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SCATTERING OF UNCOLLIMATED COBALT 60 GAMMA RADIATION BY CONCRETE AND LEAD BARRIERS

by

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Measurements of the radiation from bare, unshielded cobalt 60 sources frequently require knowledge of the fractional contribution at a detector due to radiation scattered from the uncollimated beam by nearby barriers. One important example, the determination of source output, or exposure rate in roentgens per unit time at a specified distance in air from the bare radioactive source, requires a correction to the measured exposure rate to take into account the radiation scattered by the walls, floor and ceiling of the enclosure. This correction can sometimes amount to one or two percent. It is of particular importance, of course, in accurate comparisons of measurements of output made by different laboratories, where conditions are not likely to be identical.

A number of investigations of the backscattering of cobalt 60 gamma radiation have been reported. Among these, gamma ray albedos have been calculated by PERKINS (1955) and by BERGER & RASO (1960), and experimentally determined by BULATOV & GARUSOV (1960) and HYODO (1962), and

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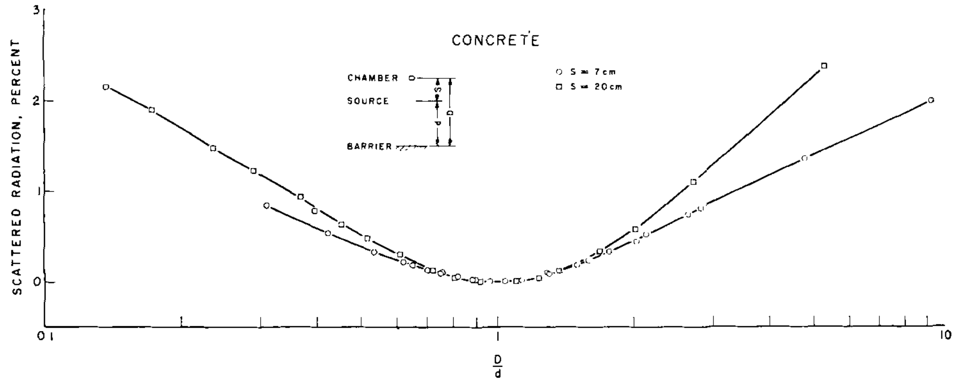

Fig. 1. Radiation scattered by a concrete barrier, shown as a percentage of the primary exposure rate, versus the ratio $\frac{D}{d}$ with source and chamber in a line normal to the surface of the barrier.

the radiation backscattered from a broad parallel incident beam at the surface of a barrier has been calculated by CORNER & LISTON (1950). The geometries in these investigations, however, differ greatly from that of interest here where an isotropic point source and a point detector are situated some distance from a scattering barrier. In measurements of backscattering by VAN DILLA & HINE (1952), JONES et coll. (1955) and CLARKE & BATTER (1962), experimental arrangements more nearly similar to those considered here were used, but they lacked the accuracy desirable when the scattered radiation incident on the detector amounts to less than one or two percent of the primary radiation.

This paper describes measurements of the fractional exposure due to scattered radiation which were carried out for two geometric conditions: detector and point source in a line normal to the surface of the barrier, and detector and point source in a line parallel to the surface.

Method

The radiation scattered by a concrete barrier was determined by measuring the increase in exposure rate as a cobalt 60 source and ionization chamber, held at a fixed separation, were moved toward the concrete floor of a large room whose dimensions were 8 × 10 × 4 metres. Scattering by lead was determined by covering the floor beneath the source with 1/4-inch lead sheet to a radius of 2 metres.

