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MEASUREMENTS OF LIGHT TRANSMITTANCE THROUGH
THICK SHIELDING WINDOWS

by

T. W. Eckels

Chemical Engineering Division

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SUMMARY

A method is described for determining the light transmittance of thick shielding windows installed in walls. The equipment described permits measurements to be unaffected by the level of room lighting or by the movements of personnel who may be wearing light-colored clothing. In the particular cave installation described here it will be possible to make periodic measurements throughout the life of the window without taking any of the equipment into the cave itself. The results are reproducible within 2 per cent.

Two supporting experiments are reported to substantiate the statements regarding accuracy and reproducibility of results.

INTRODUCTION

As analytical chemistry and reactor fuel reprocessing proceed with more radioactive materials, the demand rises for caves with shielding walls and shielding windows of ever greater thickness and/or density.

In the Chemical Engineering Division of Argonne National Laboratory a complex of three cells, known as the Senior Cave, has been built. Figure 1 shows a plan view of these cells. Two of them, designated Cell A and Cell B, were designed to contain 10^4 curies of 1-Mev gamma. The third, Cell C, was designed for 10 curies of 1-Mev gamma.

Another installation with a much higher level of gamma radiation is being built at the National Reactor Testing Station in Idaho as part of the experimental reactor EBR-II. This plant, known as the Fuel Cycle Facility, will reprocess multi-kilogram quantities of spent reactor fuel metals. Gamma-radiation levels of 10^5 to 10^6 roentgens per hour may be incident upon the shielding windows for extended periods.

One of the problems expected to arise is that resulting from coloration of the glass of the windows. Non-browning glass is used in the construction of shielding windows, but "non-browning" is a relative term. All glasses brown with sufficient exposure to gamma radiation. Very few shielding

windows have actually experienced radiation to integrated gamma exposures of the order of 10^9 to 10^{10} roentgens. To our knowledge none have been measured quantitatively for light transmittance when new and at periodic intervals during their useful lifetimes. Such records should be useful in developing better windows and in comparing the merits of existing types.

Figure 1

Plan of Radiochemistry Cave D-205

A method of making light transmittance measurements of complete windows accurate to ± 2 per cent would also permit checking the validity of light transmittance data furnished by shielding glass manufacturers. The manufacturers' data are usually based on readings of one-inch thick samples using monochromatic light. Needless to say, a fairly small error in the one-inch value will give a very large error if raised to the 60th power for a five-foot thick window. If such a window were expected to give 15 per cent light transmittance and it actually gave $7\frac{1}{2}$ per cent, then the lighting requirements inside the cell would be doubled! An error of ± 1.0 per cent in the internal light transmittance per inch derived from a one-inch

sample would cause an error of +45.5 per cent in the computed transmittance of 60 inches of that glass. On the other hand, an error of 2 per cent in measuring the light transmittance through 60 inches of glass would correspond to an error of only 0.04 per cent in the one-inch sample.

However, to make light transmittance determinations for windows installed in walls poses three major problems, all concerned with reproducibility of results.

1. Geometry

Both the light source and the measuring instrument must be moved to get the necessary two readings to determine transmittance. The alignments of the light source with the instrument must be duplicated within close limits, and also the distance between light source and instrument must be duplicated for each light measurement, first through air alone, then through the window and air, followed by a second reading through air alone as a check.

2. Stray Light

A practical method should not require elaborate precautions as to permissible light levels in the cell and operating areas during measurement. Nor should the measurements be affected by movements of personnel who may be wearing light-colored clothing, etc.

3. Directional and Area Effects on the Measuring Element

Photo cells and photo tubes are affected to varying degrees by minor variations in the angle which the incident light makes with the receiving face of the measuring element. Also, a given amount of light energy incident near the circumferential edge of the cell face does not usually produce the same amount of electrical energy as that same amount of light energy incident upon the central area of the cell face or tube window.

The procedure described below solves the above problems and, in addition, keeps all the equipment out of the cell. This is accomplished by mounting the measuring equipment on the operator side of the window and shining the light from outside the cell through a cylindrical access hole in the rear wall opposite the window being measured. The hole is normally filled with a cylindrical, solid steel plug. During radiographing of the Senior Cave it was established that a source giving 6000 r/hr at 1 ft when located in the center of the Cell A or B would give 1 r/hr at 2 inches outside the rear wall on the axis of the open 4-inch diameter hole. Light transmittance measurements, however, will be coordinated with the experimental work, so that the primary sources of gamma radiation can be removed or placed in the adjoining cell. Then streaming radiation would present no problem during measurements.

