U. S. Department of Commerce
National Bureau of Standards

Research Paper RP1983
Volume 42, May 1949

Part of the Journal of Research of the National Bureau of Standards

Concrete as a Protective Barrier for Gamma Rays from Radium[1]

By Harold O. Wyckoff and Robert J. Kennedy

Several papers [1, 2, 3] [2] and Handbooks [4, 5] have been published during the past 20 years dealing with barrier requirements for shielding against gamma radiation from radium. These publications have usually suggested lead for the barriers because a large proportion of the applications required restricted space and ready transportability of the barrier and gamma-ray source. For high-energy X-ray installations, it is often more economical to use concrete barriers. It has been suggested that concrete might also be useful for shielding in gamma-ray installations if attenuation curves were available. The present paper presents this required information for radium.

I. Introduction

Gamma rays are attenuated by photoelectric absorption, Compton absorption and scattering, and pair production. In the energy range considered here (less than 3 million electron volts), the photoelectric, Compton absorption, and pair-production phenomena may be considered to produce true absorption of the photons, inasmuch as the high-speed electrons so produced in the barrier have a small probability of reradiating. At a point whose distance from the far side of the barrier is small compared to the dimension of the irradiated area, there will be an appreciable number of photons scattered from the barrier. However, if a point is chosen far enough from the barrier as compared to the irradiated dimensions, there will be an inappreciable number of such scattered photons measured at the point in question. As a result of this apparent variation of attenuation, one may describe two limiting barrier requirements. They are often spoken of as narrow- and broad-beam conditions where the terms indicate the relative angle subtended at the chamber by the irradiated area. Further discussion of these cases is contained in a previous publication [7].

Another effect of scattered radiation, previously discussed by Failla [6], may also be observed for broad-beam measurements. Since each Compton process produces a photon of lower energy, and since the air ionization chamber reading is proportional to the photon energy and to the true absorption coefficient in air, it is evident that the scattered photon will produce a smaller effect in the ionization chamber than its parent, provided the true air absorption is approximately independent of energy. Although this coefficient is approximately constant for energies between 70 and 3,000 electron kilovolts, it increases rapidly as the energy is reduced below 70 kiloelectron volts. It is thus possible for scattered photons of energy below 70 kiloelectron volts to produce a larger effect in the chamber than their parents. Photons of energy below 70 kiloelectron volts are readily absorbed photoelectrically by high atomic number absorbers, such as lead, so this effect cannot be observed for the high atomic number absorbers but can be observed in materials such as concrete. The effect is observed in concrete as a slight increase in the dosage rate for small absorber thicknesses [7].

II. Experimental Arrangement

A Bakelite-walled air-filled ionization chamber with an FP54 electrometer was used for the measurements. The FP54 was used as a null instrument by opposing the voltage drop across

[1] Supported in part by the United States Atomic Energy Commission.

[2] Figures in brackets indicate the literature references at the end of this paper.

the grid resistor with a known potential from a potentiometer.

The absolute calibration of the dosage-measuring system was determined by an auxiliary experiment. A known radium source and the measuring system—fixed relative to each other—were varied in elevation above the floor within a 60-foot-high room. The lateral position of the scattering objects in the room were of the order of five times farther from the source than the measuring system. Figure 1 shows the relative

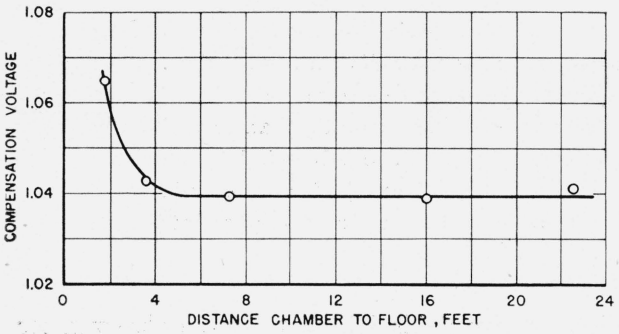

FIGURE 1. *Calibration curve of dosage measuring system.*

A small radium source and the ionization chamber—fixed relative to each other—were moved vertically in a large room where the floor was the principal scattering object. The abscissa gives the distance of the source-chamber combination above the floor and the ordinate gives the corresponding relative dosage rates. The horizontal position of the curve is interpreted as indicating that the scattering from the floor has become negligible.

