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U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Standard Reference Materials:

White Opal Glass Diffuse Spectral Reflectance Standards for the Visible Spectrum (SRM's 2015 and 2016)

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Abstract

Vitrolite white opal glass has been calibrated for use as diffuse spectral reflectance standards since 1944. Its uniformity and long-term durability make it useful as an everyday working standard for spectrophotometric measurements in the visible spectral range. However, its translucency can introduce some errors in such measurements if improperly used. Prior to 1965 the Vitrolite reflectance standards were issued with diffuse reflectance values relative to freshly smoked magnesium oxide. Since that date the calibration of these standards is reported on an absolute reflectance scale or one which is relative to a perfect diffuser. Since the completion of the NBS reference spectrophotometer for diffuse reflectance measurements in 1975, work on the perfection of techniques for determining a more accurate absolute reflectance scale has made it possible to further improve these measurements. As a result of this effort, the Vitrolite reflectance standards are now more accurately characterized and are being issued as a Standard Reference Material.

Key Words: diffuse; reflectance; spectrophotometry; standard; translucency; Vitrolite.

1. Introduction

Vitrolite [1][1] is a white opal glass originally manufactured in large quantities for wall tile and used for various architectural applications. The glass was produced prior to World War II. NBS retains a limited supply in the form of large sheets of approximately 30 inches square from which the reflectance standards are selected. A large percentage of the glass is rejected because of surface defects such as scratches and pits.

Vitrolite possesses several properties that make it useful as a reflectance standard for the visible spectrum. These properties include; a relatively high reflectance, good diffusion of the incident light, a fire polished surface which can be cleaned repeatedly, and long-term stability. The glass from a given melt is usually uniform in reflectance at any given wavelength to within ±0.2 percent.

Vitrolite is translucent enough to cause some problems in using it as a reflectance standard. However, this does not eliminate its usefulness, if proper care is taken to avoid the geometrical conditions of illumination in which translucency errors occur. These conditions are specifically outlined for the user in the discussion of Vitrolite translucency, appearing later in this paper.

Vitrolite has been calibrated and issued as working standards of spectral reflectance by the National Bureau of Standards since 1944. The first melt from which reflectance standards were selected was referred to as the "V1" melt. The majority of standards issued came from melt V3 and melt V6. The original master standard was selected in 1938 and labeled as Standard V1-G3. A back-up master was also selected at that time and referred to as Standard V1-G4. These two standards are nearly identical in spectral reflectance and are still in use after forty years. Standard V1-G3 has been used as a diffuse reflectance calibration standard in the making of thousands of reflectance measurements during this period while Standard V1-G4 has been stored. After many years of cleaning and handling, Standard V1-G3 shows some very fine scratches; however, its reflectance relative to V1-G4 has remained the same. The long-term stability of Vitrolite is believed to be very good.

Most of the Vitrolite reflectance standards issued by NBS were calibrated on a Hardy (General Electric) spectrophotometer for 6 degree incidence and hemispherical collection of reflected light, for a 10 nanometer bandpass. Some standards were calibrated on a Beckman spectrophotometer for 0/45 degree reflectance which used a ring-collector type reflectance attachment.

The standards issued before 1965 were calibrated relative to freshly prepared smoked magnesium oxide. After 1965 they were issued with the calibration data relative to a perfect diffuser ("absolute" reflectance scale). The absolute reflectance scale established in 1965 [2] was given further refinement in 1977 with the completion of the reference spectrophotometer for diffuse reflectance [3]. The master Vitrolite calibration scale is presently maintained through periodic recalibration by absolute reflectance techniques, using the double-sphere or Van den Akker method [4]. The master Vitrolite working standard is Standard V6-D1. This standard is calibrated on the NBS reference spectrophotometer for diffuse reflectance by the absolute reflectance methods. The uncertainty in its calibration is believed to be no more than ±0.0015.

