saturation thickness in cm	Extrapolated total number albedo value			
			Present work	Sinha *et al* (1983)	Hyodo (1962)	Monte Carlo Berger and Raso (1960)
L	82.00	0.40	0.125 ± .007	0.105 ± 0.002	0.17 ± .02	0.10
L_1A_1	68.11	1.20	0.145 ± .007			
L_2A_1	74.97	0.70	0.140 ± .007			
L_3A_1	76.88	0.60	0.135 ± .007			
A	13.00	7.80	0.475 ± .007	0.48 ± 0.01	0.52 ± .02	—
L_1C_1	46.36	6.40	0.240 ± .007			
L_2C_1	53.24	4.60	0.195 ± .007			
L_3C_1	57.72	2.60	0.165 ± .007			
C	13.53	12.00	0.540 ± .007	0.49 ± 0.01	—	0.383
L_1I_1	56.54	1.30	0.145 ± .007			
L_2I_1	64.61	1.20	0.135 ± .007			
L_3I_1	69.48	0.90	0.130 ± .007			
I	26.00	3.0	0.390 ± .007	0.38 ± 0.01	0.42 ± 0.02	0.30

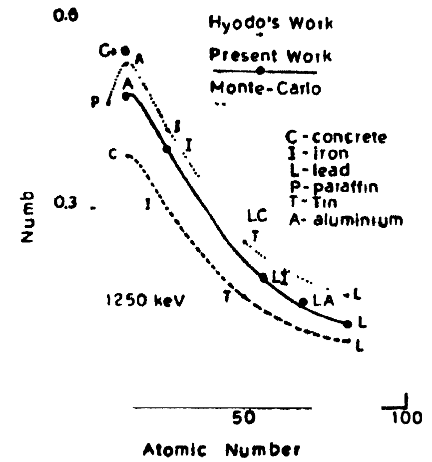

Figure 6. Total albedo as a function of atomic number.

The saturation thicknesses for elements and stratified configurations for 1250 keV incident photons shown in Table 3 have been compared with those values for 662 keV photons reported earlier by Bhattacharjee and Sinha (1988b). It is

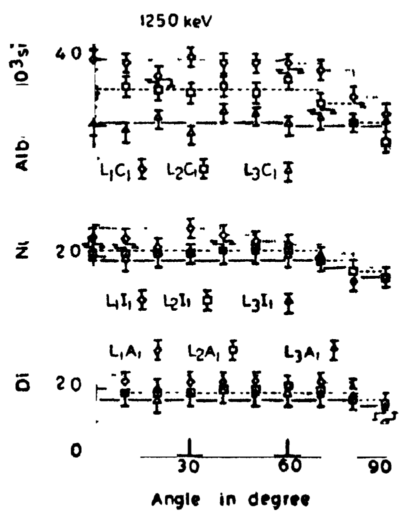

Figure 7. Angular distribution of backscattered 1250 keV photons for stratified configuration of scatterers.

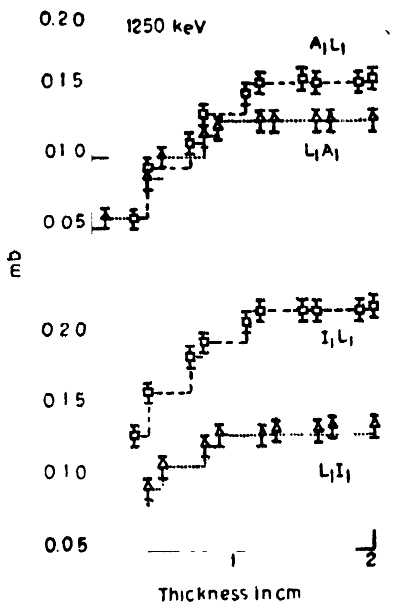

Figure 8. Difference in tot$_{\varpi}$ number albedo values between configurations A_1L_1, L_1A_1 and I_1L_1, L_1I_1.

found after comparison that the saturation thickness increases with the increase of the incident photon energy and decreases with the increase of Z or Z_{eff}. This fact is confirmed when compared with the observations of Paramesh *et al* (1983).