ionization obtained as a function of the distance of the system from the floor. The horizontal portion of the curve indicates that the scattering from the floor is producing a negligible portion of the ionization current in the chamber. A calibration of the measuring equipment under these conditions was thus obtained from the grid voltage, the distance between the source and the chamber, the amount of radium in the source, the emission constant for radium, and the air-wall correction [8]. The calibration so obtained agreed to within 1 percent with that calculated from the mass of air in the chamber and the value of the electrometer grid resistor. Such accuracy was assumed to be adequate for the present experiment.

For the attenuation experiments, the ionization chamber and electrometer tube were placed inside a concrete-lined pit 6 feet square by 10 feet deep, previously described for similar X-ray experiments [7]. The chamber could be moved vertically and in arcs about one corner of the pit by remote control. The grid resistor could be selected from a remote position and the potential across the grid resistor determined by remote indicators. The value of the grid resistor and grid voltage, together with the known calibration of the instrument, permitted the computation of the dosage rates obtained at the position of the chamber. The source was suspended at various positions vertically above the center of the open end of the pit.

Two experimental conditions were used to obtain the narrow- and broad-beam attenuation curves. For broad-beam conditions the absorbers were placed on top of the open end of the pit. The concrete samples consisted of slabs approximately 8 feet square by 6 inches thick. These gave a 1-foot overlap over the whole lip of the pit. The individual lead absorbers were 2 feet by 8 feet by ⅛ inch. Each ⅛-inch thick layer covered the whole pit with an overlap of at least ¼ inch at the lead joints. Lap joints were staggered in adjacent layers so that none of the joints were closer than 9 inches to a line through the chamber and source. The lead sheets, being quite flexible, required additional support, which was provided by placing plyboard over the pit to reduce the aperture. An unsupported area of lead, 3 feet square, was thus obtained in the center of the pit opening.

For narrow-beam conditions, the source was placed inside of a lead shield having a 1-inch-diameter diaphragm. Small-diameter absorbers were then placed immediately below this diaphragm, which was about 11 feet from the top of the pit. The maximum irradiated area of the absorber was not more than 2½ inches in diameter.

III. Results

Attenuation curves were obtained with the chamber directly below the source and 7.5 inches below the lip of the pit. In order to determine the effect of pit-wall scattering on the ionization chamber readings, measurements made with no absorber over the pit were compared with those obtained in the scatter-free auxiliary experiment. The pit measurements were approximately 6 percent larger than those obtained for the auxiliary experiment. As the pit walls were the nearest scattering objects, it was assumed that they contributed the major portion of the 6 percent. All dosage measurements reported in this paper for broad-beam measurements have therefore been corrected by this 6 percent to compensate for the

scattering from the pit walls. As will be shown later, this scattering is not independent of the position of the chamber in the pit.

Experimental data were first obtained for lead absorbers to compare with previously published data of other workers. The results are shown in figure 2. The narrow-beam data reported here agree very well with that of Kaye but is about 20 percent higher than that of Braestrup. The broad beam data reported here agree very well with those of Braestrup and, considering the spread of points, are in adequate agreement with those of Kaye. This agreement seems satisfactory, considering the difficulty of accurately transferring experimental points from small-scale published curves and the difficulty of minimizing the scattering for experimental arrangements other than those reported here.

Figure 3 shows the broad-beam radiation attenuation in concrete of density 2.35 grams per cubic centimeter for the two sources. The smaller source was certified as 0.0484 curie. Although the large source was not certified, it is evident from the measurements that it was equivalent to 0.42 curie. The distance between the source and chamber was actually 1 meter for both curves, but the inverse-square law was found to hold for both sources as the sources were raised from 1 to 3 meters from the chamber. These curves may therefore be used for source-to-chamber distances of from 1 to 3 meters after making the proper inverse square correction. As noted above, the center of the chamber was 7½ inches below the floor. From these curves it is seen that the first half-value layer is 3.5 inches, whereas subsequent half-value layers are 2.7 inches.