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

2. Calibration of the SRM Vitrolites

The SRM (Standard Reference Material) Vitrolite reflectance standards have been calibrated on a Hardy spectrophotometer using the Vitrolite master to transfer the NBS absolute reflectance scale to these working standards. The uncertainty in the calibration of these working standards is larger than the uncertainty assigned to the master Vitrolite due to additional errors associated with the performance of the transfer spectrophotometer and its data recording system. Because of these factors, the uncertainty assigned to the working standards is ±0.010 (one percent).

Master V6-D1 is too valuable to be used on an every-day basis; therefore the absolute scale was transferred to Standard V1-G3 which is used for day-to-day calibration work. The transfer of the absolute reflectance scale from Master V6-D1 to V1-G3 was accomplished by measuring V6-D1 on the transfer instrument (Hardy spectrophotometer). The ratio of the absolute value of V6-D1 to its measured value is then applied to the measured value of Standard V1-G3. By this technique the absolute reflectance of Standard V1-G3 is established on a scale directly traceable to the NBS Reference Diffuse Reflectance Instrument through the use of Master V6-D1 as a transfer standard.

The photometric scale of the Hardy spectrophotometer has some nonlinearity and all measurements are adjusted to correct for this error. Corrections are also made for slight errors in the wavelength scale.

The calibration of Standard V1-G3 with the specular component excluded from the measurement could not be made by direct comparison to Master Vitrolite V6-D1 because the V6-D1 standard is only calibrated for the condition of illumination and viewing in which the specular component is included in the measurement. The calibration of Standard V1-G3 for the excluded specular measurement was accomplished by first measuring the standard with the specular component included and then inserting black cavities into the sphere to exclude the specular component. In this way the calibration of Standard V1-G3 for the excluded specular mode was accomplished by measuring its value relative to the included specular mode. The specular component is approximately four percent of the total reflectance.

The recalibration of Standard V1-G3 by transferring the absolute reflectance scale from Master V6-D1 resulted in a new set of reflectance values for Standard V1-G3. The new calibration values for Standard V1-G3 agreed with the previous (1974) absolute reflectance calibration to within ±0.005 (one-half percent) for both the included and excluded specular component measurements.

The calibration of 100 samples for certification as SRM's was accomplished by direct comparison to Standard V1-G3 at 10-nanometer intervals over the wavelength range 400 to 750 nanometers. Each sample was measured twice with the specular component included and twice with the specular component excluded. The two measurements were made for two orientations, rotating the sample 90 degrees in the plane of the measured surface between measurements. The two measurements are then averaged.

All of the reflectance measurements were made with the samples backed by black felt. The reasons for using the black backing are related to the Vitrolite translucency and will be discussed in more detail in a later section dealing with this subject. (See a copy of the certificate in Appendix I.)

3. Using the Vitrolite Reflectance Standard

The proper understanding of certain geometrical conditions affecting the photometric accuracy of reflectance measurements in which Vitrolite is used as a working standard can help the user to avoid errors that may be introduced into his measurements. These errors may result from a misunderstanding of the measuring geometry for which the standard was calibrated or from a disregard for the restrictions imposed on the Vitrolite's use due to the inherent translucency of this glass.

The Vitrolite reflectance standard has a fire polished surface which gives it durability and stability. This polished surface reflects approximately four percent of the incident light as specular reflection. The total 6-degree hemispherical reflectance of Vitrolite includes this specular component of reflected light. If the Vitrolite is calibrated for the condition of illumination and viewing in which the specular component is included, then this calibration data should not be used if the Vitrolite is used in a geometry of illumination and viewing where the specular component is excluded from the measurement. An example of the latter condition would be a measurement of reflectance for a geometry in which the Vitrolite is illuminated at an angle of incidence of 45 degrees from the normal and viewed by the detector at the normal to the Vitrolite surface, or the reverse condition where the illumination is normal to the surface and the detector views the Vitrolite at 45 degrees from the normal. If a reflectance standard is to be used on an instrument using a 0°/45° or 45°/0° geometry, that reflectance standard should be calibrated for these conditions of illumination and viewing.