PROCEDURE - GENERAL

A sectional view of one of the Chemical Engineering Senior Cave cells (Figure 2a) shows the arrangement of equipment for making a light measurement (I) through the window. After suitable locations had been determined for the various pieces to assure reproducibility of readings, measurements of the distances shown in the drawing were made. The equipment was then moved to a clear area, as shown in Figure 2b, in order to make a light measurement (I_0) through an all-air column of equal path length. A detailed list of the equipment is presented as Table III in the Appendix.

Figure 2a

Cell Section Showing Arrangement of Equipment for
Light Intensity Measurement through Window (I)

With the proper attention to several details, the light transmittance will be the ratio of light intensity reading as made for the situation of Figure 2a to that for Figure 2b:

$$T = I/I_0$$

Figure 2b

Arrangement of Equipment for Light Intensity Measurement through Air Column (I_0)

The chronological order of the steps of the procedure follows:

I. Set-up for Light Measurements through the Window

A. The Light Source

1. The Light Beam

The distance between light source and receiving box for the cave installation of this example was about 12 feet. It was desired to have a light beam of approximately $1\frac{1}{2}$ -inch diameter at that distance. The lamp house was first aimed into the collimator to give at 12 feet a beam of as uniform intensity as possible over its cross-sectional area with the collimator leveled. At this time all adjustments for pieces attached to the optical bench were securely locked, since even a slight movement of the lamp with reference to the collimator can change readings by as much as 10 to 15 per cent. It was found necessary in this case to install a smaller stop in the filter holder of the collimator to reduce the diameter of the beam to the desired $1\frac{1}{2}$ inches. Any later adjustments to correct the angle of elevation of the beam should be made only with use of the leveling screws in the bench bases.

2. Positioning the Light Source for a Light Measurement through the Window

As shown in Figure 2a, the light source is supported on an elevating table so that the collimator tube projects two inches beyond the optical bench and the leading edge of the table. This overhang aids in

positioning the collimator in the center of the cylindrical opening in the rear wall of the cave. It also makes it possible to suspend a plumb bob from the collimator tube just behind the bezel ring for accurate positioning of the light source, as shown in Figure 2b, for the air-column reading.

For accurate and reproducible readings through the window it is necessary that the light beam strike the window perpendicularly. As will be noticed, the table top can be positioned firmly against the wall. If the location of the front end of the optical bench assembly is permanently marked on the table top and the bench assembly is subsequently maintained at this fixed position, then the leading edge of the table will contact the same stretch of wall on successive set-ups. Inasmuch as walls are rarely plane vertical surfaces, just as floors are even more rarely plane horizontal surfaces, this precaution will reduce errors. With the aid of an observer stationed on the operator side of the window, the light beam can be made perpendicular to the glass surface by adjusting the bench assembly so that the reflection of the beam is thrown back on itself, giving a circle of light centered into the cylindrical opening in the rear wall of the cell.

B. The Light Receiving Box and Photometer

1. The receiving box of Figure 3 is a combination collimating device and light integrator. The collimating section is about 12 inches long, with two concentric holes in the ends, each hole being two inches in diameter. The interior is painted flat black. Alignment of the box can be accomplished by adjusting it until a circle of light centered in each hole can be observed when a sheet of thin paper is placed over each hole in turn. The box has a hinged lid for access to the interior.

All of the light entering the collimator passes into the integrating section. This section is cubical in shape, 6 x 6 x 6 inches, and is lined with white blotting paper. This lining was chosen for its essentially flat curve of diffuse reflectance through the visible spectrum. The light is semispecularly reflected to the sides of the integrating section by a baffle whose cross section is that of an isosceles right triangle. The apex edge of this prism is vertical and splits the light beam. The two beam-reflecting faces of the prism are faced with white enameled paper, which also has desirable spectral reflectance characteristics. Rather sharply defined semicircles of light are cast on the two sides of the integrating section, and these semicircles are at equal distance from the rear wall of the box when the baffle is properly positioned. The rear rectangular face of the baffle is faced with white blotting paper and is the principal area scanned by the phototube window, which is positioned through a third concentric hole in the rear face of the box.

Figure 3
Light Receiving Box

By adjusting the fore and aft locations of the wedge-shaped baffle along the axis of the three holes, a useful range of intensity observed by the photocell is possible. In conjunction with the sensitivity control of the instrument itself, it is possible to get a full-scale reading when measuring the intensity through the all-air column.

The collimating section makes it possible to take readings completely unaffected by cell or operating area light levels as high as 250 foot-candles.