The cobalt 60 source and ionization chamber were held at the end of a horizontal support, 1 metre long, which could be raised or lowered along a

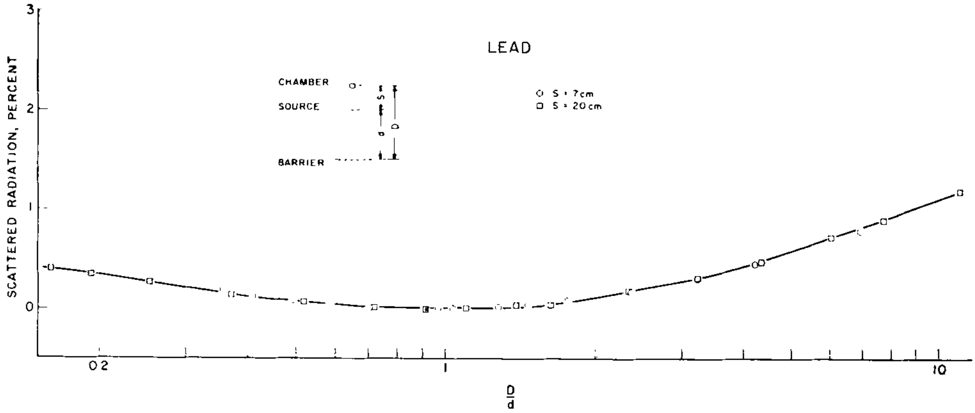

Fig. 2. Radiation scattered by a lead barrier, shown as a percentage of the primary exposure rate, versus the ratio $\frac{D}{d}$ with source and chamber in a line normal to the surface of the barrier.

vertical rod mounted between the floor and ceiling near the centre of the room. The entire framework was as light as possible, consistent with mechanical stability.

The cobalt 60 source was a cylindrical pellet, 1 mm in diameter by 1 mm long, having an activity of 0.5 curies. Since self absorption in a radial direction would be about 0.35 percent less than that in the axial direction, it was necessary to maintain a fixed orientation of the pellet as well as a constant separation from the ionization chamber. For most measurements, the pellet was clamped in a plastic capsule on the end of a rod mounted on the base of the ionization chamber. In order to obtain an indication of the extent to which this mounting might have influenced the results through scattering and attenuation, a comparison was made with an arrangement in which the mass of material in close proximity to the chamber and source was reduced to a minimum. The bare pellet was supported in this case on the centre of a mylar sheet stretched over a thin ring, 1/2 inch (about 1.25 cm) in diameter. The ring and the ionization chamber were mounted on the ends of the lightest possible, U-shaped framework, each arm of which had a length of 25 cm. The two methods of mounting gave the same results within the accuracy of measurement. This would indicate that the radiation scattered by the barrier is not sensitive to the presence of degraded radiation arising from scattering within the source capsule, and that the results obtained might apply also to other encapsulated sources.