The solid curves of figure 4 give the experimentally determined variation in dosage rate with distance between the chamber and barrier. All data have been computed back to a distance of 1 meter between chamber and source by the inverse-square relation. If the inverse-square relation holds, all the curves on this graph should be hori-

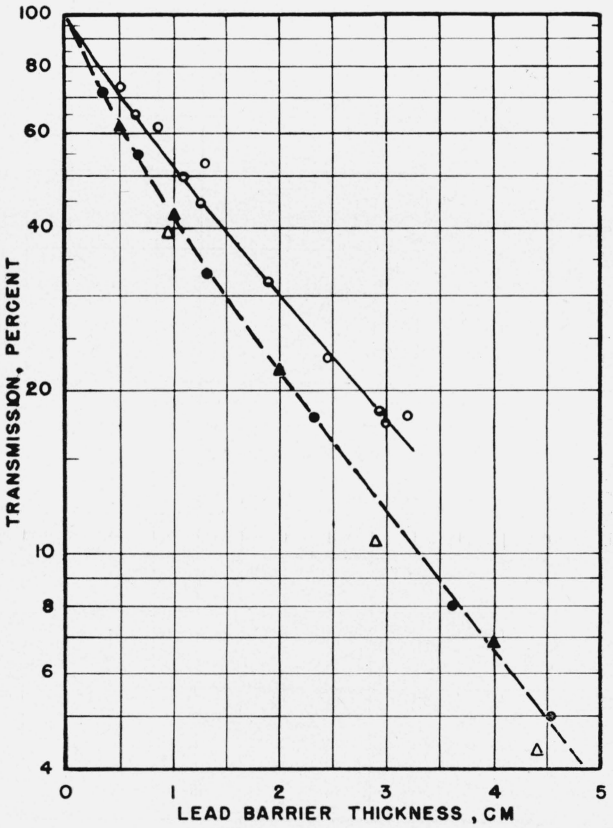

FIGURE 2. *Comparison of the attenuation in lead of the gamma rays from radium as obtained by various workers*

Narrow-beam conditions: ▲, Kaye, Binks, and Bell; △, Braestrup; ●, National Bureau of Standards broad-beam conditions; ○, Kaye, Binks, and Bell; ◓, Braestrup; ◒, National Bureau of Standards.