Some integrating spheres have removable plugs which have been placed in the sphere wall for the purpose of including or excluding the specular component of the reflected light from the sample. The plug is usually filled with a white material similar to the coating of the integrating sphere. This white plug is used when making reflectance measurements with the specular component included. It is replaced with a black plug or black cavity for making measurements with the specular component excluded from the total reflected signal.

There are some important points to consider when using the black cavity for the excluded specular mode of operation. The efficiency of the integrating sphere changes when the white plug is replaced with a black cavity. This in itself would not be a problem. However, the change usually affects the sample beam more than it does the reference beam and results in a slight change in the balance between the two beams. Because of this effect it is better to use a reflectance standard which has been calibrated for the same geometry, particularly when making measurements with the specular component excluded. Because a Vitrolite calibration for the excluded specular mode of measurement is so dependent on the sphere geometry, it is difficult to use such a calibrated standard to obtain a proper calibration unless the solid angle subtended by the specular light trap at the illuminated area of the Vitrolite is the same for the integrating sphere on which it is used as for the original calibration geometry. The assigned calibration data for the excluded mode of measurement should only be used when the geometry of the integrating sphere is similar to that of the Hardy spectrophotometer on which the standards were calibrated. The beam is incident on the Vitrolite at 6 degrees from the normal and the light trap subtends a solid angle of 15 degrees at the center of the illuminated area. It is recommended that a similar light trap be placed in the specular position for the reference beam of the integrating sphere when making measurements with the specular component of the Vitrolite excluded.

This is done to maintain the same balance between sample and reference beams. The effects of the use of one or two light traps in an integrating sphere of the type used in a Hardy spectrophotometer is outlined in figure 1. Figure 1 is included in this discussion in order to illustrate what has come to be known over the years as the "one black port versus the two black port" argument or problem.

In figure 1 there are six cross-sectional views of an integrating sphere of the type used in a Hardy spectrophotometer. Each of these cross sections depicts the path of the sample and reference beam, the sample and reference ports, and the removable plugs for excluding the specular component of the reflected beams. The six geometries illustrated in figure 1 show the effect of using one black cavity or two black cavities when making measurements of the reflectance of an opal glass. This white opal glass has been finely ground to provide a diffusely reflecting surface. In figure 1-A two magnesium oxide targets are used to balance the sample and reference at 100 percent. Note that these measurements date back to an earlier time when smoked MgO was used to coat the measuring integrating sphere and the reference target of the reflectometer. These two targets have the same reflectance and give a reflectance value of 1.000 when the photometric scale is adjusted to record this value. They are shown to be the same by measuring them, interchanging them, and repeating the measurement. In figure 1-B the opal glass has been placed in the sample beam. Its reflectance relative to the magnesium oxide reference target is 0.986 with the specular component included in the total reflected signal. Placing a black cavity light trap in the sphere wall (figure 1-C) at the angle of specular reflection for the opal glass results in a reflectance value of 0.980. This is 0.006 less than the reflectance of the opal glass with the specular component included and might lead to the conclusion that the opal glass has a specular component of 0.006. However, the same difference can be obtained with a magnesium oxide target as can be seen in figure 1-D where the magnesium oxide target is 0.994 or 0.006 less than the 1.000 value found for the geometry illustrated in figure 1-A. Placing a second black cavity in the sphere wall at the angle of specular reflection for the reference beam as shown in figure 1-E results in a reflectance value of 1.000 for the magnesium oxide sample. The reflectance value for the opal glass is 0.986 when measured with two black cavities as shown in figure 1-F. This is the same value as was found for the opal glass with the specular component included. The difference in the values of reflectance obtained with one black cavity versus two black cavities for both the magnesium oxide and the opal glass is 0.006. The following results are obtained for the reflectance of Vitrolite relative to a magnesium oxide reference beam target at 550 nanometers.