The ionization chamber had a volume of about 35 cm^3 and a wall thickness

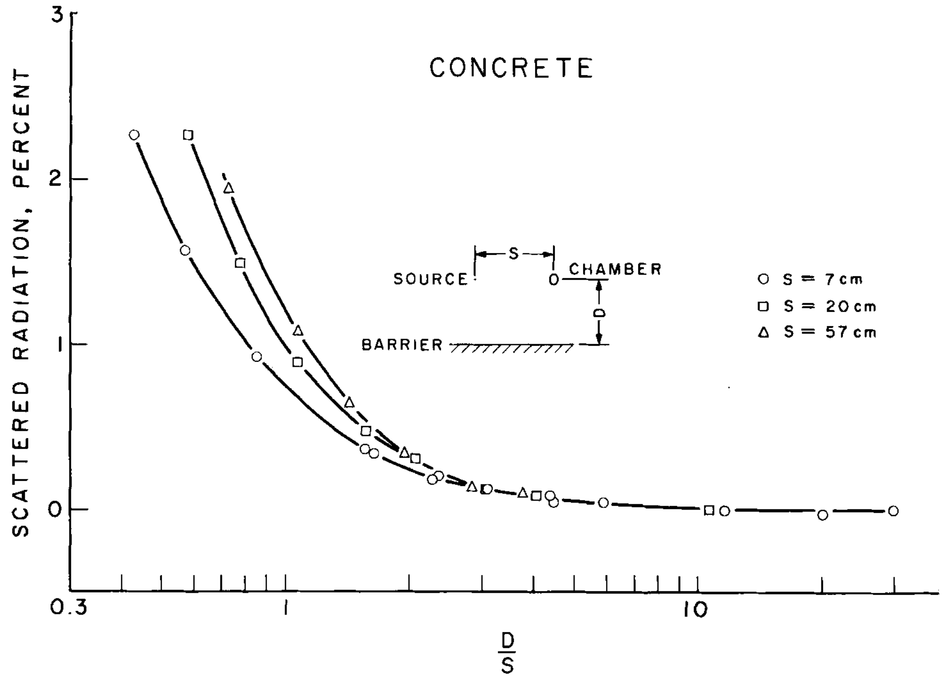

Fig. 3. Radiation scattered by a concrete barrier, shown as a percentage of the primary exposure rate, versus the ratio $\frac{D}{S}$ with source and chamber in a line parallel to the surface of the barrier.

of 4 mm, sufficient to achieve electronic equilibrium for cobalt 60 gamma radiation. Calibration of the ionization chamber against standard chambers showed a difference in sensitivity between the energy of cobalt 60 gamma radiation and the energy of backscattered radiation of less than 5 percent. The fraction of each measured exposure rate which was due to scattered radiation was corrected for this difference in sensitivity. There was also a variation of sensitivity with the angle of incidence of the radiation. At the energy of backscattered radiation, this variation was less than 5 percent except for a rapid fall-off at incident angles less than 30° from the axis of the chamber passing through the connecting cable. Although calculation of the resulting error would require detailed knowledge of the scattering, elementary considerations lead to an estimate of an upper limit of the error of 2 to 4 percent of the scattered radiation measured in this experiment, depending upon the particular geometry.

The ionization current was measured with the usual Townsend balance circuit, in which the charge was collected on a guarded, air-dielectric capacitor,

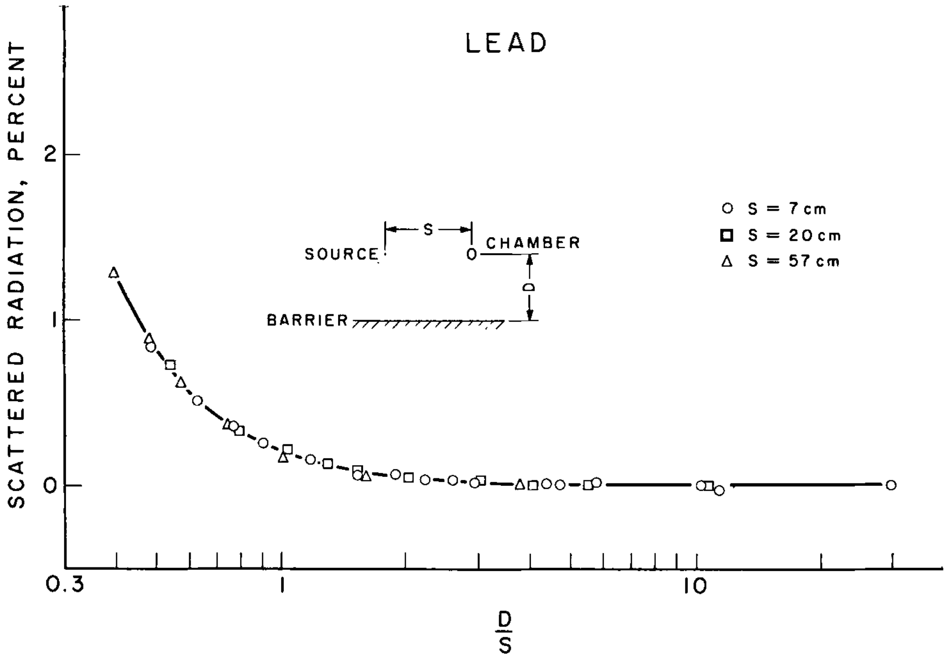

Fig. 4. Radiation scattered by a lead barrier, shown as a percentage of the primary exposure rate, versus the ratio $\frac{D}{S}$ with source and chamber in a line parallel to the surface of the barrier.