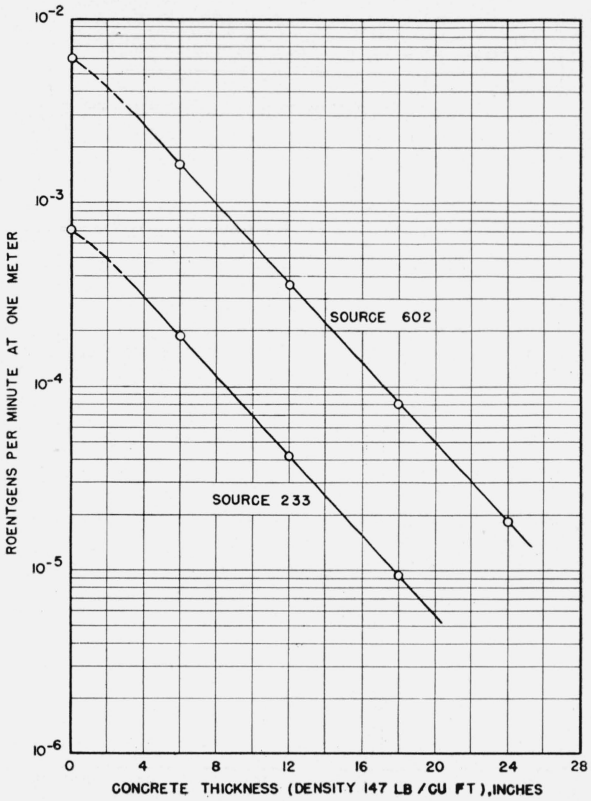

FIGURE 3. *Broad-beam attentuation in concrete of the gamma rays from radium.*

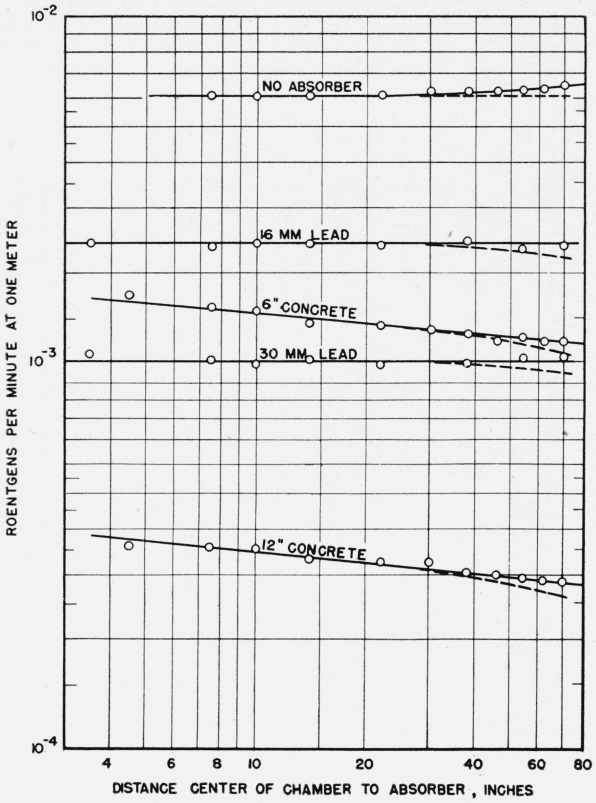

FIGURE 4. *Variation of dosage rate with distance between chamber and radium source.*

A correction has already been made for the inverse-square variation.

zontal lines. The curve for "no absorber" indicates that this relation holds for small distances. The upward trend at distances larger than about 2 feet indicates that scattering from the walls of the pit is providing an additional contribution over and above the 6 percent, for which correction has already been made. The contribution of wall scattering for the no absorber curve amounts to about 8 percent of the direct beam at a distance of 70 inches below the lip of the pit.

Since the gamma rays from radium are of relatively high energy and the scattering of such radiation should be principally forward, the increase in dosage rate for lower positions of the chamber in the pit is therefore reasonable. Actually, the curves for the attenuated beams given in figure 4 do include some of the wall-scattered radiation. If the same percentage of wall scattering is assumed for the attenuated-radiation curves, the dotted curves are obtained. However, the part of the primary beam producing the scattering must pass obliquely through the absorber and is thus attenuated to a greater extent than the normal beam. The amount of wall-scattered radiation reaching the chamber with an absorber over the pit should thus be reduced in the same proportion. The true curve (without wall scattering) should thus fall between the solid and dotted curves for the attenuated beam. The downward slope of the resultant concrete and lead curves indicate that the scattered radiation from the absorber becomes less important as the distance from the absorber increases. The more nearly horizontal curve for the lead absorbers indicates that the scattering in lead is much less important than in concrete. This is to be expected as the scattered radiation may be more easily absorbed photoelectrically in lead than in concrete.