(a) Vitrolite, included (two white plugs) = 0.929

(b) Vitrolite, excluded (one black cavity) = 0.888

(c) Vitrolite, excluded (two black cavities) = 0.894

Again, the difference between the values of reflectance of Vitrolite with one black cavity versus two black cavities is 0.006. This difference of 0.006 occurs for measurements of reflectance of the magnesium oxide, opal glass, and for the Vitrolite. This is a common difference that appears related to the geometry of the sphere rather than a property of the materials being measured. If the assumption is made that magnesium oxide is a nearly perfect diffuser, having no specular component, then the results obtained with one black cavity as shown for the sphere configuration illustrated in figure 1-D must be incorrect because the results of

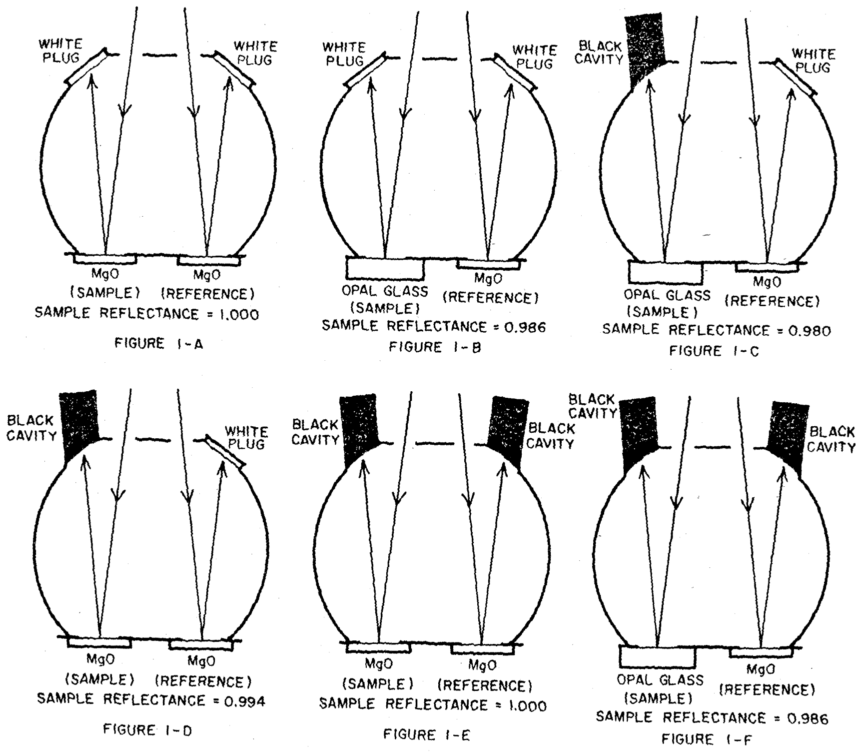

FIGURE 1-A

FIGURE 1-B

FIGURE 1-C

FIGURE 1-D

FIGURE 1-E

FIGURE 1-F

Figure 1. Six geometries illustrating the various possible combinations of targets and ports commonly used in an integrating sphere of the Hardy spectrophotometer to measure the reflectance of a sample with the specular component either included or excluded.

this measurement are 0.006 less than those obtained with a white plug (figure 1-A). Placing a second black cavity in the sphere does not reduce the reflectance of the magnesium oxide by an additional 0.006 but restores the value to 1.000, which is the same as was originally set for the configuration illustrated in figure 1-A. When one side of the sphere is geometrically different from the other, as is the case when a black cavity is placed in only one side of the sphere, the detector does not sense the sample and reference beams as being equal even though the targets for these two beams are equal in reflectance. The important point to remember is that when making reflectance measurements with the specular component excluded, the 100 percent line values should be set with two black cavities, and the Vitrolite standard and the samples should also be measured with two black cavities because the standard values for the reflectance of the Vitrolite for the specular excluded mode of operation were derived for this sphere configuration. The Vitrolite calibration for excluded specular component may not be valid for use on integrating spheres in which the specular component is excluded by a geometry differing from the one illustrated in figure 1-F.