the compensating potential supplied from a portable potentiometer, and the null indicated by a vibrating reed electrometer. Exposure times were measured by means of an automatic timer somewhat similar to the one described by Costrell & Attix (1957), in which a highly stable, 1000-cycle oscillator fed a scaler which was gated by the vibrating reed electrometer. The gate was operated, both on and off, by the passage of the meter pointer past some arbitrary fixed position. The passage of the pointer was detected photoelectrically, using a small beam of light focussed on the face of the meter. Exposure times could thereby be measured to within a few milliseconds.

A thermistor mounted on the side of the chamber enabled corrections for fluctuations in temperature to be made. Ionization currents were corrected also for variations in air pressure, including those changes caused by differences in elevation of the chamber.

It was found that the stability of the entire apparatus enabled measurements of exposure rate to be made with a standard deviation of less than 0.02 percent.

The possibility of differences in the radiation scattered by the surrounding

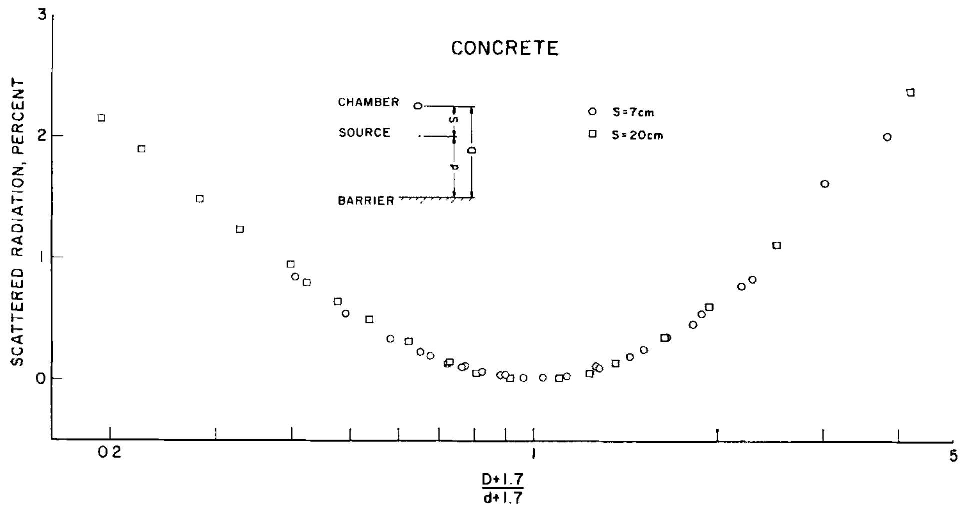

Fig. 5. Radiation scattered by the concrete barrier, shown as a percentage of the primary exposure rate, versus the ratio $\frac{D + 1.7}{d + 1.7}$ with source and chamber in a line normal to the surface of the barrier.

air affecting the measurements was considered. Such differences would be due to the displacement of air accompanying the approach of the barrier to the source and detector. On the basis of Monte Carlo calculations by Lynch et coll. (1958), it was estimated that the greatest change in radiation scattered by the air would be of the order of 0.01 percent of the primary radiation. No corrections were made for this effect.

Results

Exposure rates were normalized to the exposure rate corresponding to complete absence of radiation scattered by the barrier, and the fractional increase in exposure rate due to the introduction of the barrier was plotted as the percent scattered radiation.

The results obtained with the source and chamber in a line normal to the surface of the barrier are shown in Figs 1 and 2 for concrete and lead respectively. Figs 3 and 4 show the results for concrete and lead with the source and chamber in a line parallel to the surface. In these figures,

D = distance from surface of barrier to ionization chamber,
d = distance from surface of barrier to cobalt 60 source, and
S = distance from source to chamber.

