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## The Albedo of Various Materials for 1-Mev Photons*


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The Monte Carlo method has been used to determine the albedo of 1-Mev photons reflected from semi-infinite slabs of water, aluminum, copper, tin, and lead at various angles of incidence. The case histories of 67 photons were followed. For normal incidence the number albedo varies from 33 percent for water to 0.5 percent for lead, and the energy albedo from 5 percent for water to 0.1 percent for lead.


IN a recent experiment[1] the authors have studied the photons backscattered from semi-infinite media of various $Z$ when the $Co^{60}$ gamma rays were incident upon them. The experiment was slanted to permit a general analysis of the backscattering but did not lend itself to a measure of the albedo, i.e., the fraction of the incident radiation which actually emerged from the target. It occurred to us that a more reliable estimate of this quantity, on which there really existed no information, could be obtained by a "theoretical experiment" using the Monte Carlo technique.

Since only rough answers were required and backscattering events are not too unlikely, it was feasible to do such a Monte Carlo calculation using a desk computer. The results presented here derive from the case histories of 67 1-Mev gamma rays in an infinite medium.

The calculation was carried out for a point monodirectional source in an infinite medium so that various boundary conditions might be applied to it at will. The medium was first treated as a pure Compton scatterer so that the basic calculation was applicable to all elements. Photon absorption by photoelectric effect was included afterwards by calculating the survival probability along the photon's path for five different materials, water, aluminum, copper, tin, and lead. The survival curve is an exponential which changes slope discontinuously at every collision. Each case history was followed until the photon energy was less than 30 kev, beyond which the survival factor $S$ usually fell below 0.1 percent for water and was much smaller for higher $Z$ materials. The details of the calculation are set forth in NBS Report No. 2768.[2]

To determine the backscattering of photons that impinge on a medium with an angle of incidence $\alpha$ the infinite medium of the Monte Carlo problem was sliced with an exit plane drawn through the source so that its normal formed an angle $\alpha$ with the original direction of the photons. Each photon which crossed the exit plane was characterized by a survival factor $S_x$ evaluated for the point where its track first crossed the exit plane. For trajectories that never crossed the exit plane we set $S_x=0$.

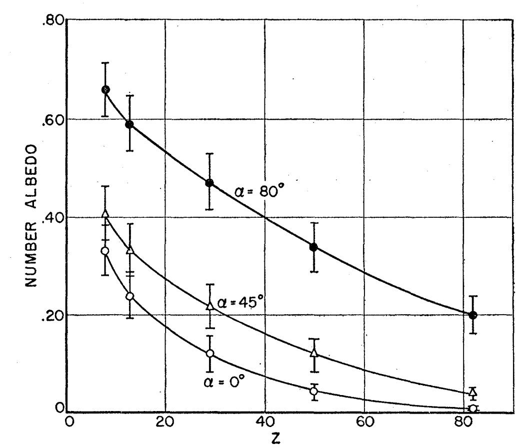


FIG. 1. The number albedo plotted as a function of $Z$ for three angles of incidence, 0°, 45°, and 80°.

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[1] E. Hayward and J. H. Hubbell, J. Appl. Phys. (to be published).

[2] E. Hayward and J. H. Hubbell, National Bureau of Standards Report NBS 2768, 1953 (unpublished).

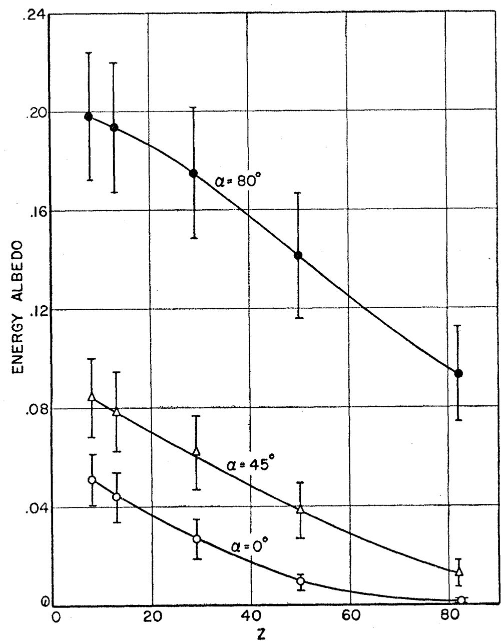


FIG. 2. The energy albedo plotted as a function of $Z$ for three angles of incidence, 0°, 45°, and 80°.

Figures 1 and 2 show different types of albedo as a function of $Z$ for three angles of incidence, defined as follows: (1) The number albedo is $S_x$ averaged over all photons $\langle S_x\rangle$. (2) The energy albedo is the fraction of the incident energy that escapes $\langle S_x\epsilon\rangle$, where $\epsilon$ is the fraction of the incident energy carried by the emergent photon. (3) The dose albedo is the energy albedo further weighted to the response of a dosimeter to different photon energies, $\langle S_x\epsilon\sigma_a(\epsilon)/\sigma_a(1\text{ Mev})\rangle$, where $\sigma_a(\epsilon)$ is the energy absorption coefficient of air, for photons of $\epsilon$ Mev. The dose albedo is not shown as it does not differ significantly from the energy albedo for 1-Mev incident photons. The standard deviations in the number and energy albedos are, respectively,

$$\pm[(\langle S_x^2\rangle-\langle S_x\rangle^2)/N]^{\frac{1}{2}} \text{ and } \pm[(\langle S_x\epsilon\rangle^2)-\langle S_x\epsilon\rangle^2)/N]^{\frac{1}{2}},$$

where $N$ is the size of the sample.

The albedo for an isotropic source may be obtained from that for monodirectional sources by integration over all angles of incidence $\alpha$. The number and energy albedos given in Figs. 1 and 2 pertain to $\alpha=0°$, 45°, and 80°. For each atomic number these albedos were plotted against $\cos\alpha$ and a smooth curve drawn from 1 to 0 through the three points. The area under each curve represents the number or energy albedo for the isotropic source. These albedos are shown in Fig. 3 and have errors of about $\pm 10$ percent.

The dependence of the albedos on $Z$ and on the angle of incidence can be easily understood because of the increase in the photoelectric absorption with $Z$ and the likelihood of escape with small deflection and small energy loss for grazing incidence. The variation of the albedos with incident energy has not been explored, but we expect the albedo to increase as the photon energy decreases.

General boundary problems are now being coded by other workers for an automatic computer. The computation will be done essentially in the same way, except that the size of the sample will be large enough so that energy and angular distributions may be obtained. It will also be done for a variety of incident energies.

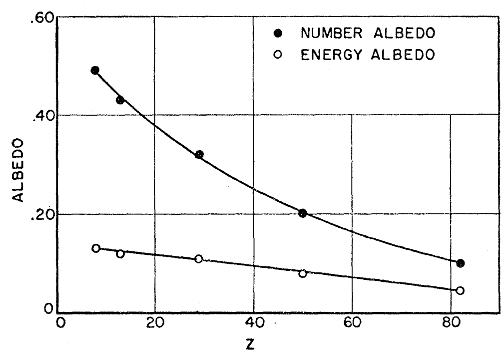


FIG. 3. The number and energy albedos plotted as a function of $Z$ for an isotropic source.

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