The angular distribution of backscattered photons for stratified configurations for lead, concrete, iron and aluminium for 1250 keV photons has been shown in Figure 7. It shows that the differential value gradually decreases towards 90° and becomes minimum at this angle which agrees with the observations of Klein and Nishina.

The total albedo values for A_1L_1, L_1A_1 and I_1L_1, L_1I_1 configurations have been shown in Figure 8. In the lead-aluminium combination aluminium or lead slabs have been alternately kept as the front layer. Similarly in the lead-iron combination iron or lead slabs have been alternately changed as the front layer. The histographs show that the total albedo values are higher when scatterer(s) of lower atomic number is used as the front layer. The difference in the total albedo values between the pairs of lead-aluminium and lead-iron combinations is 19.44% and 39.58% respectively. The same value for lead-concrete combination has been found to be 28.35%. All these indicate that backscattering of gamma rays mostly arises in the region near the front surface of the scattering configuration.

5. Conclusion

It has been confirmed in the present investigation that the total number albedo values decrease with the increase of atomic number. This is because the cross section for photo-electric absorption for incident photons increases with the increase of atomic number. For the same reason the albedo values for any configuration lie between those values of constituent layers.

Although the effect of backscattering from the first layer shows its dependence on the Z of the front layer but the same effect for the whole configuration shows its dependence on its Z_{eff}. This actually indicates that the effect of backscattering is a surface phenomenon which is a significant observation of the investigation. It is also important for the selection of the front layer for the design of a stratified shield.

The dependence of albedo values and saturation thickness on the energy of incident photons and Z_{eff} of a configuration is also a significant observation which leads to the conclusion that a stratified configuration assumes a virtual homogeneous property inspite of its heterogeneous composition.

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References

Berger M J and Raso D J 1960 *Radiat. Res.* **12** 20
Bhattacharjee A and Sinha A K 1988a *Indian J. Phys.* **62A** 31
— 1988b *Nucl. Instr. Math.* **34B** 9
——1989 *Pramana J. Phys.* **33** 493
Biswas M, Sinha A K and Roy S C 1979 *Nucl. Instrum. Meth.* **159** 157
——1980 *J. Nucl. Sci. Tech.* **17** 559
Bulatov B P and Garusov E A 1960 *J. Nucl. Engg.* **11** Part A 159
Elias E, Segal Y and Notea A 1973 *J. Nucl. Engg.* **27** 318
Ghose A M 1965 *Nucl. Instrum. Meth.* **34** 45
Hayward H and Hubbell J 1954 *Phys. Rev* **93** 955
Hubbell J *'Photon cross sections, Attenuation co-efficients and Energy absorption co-efficients from 10 keV to 100 GeV'* **NBS circular 29** (National Institute of Standards and Technology, USA)
Hyodo T 1962 *Nucl. Sci. Engg.* **12** 178
Nakamura T and Hyodo T 1968 *J. Nucl Sci Tech* **5** 458
Nakata M 1961 *Hi-Hakai Kansa* (In Japanese) **10** 263
Paramesh M, Venkatramiah P, Gopal K and Sanjeviah H 1983 *Nucl. Instrum. Meth.* **206** 327
Pozdneyev D B 1967 *J. Nucl Engg.* **21** 197
Sinha A K and Bhattacharjee A 1987 *Proc. IEEE/9th Conf. Engg. in Medicine and Biological Society* (Boston, USA) p 1967
Sinha A K, Chatterjee A and Ghose A M 1983 *Proc. 2nd. Int. Symp. Radn. Phys.* (Penang Malaysia) p 918
Steyn J J and Andrews D G 1967 *Nucl. Sci. Engg.* **27** 318