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ATTENUATION OF GAMMA RADIATION BY
HIGH DENSITY LEAD GLASS COMPARED WITH
STEEL

By
R. G. Wheeler

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Hanford Works
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Technical Information Service, Oak Ridge, Tennessee

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R. G. Wheeler
Metallurgy Section
Pile Technology Division

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HANFORD WORKS
RICHLAND, WASHINGTON

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- Reference: (1) Letter, J. M. Holeman to F. B. Quinlan, "Penberthy Glasses," December 19, 1949.
(2) TNX-7, C. W. J. Wende.

INTRODUCTION

The problem of designing a direct viewing window for steel radiometallurgy cells would be simplified if optical quality lead glass were available which would attenuate gamma radiation as effectively as steel. Small lead glass specimens having densities over 6.0 g/cc were made available for experimental use by the Penberthy Instrument Company, Spokane, Washington. This report summarizes the results of investigations of these two shielding materials.

SUMMARY

Calculations, based on absorption coefficients obtained from Report TNX-7, indicate that 80 per cent PbO in glass should attenuate 1.5 to 2.5 mev gamma radiations as effectively as steel. The comparison of steel with lead glass having a density of 6.17 g/cc showed that for practical purposes the shielding properties of the two materials are the same, when irradiated uranium and aluminum are used as the sources of radiation.

The efficiency of light transmission of 6.17 density lead glass compared favorably with 4.6 density commercial fluoroscopic grade lead glass.

DETAILS

A comparison of gamma ray attenuation of lead glass can be calculated from published absorption coefficients of the elements involved. Absorption coefficients for 1.5 and 2.5 mev gamma radiation obtained from Report TNX-7 are as follows:

<u>Element</u>	<u>Absorption Coefficient (cm⁻¹)</u>	
	<u>Radiation Energy</u> 2.5 mev	<u>Radiation Energy</u> 1.5 mev
Pb	0.47	0.65
Fe	0.31	0.40
* Si, O & K	0.067	0.087

* Assumed to be the same as carbon.

Lead glass containing 80 per cent PbO contains 74 per cent lead and enough silicon, oxygen and potassium to make up the balance. A weighted average of the absorption coefficients of the ingredients for 80 per cent PbO lead glass yields a coefficient μ of 0.365 for 2.5 mev and 0.504 for 1.5 mev radiation.

$$\mu_{\text{glass}} / \mu_{\text{iron}} = 0.365 / 0.31 = 1.17$$

Considering that the PbO content of the glass and the energy of radiation were approximations, the calculated ratio of 1.17 to 1 agrees well with the observed absorption coefficient ratio of 1. The calculated absorption coefficient ratio of 80 per cent PbO glass to iron for 1.5 mev radiation is 1.26.

The arrangement of equipment used to expose specimens to radiation from a uranium source is shown in Figure 1. The setup for the aluminum source shown in Figure 2 is similar to that used for uranium except that the radiation was collimated through only two lead bricks because the gamma activity from the aluminum source was not as intense as that from the uranium source. The uranium source (approximately 3/8" thick and 1-1/2" diameter) was cut from an 8" slug.

The aluminum source was a stack of four pieces of metal cut from the center section of a vertical safety rod thimble. Two specimens of mild steel and two specimens of Penberthy glass used to attenuate the radiation are described in Table I. Relative intensities of radiation before and after attenuation by the shielding specimens were measured with a Lauritsen electroscope. The geometry of the beam of radiation emerging from the collimator shown in Figure 1 was determined with x-ray film packets. Each packet contained one film sensitive to gamma radiation and another film less sensitive to gamma radiation. The use of two films in each packet extends the range of radiation intensity that can be measured.

Positive prints of two sets of x-ray film placed in the path of the beam of radiation are shown in Figure 3. One set was exposed for 17 hours and the other for 5 hours.

The position of each packet, containing a sensitive and insensitive film, is shown in Figure 1. An aluminum shield, 0.05 inches thick, was placed between the first film and the lead brick collimator to filter out the beta radiation. Densitometer readings converted to mr/hr are shown in Table II. Two densitometer readings were taken for each film, one for the lightest and one for the darkest part.

From the film data it was estimated that background radiation was at least 50 per cent as effective in discharging the Lauritsen electroscope as the controlled beam of radiation. Absolute absorption coefficients could not be determined because the method did not permit quantitative evaluation of the radiation passing around the specimens and affecting the ionization chamber as background.