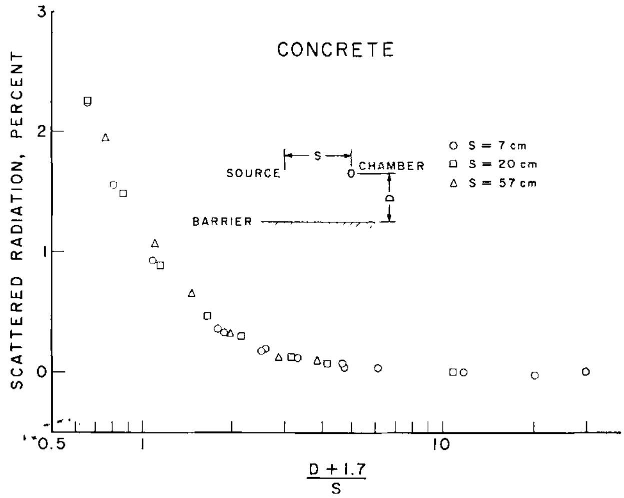

Fig. 6. Radiation scattered by the concrete barrier, shown as a percentage of the primary exposure rate, versus the ratio $\frac{D + 1.7}{S}$, with source and chamber in a line parallel to the surface of the barrier.

Normalization was carried out in two steps. First, exposure rates were normalized to the exposure rate obtained with the source and chamber midway between the floor, or barrier, and the celling of the room. In this mid-position, however, the total exposure rate would still include some small residual contribution, found to amount in nearly all cases to no more than 0.01 percent, from radiation scattered by the barrier. The exposure rate in the absence of this contribution was estimated by extrapolation to the point where $\frac{D}{d}$ equals 1, corresponding to the barrier being at an infinite distance, and the extrapolated value was then used for the second normalization.

It might be argued that the decreasing slope of the curves as $\frac{D}{d}$ approaches 1 could have been caused largely by the increasing scattered radiation from the ceiling compensating for the decreasing scattered radiation from the floor as the source and chamber were raised to the mid-position. It then would follow that the true curve of scattered radiation, after correction for the radiation scattered by the ceiling, should maintain a slope greater than shown in the figures as $\frac{D}{d}$ approaches 1, and that possibly a significantly different

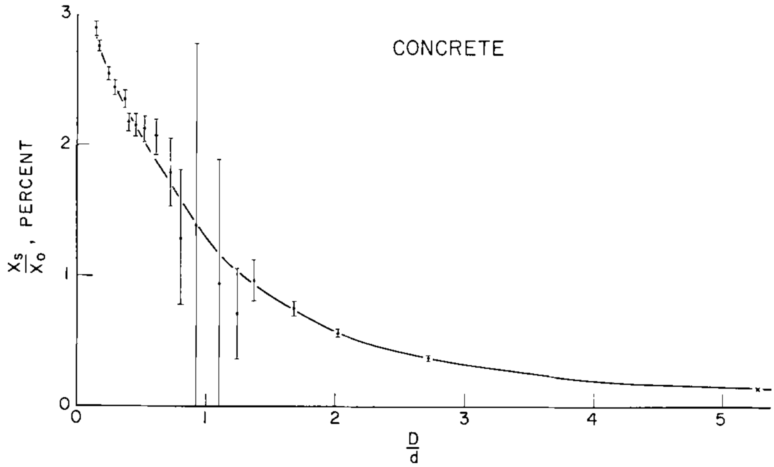

Fig. 7. Radiation scattered by the concrete barrier, shown as a percentage of the primary exposure at the surface of the barrier, versus the ratio $\frac{D}{d}$ with source and chamber in a line normal to the surface of the barrier.

extrapolated value and normalization would thereby be obtained. However, any proposed true curve which differs appreciably from those in the figures would fail to satisfy two conditions. One is discussed later in connection with Figs 7 and 8. In addition, any such proposed true curve can be shown to be unable to yield the experimental curve by summing the resulting floor-scattered and ceiling-scattered radiations. In this connection, it is worth pointing out that, with respect to the ceiling, all the positions occupied by the source and chamber in the experiment corresponded to values of $\frac{D}{d}$ lying within two narrow ranges. When S was 20 cm, for example, the values of $\frac{D}{d}$ with respect to the ceiling lay approximately between 0.90 and 0.95, or between 1.05 and 1.10. Hence, the entire variation of radiation scattered by the ceiling and which contributed to the experimental results is exhibited by the curves within these two narrow ranges.