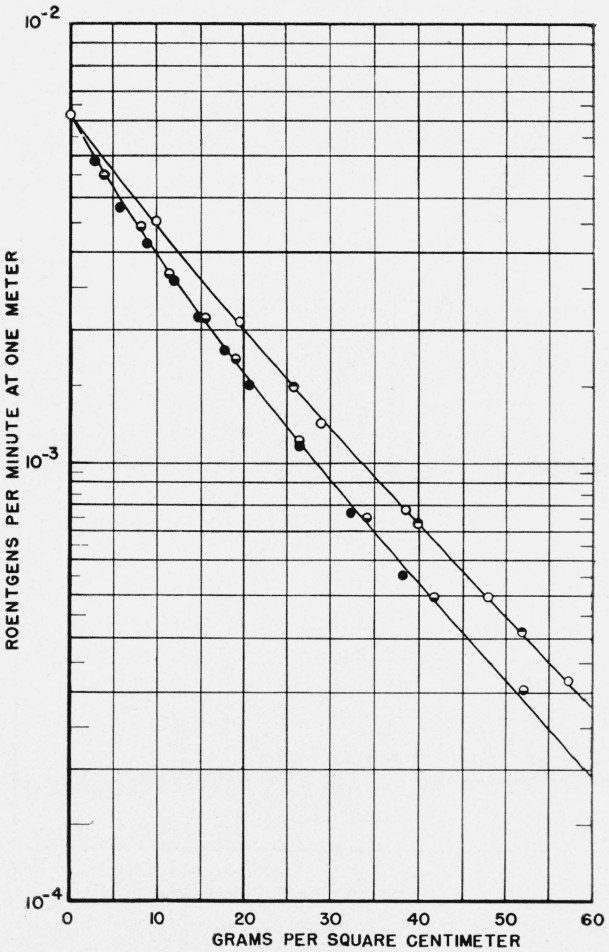

FIGURE 5. *Narrow-beam attenuation of gamma rays from radium.*

◒, lead; ◓, lead glass; ●, concrete; ○, steel.

Figure 5 shows the narrow-beam attenuation data for lead, lead glass (62% lead oxide), concrete, and steel. The curves are separated because of the importance of photoelectric absorption in lead. Variations of photoelectric absorption with atomic number is shown to be small at least for the range between concrete and steel. The broad-beam-attentuation curves given here are thus applicable also for this range of atomic number, provided the same mass of barrier is used. The latter statement has been verified by comparison of experimental results obtained by Kaye for iron with those reported here for concrete.

TABLE 1. *Barrier thickness requirement with radium source*

Source strength	Source to personnel distance					
	1 meter		2 meters		3 meters	
	Lead	Concrete	Lead	Concrete	Lead	Concrete
Millicuries	*mm*	*in.*	*mm*	*in.*	*mm*	*in.*
1,000	----	20.3	----	14.7	----	11.4
500	----	17.5	----	11.9	34.5	8.7
200	----	14.8	33.3	8.3	17.5	5.0
100	----	11.0	20.7	5.5	5.8	2.0
50	32.7	8.2	7.7	2.5	0	0
20	15.8	4.5	0	0	0	0
10	4.3	1.5	0	0	0	0

IV. Conclusions

From the curves of figures 2 and 3 it is possible to compute the barrier requirements listed in table 1. A permissible dosage rate of 0.3 roentgen per 48-hour workweek is assumed. It is assumed that personnel may be as near as 7.5 inches to the outside of such a barrier. If personnel are located at a distance of more than 3 feet from the barrier, 1 inch may be deducted from the concrete, and 4 millimeters from the lead requirements listed in the table.

V. References

[1] G. W. C. Kaye, W. Bell, and G. E. Binks, Brit. J. Radiol. **9,** 161 (1936).

[2] G. W. C. Kaye, W. Bell, and G. E. Binks, Brit. J. Radiol. **8,** 6 (1935).

[3] C. B. Braestrup, Radiology **46,** 385 (1946).

[4] Radium protection, NBS Handbook 23 (1938).

[5] Safety code for the industrial use of X-rays (American Standards Association, 70 East 45th St., New York, N. Y.).

[6] G. Failla, Am. J. Roentgenol. Radium Therapy **54,** 553 (1945).

[7] H. O. Wyckoff, R. J. Kennedy, and W. R. Bradford, J. Research NBS **41,** 223 (1948) RP1920.

[8] G. C. Laurence, Can. J. Research [A] **15,** 67 (1937).

WASHINGTON, December 9, 1948.