The preceding logic clearly makes a good argument in favor of using the two black ports to make measurements of spectral reflectance with the specular component of sample reflectance excluded from the measurement. However, further consideration of the information illustrated in figure 1 will show that it is possible to obtain the correct reflectance in the excluded mode by using only one black cavity on the sample beam side of the integrating sphere if the substitutional method is used. If the reflectance value shown in figure 1-C is divided by the reflectance value shown in figure 1-D, one obtains the following:

Reflectance of opal glass = .980/.994 = .986
(using one black cavity).

The calculated reflectance is the same as the measured reflectance obtained with two black cavities as shown in figure 1-F. The point to remember is that the correct reflectance for the excluded specular component mode of measurement can be obtained using one black port or two black ports if the correct procedures are followed. In summary the correct and incorrect procedures are:

Excluded Specular Component (using one black port)

The correct procedure for using one black port on the sample side is to set the 100 percent value to read 1.000 with the black cavity in place on the sample side, then substitute the sample for the white diffuser used to set the 100 percent value.

Excluded Specular Component (using two black ports)

The correct procedure for using two black ports is to set the 100 percent value as shown in figure 1-E, then substitute the sample for the white diffuser as shown in figure 1-F.

Incorrect Method (using one black port)

The incorrect procedure for measuring in the excluded mode is to set the 100 percent value as shown in figure 1-A and then make a measurement as shown in figure 1-C.

It is important to remember that double-beam instruments such as the Hardy type integrating sphere illustrated in figure 1 are ratio-recording spectrophotometers and the values of reflectance obtained with such instruments are relative and not absolute. That is they are relative to the reflectance of whatever white diffuser is used to set the 100 percent value of the photometric scale. The Vitrolite reflectance standard is assigned absolute reflectance values so that the user can adjust his relative measurements to a common absolute scale, regardless of the reflectance of white diffusers used to balance the two beams of the spectrophotometer. The two white diffusers used to set the 100 percent value can be any reasonably white, diffuse reflecting surfaces. They should be of approximately equal reflectance. The Vitrolite reflectance standard is assigned absolute reflectance values that can be used to adjust the reflectance values of any diffusely reflecting sample to the same absolute reflectance scale. The ratio of the absolute reflectance of the Vitrolite standard to the measured reflectance of the standard, multiplied by the measured reflectance of a test sample will adjust the reflectance values of the test sample to the absolute reflectance scale of the Vitrolite standard. This adjustment to the absolute scale will not correct for errors such as incorrect zero calibration or nonlinearity of the photometric scale.

4. Vitrolite Translucency

Vitrolite is an opal glass in which the incident light is scattered internally by body scattering rather than by surface scattering. Body scattering provides a more uniform scattering or diffusion than surface scattering. However, the translucency associated with Vitrolite may introduce some problems when using it as a reflectance standard. The principal problem with the Vitrolite is the loss of a portion of the incident light beam due to diffusion of the light out the back, the edges, or behind the integrating sphere sample port edge. Improper use of the Vitrolite reflectance standard with respect to these translucency effects will result in errors in the photometric accuracy of the reflectance measurements.

A detailed analysis of Vitrolite translucency was carried out at NBS in order to determine the geometrical conditions and parameters within which Vitrolite can be used as a reflectance standard without encountering errors due to its translucency. This study was performed through the use of the NBS Reference hazemeter [5]. This instrument is well suited for experiments involving scattering and translucency. It has a collimated light beam having a color temperature of approximately 6800 K (CIE Source C). The beam diameter can be varied. The integrating sphere can be used for transmission or reflection. The sample port diameter is also variable. The detector is equipped with a visual response filter giving the hazemeter a peak response near 550 nanometers.

The Vitrolite used in the translucency study was prepared by grinding five samples of the original stock to thicknesses of 2, 4, 6, 8, and 10 mm. The samples were ground to these thicknesses by removing glass from the back surface, leaving the fire-polished front surface in its original condition. These five samples were 100 × 100 mm in area.