From the dimensions of the room, it follows that the scattered radiation arising from the four walls was no greater than several hundredths of one percent. Since only the change in this scattered radiation as the source and chamber were moved vertically would have affected the results, such effects were neglected. Similarly, the change in radiation scattered by the ceiling as the source and chamber were moved vertically was generally less than 0.01

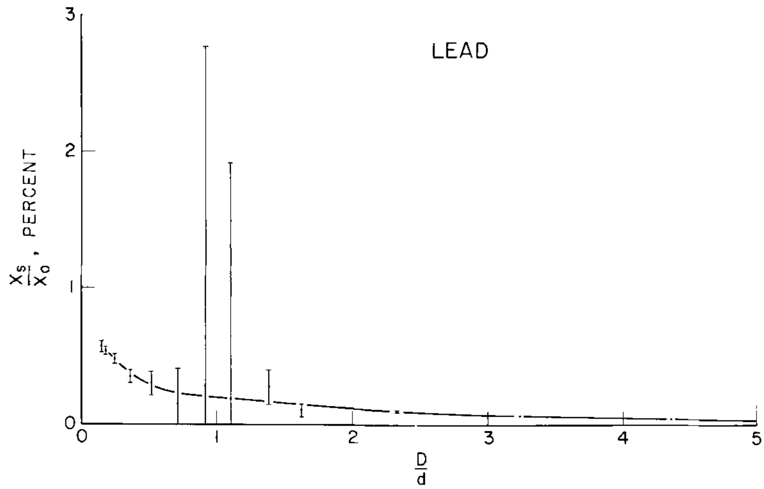

Fig. 8. Radiation scattered by the lead barrier, shown as a percentage of the primary exposure at the surface of the barrier, versus the ratio $\frac{D}{d}$ with the source and chamber in a line normal to the surface of the barrier.

percent, and was considered negligible except in one case. With S = 57 cm, the scattered radiation from the ceiling was estimated to amount to between 0.04 and 0.10 percent, and appropriate corrections were applied to the data.

The percent scattered radiation was plotted against the ratios $\frac{D}{d}$ and $\frac{D}{S}$ in the expectation that geometrical scaling for different source to chamber separations might apply, and that generally applicable curves would result. It is seen that the curves for lead for the different source to chamber separations do coincide within the accuracy of measurement. The divergence of the curves in the case of concrete is due to the fact that interactions take place within the concrete at depths comparable with some of the barrier to source separations. In place of distances measured from the surface of the concrete barrier, one might substitute corresponding distances measured from some effective plane of scattering within the barrier. The depth of the effective plane might be defined as that depth above which one half of the backscattered photons arise. Elementary calculation, considering attenuation of the incident primary and of the emergent backscattered photons, gives a depth of 1.7 cm. The data of Figs 1 and 3 are re-plotted in Figs 5 and 6, using (D + 1.7) and (d + 1.7) in place of D and d. It is seen that the curves are brought nearly into coincidence.

It is interesting to deduce the scattered radiation at the detector as a fraction of the radiation illuminating the surface of the barrier when the source and detector are in a line normal to the surface. If X_s is the exposure due to scattered radiation at the detector, and X_o is the exposure due to primary radiation at the point on the surface of the barrier where the primary radiation is incident normally, then

$$\frac{X_s}{X_o} = \frac{X_s}{X_p}\left(\frac{\mathrm{d}}{\mathrm{S}}\right)^2$$

where X_p is the exposure at the detector due to primary radiation. For concrete, $\frac{X_s}{X_p}$ is obtained from the data of Fig. 1, and Fig. 7 shows the ratio $\frac{X_s}{X_o}$ obtained for S equal to 20 cm. Fig. 8 shows the same ratio for lead, using the data of Fig. 2.