2. Positioning the Receiving Box

The beam of light from the light source is approximately $1\frac{1}{2}$ inches in diameter as it emerges from the window. If the box is set at some fixed distance, such as two inches away from the "cold" cover plate

of the window, the box can be adjusted so that the beam is cast concentrically through the two-inch hole in its face. This condition can be checked by holding a piece of paper over half the hole and observing the reflection in the glass of the window. After achieving proper alignment of the box, as described in Section I on the preceding pages, all the pertinent distances are recorded. They should be accurate to $\pm \frac{1}{8}$ inch ($\pm \frac{1}{4}$ inch on distances over 10 feet).

II. Air-column Set-up and Initial Intensity Reading (I_0)

A. Positioning the Equipment

In an area with the necessary clear floor area, these dimensions are duplicated for an all-air column reading.

It is essential to hang plumb bobs from fixed locations on the collimator and receiving box to re-establish the proper distance from light source to box to the desired $\pm \frac{1}{4}$ inch. The distance, with proper corrections for plumb bob locations, is laid out on the floor. It is useful to paint on the floor one-inch circles with perpendicular diameter lines in a contrasting color to serve as plumb bob targets.

B. Aligning the Equipment

The wheeled table with receiving box is positioned at one mark and the wheeled elevating table with the light source is positioned at the other mark. It will be found best not to make any adjustment to the light source ensemble. The receiving box should be raised or lowered with its scissors jack as necessary to re-establish the centering of the light beam through the two holes in series. Longitudinal alignment in the horizontal plane can be achieved by rotating the table as needed. Vertical longitudinal alignment may be accomplished by shimming up the front or rear of the jack base.

C. Photometer and Baffle Adjustment

In this example the battery-operated photometer had a phototube with a spectral response peaking around 4000 to 5000 Å. An opal-glass filter was used to assure an even distribution of light energy over the tube window and a photopic correction filter was added to correct the response of the tube to that of the human eye.

The instrument has a stepless sensitivity control which was centered. With the given distance of about 12 feet and the various box parameters, there was a fore and aft position for the baffle within the integrating cube which would permit a full-scale reading of 100 in arbitrary units. The ability to reproduce this reading within 1 per cent or less at any time over

a 3 to 4-hour period without readjusting the sensitivity or the position of the wedge baffle is a measure of the care with which the other parts of the procedure have been followed. A warm-up period of at least 30 minutes for the photometer and frequent dark-zero balance checks have been found essential.

III. Light Intensity Reading through the Window (I)

The equipment is then moved back to the window and a reading is taken there without making any adjustment to the wedge baffle or the sensitivity control of the photometer.

IV. Check Air-column Reading

The equipment is moved once more to the area for air-column reading. As stated above, this reading should be 100 ± 1 . With a little practice, 100 ± 0.2 should be attainable.

RESULTS

After the first couple of attempts while perfecting the procedure, it was found possible to get the desired reproducibility for all of the next twelve determinations in which light transmittance measurements were made for four separate windows in the Chemical Engineering Division at Argonne. Over a period of time, light transmittances through these four windows were remeasured with the same results.

More recently, the equipment has been taken to Detroit, Michigan, on two occasions to measure the light transmittances of the Junior Cave windows for the Laboratory and Service Building of EBR-II, and of various components of the Fuel Cycle Facility windows before shipment to Idaho. The data are presented in Table I in the Appendix.

Two supporting experiments were performed to verify the general accuracy of the method and equipment.

1. In the first experiment, 10 standard microscope slides, 1 in. x 3 in. x 1 mm thick, of a lime glass were measured for light transmittance, individually and cumulatively, each having two air-glass interfaces which accounted for most of the transmission loss.

Using a red gelatin filter rated at 610-millimicron effective wavelength, plus an opal filter, plus a neutral grey filter of optical density 1.0, the following results were obtained. For computational use, transmittance is usually expressed in decimal form, rather than in per cent.

<u>No. of Slides</u>	<u>Reading (T = Reading x 10⁻²)</u>	<u>No. of Slides</u>	<u>Reading (T = Reading x 10⁻²)</u>
0	100	6	56.0
1	91.0	7	50.5
2	82.0	8	46.5
3	74.0	9	42.0
4	67.5	10	38.0
5	62.5		

From these values there is obtained

$$\log 0.38 = 9.57978 - 10$$

$$0.1 \log 0.38 = 9.95798 - 10$$

Antilog 9.95798 - 10 = 0.9078, which is the average T for each of the 10 samples.