Figure 2 shows the diffuse transmission density (negative logarithm of transmittance, - log T) for thicknesses varying from 2 mm to 20 mm. The data curve in figure 2 clearly shows that Vitrolite transmits approximately 10 percent (density 1.0) for a sample thickness of about 5 mm, 3 percent (density 1.5) for a thickness of about 10 mm, and 1 percent (density 2.0) for a sample of 18 mm thickness.

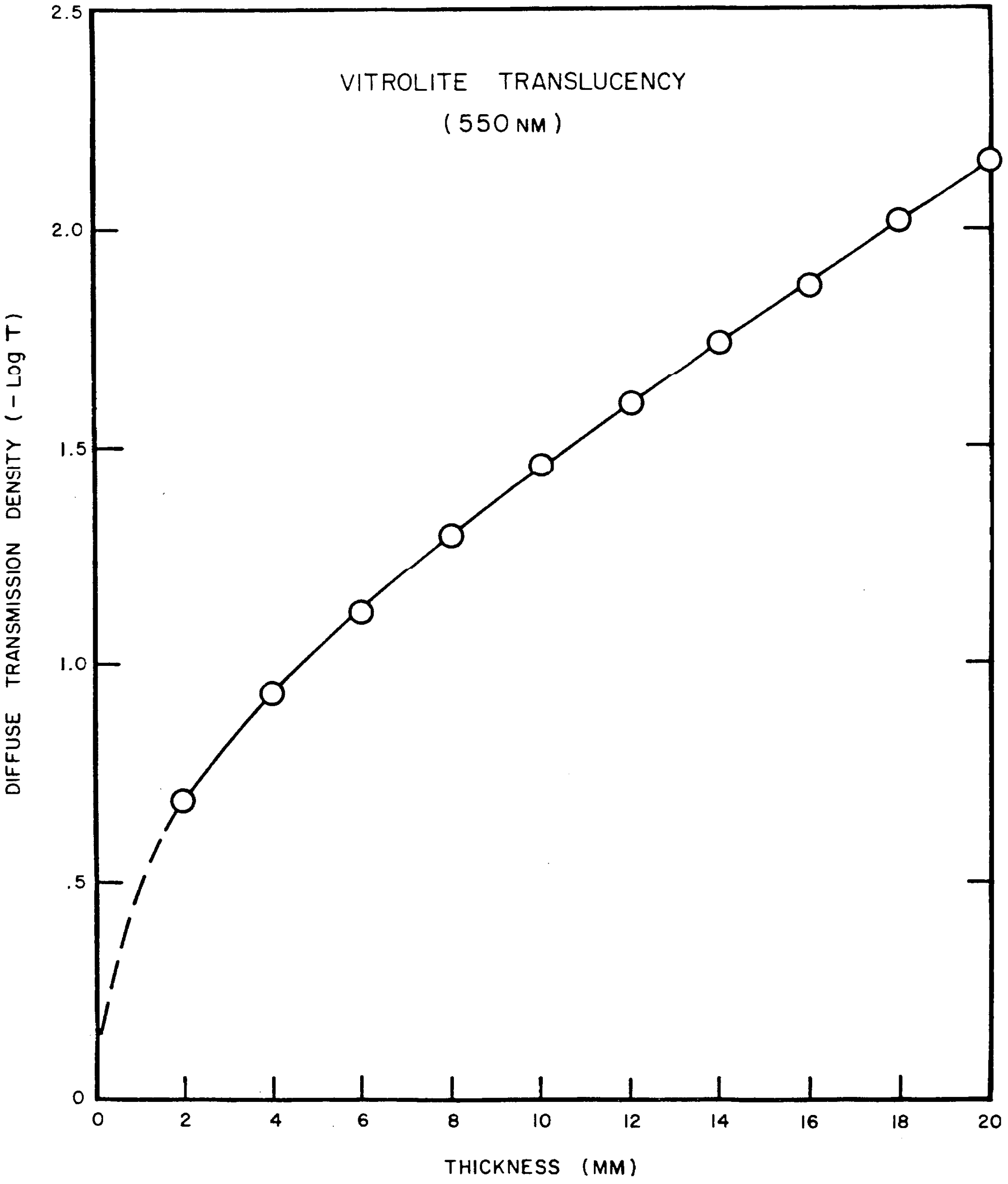

Figure 2. The diffuse transmittance (plotted on an optical density scale) to illustrate the linearity of diffuse transmittance as a function of the Vitrolite thickness. The data were obtained by means of the NBS hazemeter. This instrument has a visual response detector system with a peak response near 550 nanometers.

Since the thickest sample was 10 mm, it was necessary to combine two or three samples in order to obtain the diffuse transmission density of the thicknesses between 10 mm and 20 mm. For these measurements the Vitrolite samples were optically coupled by a thin film of water to reduce interface reflections. The combinations used for these measurements were: 10 + 2 = 12 mm, 10 + 4 = 14 mm, 10 + 6 = 16 mm, 10 + 8 = 18 mm, and 10 + 8 + 2 = 20 mm thickness.

Figure 3 shows the diffuse reflectance with the different Vitrolite thicknesses backed by a white backing of approximately 99 percent reflectance and again with a black backing of less than 1 percent reflectance. In this case the light beam was incident on the Vitrolite normal to the surface so that the specular component was reflected back through the entrance port of the hazemeter integrating sphere and excluded from the measurement.

The data curves in figure 3 show that the Vitrolite would have to be nearly 20 mm in thickness for its reflectance to be independent of the reflectance of the backing material. Since the Vitrolite stock is approximately 10 mm in thickness, it can be seen from the data shown in figure 3 that when using it as a reflectance standard, the backing must be specified. At 10 mm thickness the Vitrolite reflectance can vary by as much as 1 percent depending on the reflectance of the backing. For this reason all Vitrolite standards are calibrated with a black backing of less than 1 percent reflectance. A black felt covered plate is provided with each SRM Vitrolite standard for use as a backing.