An indication of the accuracy of the extrapolation and normalization described previously can be found in Figs 7 and 8. The vertical line through each point shows the error in $\frac{X_s}{X_o}$ corresponding to estimated errors of $\pm$ 0.0002 in the experimental ratios $\frac{X_s}{X_p}$, and of $\pm$ 0.5 mm in measured distances. The latter source of error is relatively unimportant. It is evident, however, that the values of $\frac{X_s}{X_o}$ where $\frac{\mathrm{D}}{\mathrm{d}}$ is near unity are very sensitive to errors in $\frac{X_s}{X_p}$. This means that even a small change in the curves of Figs 1 and 2 would make the curves of Figs 7 and 8 deviate greatly from the expected smooth decrease of scattered radiation at increasing distances from the barrier surface. Since the points in Figs 7 and 8 all lie nearly on the smooth curve, it is concluded that the error in $\frac{X_s}{X_p}$ resulting from the extrapolation and from the effects of scattered radiation from the ceiling is indeed small.

The curves in Figs 1 and 2 exhibit a lack of symmetry about the ordinate at $\frac{\mathrm{D}}{\mathrm{d}} = 1$. If the contribution from scattered radiation were unchanged by interchanging the positions of the source and detector, the percent scattered radiation at $\frac{\mathrm{D}}{\mathrm{d}} = x$ would be the same as at $\frac{\mathrm{D}}{\mathrm{d}} = \frac{1}{x}$, thus giving a symmetrical curve when plotted against the logarithm of $\frac{\mathrm{D}}{\mathrm{d}}$. However, one would expect the positions of the source and chamber to be not exactly interchangeable because the attenuation of photons by the barrier is not the same in the two cases. Considering only singly scattered photons arising from any specified point within the barrier and travelling in the direction of the detector, the path lengths within the barrier of primary and scattered photons are interchanged in the two cases. Attenuation of the scattered photons outweighs that of the primary photons, and the longer path length for the scattered photons when the detector lies between the source and the barrier would result in a lower contribution from scattered radiation. This is in agreement with the curves of Figs 1 and 2.

Comparison of the results for concrete and lead shows that the radiation scattered by concrete is on the average between 5 and 6 times that scattered by lead. It might be noted that, although the geometric conditions are different, this is not in disagreement with ratios of energy albedos for aluminium and lead between 8 and 3 obtained by BULATOV (1960) at incident angles between 0° and 60°.

The ratio of radiation scattered by concrete to that by lead exhibits a tendency toward higher values as $\frac{D}{d}$ approaches unity, and as $\frac{D}{S}$ increases. Both of these conditions are accompanied by an increase in angle of scattering and a consequent decrease in energy of the scattered photons. Since the ratio of the absorption coefficient of lead to that of concrete increases at lower photon energies, there would be a corresponding increase in the radiation scattered by concrete relative to that by lead.

SUMMARY

The percentage contribution to exposure rate, in roentgens per unit time, due to cobalt 60 gamma radiation scattered by concrete and lead barriers has been measured for a point isotropic source and an ionization chamber in lines normal and parallel to the barrier surface.

ZUSAMMENFASSUNG

Der prozentuale Beitrag zu der aus einer Kobalt-60-Quelle herrührenden und durch Beton-und Bleiwände gestreuten Bestrahlungsdosis wurde für eine isotropische Punktquelle mit Ionisationskammer senkrecht und parallel zur Wandoberfläche in Röntgen pro Zeiteinheit gemessen.

RÉSUMÉ

L'augmentation en pourcentage de la dose d'irradiation, en roentgens par unité de temps, due à une radiation gamma provenant de cobalt 60 et diffusée par des barrières de béton et de plomb a été mesurée dans le cas d'une source ponctuelle isotropique et d'une chambre d'ionization sur des lignes perpendiculaires et parallèles à la surface des barrières.

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