Plotted on semi-log paper, ordinate of transmittance versus abscissa of number of slides, a straight line could be drawn with a maximum deviation of any one point from this line of 1.6 per cent. The line was drawn through the first and last points, thus assuming the value for transmittance through all 10 slides to be the true value and also assuming all slides to be identical. The thickness of the slides had been measured with a micrometer and found to be 0.0394 ± 0.0005 inch.

One slide was then measured on a Beckman DU Spectrophotometer at 610 millimicron monochromatic light. This gave $T = 0.913$. Assuming the DU to give the true value

$$\Delta = 0.913 - 0.908 = 0.005$$

and accordingly

$$\% \text{ error} \approx \frac{0.005}{0.913} \times 100 = 0.5 \quad .$$

2. In the second experiment, measurements were made on four (4) one-inch long cylindrical samples of 3.3 density shielding glass containing a nominal 0.8 per cent CeO_2 . These samples were measured individually, by pairs in all possible combinations, by threes in all possible combinations, and with light passing through all four samples consecutively. The search head of the photometer in this case had an opal filter and the photopic correction filter installed.

The individual values were used to derive computed values for all the combinations. Table II in the Appendix gives the detailed readings versus computed values.

The two largest deviations of computed values from experimentally observed values were:

$$\frac{0.009}{0.744} \times 100 = 1.2\% \text{ for one pair}$$

$$\frac{0.006}{0.538} \times 100 = 1.1\% \text{ for a reading through all four samples.}$$

In both of the above experiments the samples were installed inside the collimating section of the receiving box and the 2-inch entrance hole was stopped down to $\frac{1}{2}$ -inch diameter, since the cylindrical samples were only $\frac{5}{8}$ inch in diameter.

CONCLUSIONS

It is felt that reproducibility and general accuracy of results with this equipment and technique are satisfactory.

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APPENDIX

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Table II

CROSS-CHECK PROCEDURE TO DETERMINE LIGHT TRANSMITTANCE
OF FOUR 0.8% CeO₂ MELT SAMPLES OF 3.3 DENSITY
SHIELDING GLASS

Filters used - opal and Catalog #5261 photopic correction
 Warm-up period for photometer - 30 minutes
 Elapsed time of these determinations - 2 hours

Experimental Results				
	Sample	Photometer Readings, I/I ₀	T	Calculated Values of T
Singles	M1	49.0 58.5	0.839	
	M2	52.0 58.6	0.888	
	M3	50.5 60.0	0.842	
	M4	51.0 60.0	0.848	
Doublets	M1, M2	44.0 59.0	0.744	0.839 x 0.888 = 0.745
	M1, M3	40.8 58.0	0.705	0.839 x 0.842 = 0.706
	M1, M4	41.0 58.0	0.708	0.839 x 0.848 = 0.712
	M2, M3	44.0 59.5	0.742	0.888 x 0.842 = 0.748
	M2, M4	44.0 59.1	0.744	0.888 x 0.848 = 0.753
	M3, M4	43.0 60.0	0.716	0.842 x 0.848 = 0.714
Triplets	M1, M2, M3	37.0 59.1	0.627	0.839 x 0.888 x 0.842 = 0.627
	M1, M2, M4	37.5 59.1	0.636	0.839 x 0.888 x 0.848 = 0.632
	M2, M3, M4	37.0 58.2	0.635	0.888 x 0.842 x 0.848 = 0.634
	M1, M3, M4	No measurement made		0.839 x 0.842 x 0.848 = 0.599
Quadruplets	M1, M2, M3, M4	31.8 59.1	0.538	0.626 x 0.848 = 0.532

Table III

EQUIPMENT LIST

	Source	Description
1. Photometer	Photovolt Corp. New York	Model 514-M battery operated, electronic with phototube E (peak sensitivity at 4500 Å) and photopic correction filter. Sensitivity - 0.005 foot-candles full scale in "hi" range position.
2. Light Receiving Box	Local Construction	See Text and Figure 3 for details.
3. Laboratory Scissors Jack	Central Scientific	Cenco-Lerner #19089. Approximately 12-inch lift.
4. Wheeled Table for supporting light measuring equipment		40 inches high and about 24 inches square.
5. Wheeled Elevating Table for supporting light source assembly	Economy Engineering	Model D-15502 Shoplifter 5-ft lift with wheels.
6. Light Source Assembly	OK Machine & Tool Corp. New York (Meyer Opticraft)	Cat. #44 Collimator assembly. #29 Lamphouse with 100-watt, s.c. bayonet base bulb. #26 1/2-meter length optical bench.
7. Voltage Stabilizer	Sola Electric	Sola Constant Voltage Trans- former. Cat #30888 pri. 95-125 volts, sec. 115 volts. Rated volt amps - 150.