The other important factor a user must be aware of when using Vitrolite as a reflectance standard is the problem of translucency effects where the incident light beam diffuses through the Vitrolite and escapes through the edge of the Vitrolite or gets trapped behind the edge of the sample port against which the Vitrolite is mounted. Figures 4, 5, and 6 show how these edge losses due to translucency are related to the Vitrolite thickness, incident light beam diameter, and port diameter. In all three of these figures the Vitrolite reflectance is shown for varying thicknesses and for white and black backings. Figure 4 shows the edge loss effects for a large 100 mm × 100 mm Vitrolite on a 40 mm diameter port. Figure 5 shows the same relationships with the port diameter increased to 60 mm. In figure 6 the Vitrolite diameter was 42 mm and the port diameter was 40 mm. Here the edge losses are greatest as would be expected while in figure 5 where the port diameter was much greater, there is no indication of light loss for any Vitrolite thickness or beam diameter since the largest beam diameter was 38 mm and not large enough to approach the edge of the 60-mm diameter port to a point where losses would occur.

The results of these translucency studies are summarized in figure 7 so that the user can quickly determine whether or not the geometrical conditions under which he is using the Vitrolite reflectance standard will introduce errors in his calibration because of these translucency errors. In figure 7 the percentage of the incident beam striking the Vitrolite standard that is lost from the measurement because of edge losses is plotted as a function of the ratio of the beam diameter to the port diameter. This ratio is only shown for Vitrolite of 10 mm thickness since this is the approximate thickness of these standards. Two curves are shown. The "worst case" for edge losses is shown by the curve labeled "Vitrolite (1.05 × diameter of port)". Here the Vitrolite is almost the same diameter as the port. In this case the beam diameter must be less than 15 percent of the port diameter in order to avoid edge losses. The other curve shows the edge losses for a Vitrolite having a diameter "2.5 × diameter of port". With this size Vitrolite the beam