Table III shows the average drift time of the Lauritsen electroscope fiber when the specimens were placed in the beam individually and in combination. The rate of drift of the quartz fiber of the electroscope varied directly with intensity of radiation. Deviation from linearity was found to be negligible especially for a drift on one major scale division as used in these experiments. From the data contained in Table III the attenuation of radiation by lead glass can be compared with steel. Where (μ) is the apparent absorption coefficient, (T) is the drift time of the quartz fiber, (X) is the thickness of specimens 2 and 4, and (I) is the intensity of radiation:

$$x \mu = \ln I_1 / I_2 = \ln T_2 / T_1$$

$$x = x_s$$

$$\frac{\mu_g}{\mu_s} = \frac{\ln T_{g2} / T_{g1}}{\ln T_{s2} / T_{s1}} = \frac{\ln (177.4 / 97.2)}{\ln (164 / 93.4)} = \frac{0.586}{0.570} = \frac{1.03}{1}$$

The subscripts g, s, 1, and 2 indicate, respectively, glass, steel, one specimen and two specimens combined. The observed ratio of attenuation of radiation from uranium by lead glass compared with steel was 1.03/1. By a similar calculation using data obtained with an aluminum source, a ratio of 1/1 is obtained.

Light transmission characteristics of five specimens of Penberthy lead glass as measured with a spectrophotometer are shown in Table IV. Since it is difficult to make small homogeneous samples of glass, it is believed that Penberthy glass cast in large pieces would have better optical properties and be freer from physical defects.

Optical data was furnished by J. M. Holeman, Instrument Division.

TABLE I

DESCRIPTION OF SHIELDING SPECIMENS

<u>Specimen Number</u>	<u>Material</u>	<u>Dimensions (Inches)</u>	<u>Density</u>	<u>Remarks</u>
1	Pb glass	0.427 x 1.0 diameter	6.17	Penberthy glass
2	Pb glass	0.455 x 1.0 diameter	6.17	Penberthy glass
3	Steel	Same as specimen No. 1	7.82	Mild steel
4	Steel	Same as specimen No. 2	7.82	Mild Steel

TABLE II

INTENSITY OF RADIATION FROM URANIUM SOURCE AS MEASURED

WITH X-RAY FILM AND DENSITOMETER

<u>17 Hour Exposure</u>				<u>5 Hour Exposure</u>			
<u>Film No.</u>	<u>Distance From Source (Inches)</u>	<u>Maximum Exposure Mr/Hour</u>	<u>Minimum Exposure Mr/Hour</u>	<u>Film No.</u>	<u>Distance From Source (Inches)</u>	<u>Maximum Exposure Mr/Hour</u>	<u>Minimum Exposure Mr/Hour</u>
47-T	14-1/2	485	14	52-T	14-1/2	316	0
48-T	16-1/2	87	7	53-T	16-1/2	78	4
49-T	18-1/2	75	23	54-T	18-1/2	94	37
50-T	20-1/2	63	24	55-T	20-1/2	106	66

TABLE III

ATTENUATION OF GAMMA RADIATION BY SPECIMENS DESCRIBED IN TABLE I

<u>Uranium Source</u>		
<u>Specimen Number</u>	<u>Thickness (Inches)</u>	<u>Average Drift Time "T" Seconds</u>
1	0.427	97.2
1 and 2	0.882	177.4
3	0.427	93.4
3 and 4	0.882	164.0
None		34.0

<u>Aluminum Source</u>		
<u>Specimen Number</u>	<u>Thickness (Inches)</u>	<u>Average Drift Time "T" Seconds</u>
1	0.427	152
1 and 2	0.882	192
3	0.427	155
3 and 4	0.882	196
None		115

TABLE IV
LIGHT TRANSMISSION OF LEADED GLASS SAMPLES CORRECTED FOR SURFACE
REFLECTION AND CONVERTED TO 1/4 INCH THICKNESS

Wave-length	Color	Pittsburgh	Penberthy				
		Density 4.6 %	Density 6.05 %	Density 6.11 %	Density 6.17 %	Density 6.24 %	Density 6.44 %
400	Violet	0	0	0	0	0	0
440	Blue-V	41	79	79	78	68	53
480	Blue	82	91	89	88	87	78
520 *	Blue-G	93	96	94	92	94	92
560 *	Green	96	97	95	94	95	96
600 *	Yellow-G	96	97	95	94	94	95
640 *	Orange	96	98	94	92	94	93
680 *	O-Red	96	98	94	92	94	92
700	Red	96	98	95	93	94	91

* The apparent lack of correlation between density and light transmission for certain wavelengths may probably be attributed to physical defects or coloring that is difficult to control in small melts of glass.

Fig. 1

EXPERIMENTAL SETUP FOR MAKING ABSORPTION MEASUREMENTS WITH URANIUM AS A SOURCE OF RADIATION

Intensity of radiation at the electroscope (16½ inches from source) corrected for volume and converted to one inch from source 26 R/hr at one inch.

Fig. 2

EXPERIMENTAL SETUP FOR MAKING ABSORPTION MEASUREMENTS WITH ALUMINUM AS A SOURCE OF RADIATION

Intensity of radiation at the electroscope (9 1/4 inches from source) corrected for volume and converted to one inch from the source - 860 mr/hr at one inch.

Fig. 3—The above positive prints of x-ray film, exposed as indicated in Fig. 1, show the geometry and relative radiation intensity of the diverging beam. It can be seen that scattering from the walls of the collimator causes the background to increase with distance from the collimator.

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