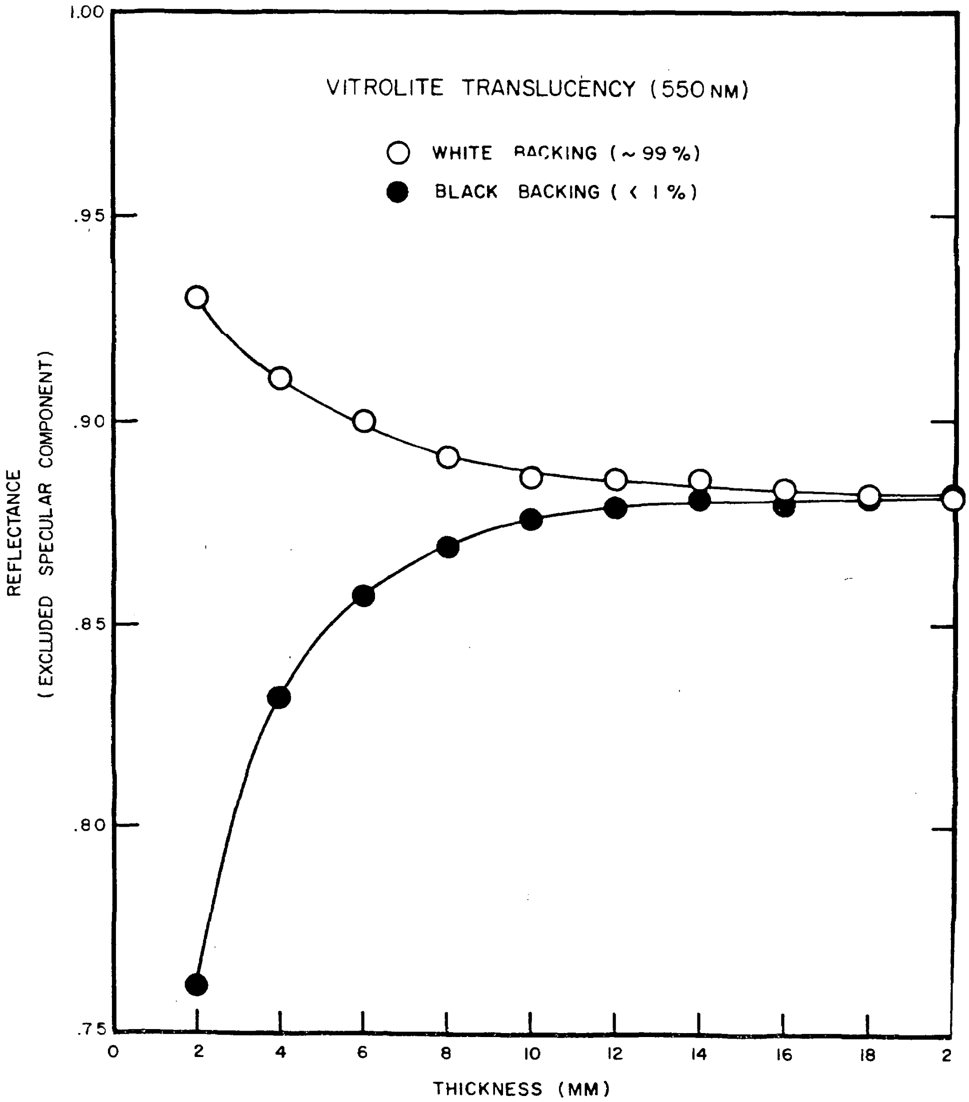

Figure 3. The reflectance of Vitrolite as a function of thickness for Vitrolite backed by a white backing of approximately 99 percent reflectance and for Vitrolite backed by a black backing of less than one percent reflectance. The data were obtained by means of the NBS hazemeter. This instrument has a visual response detector system with a peak response near 550 nanometers.

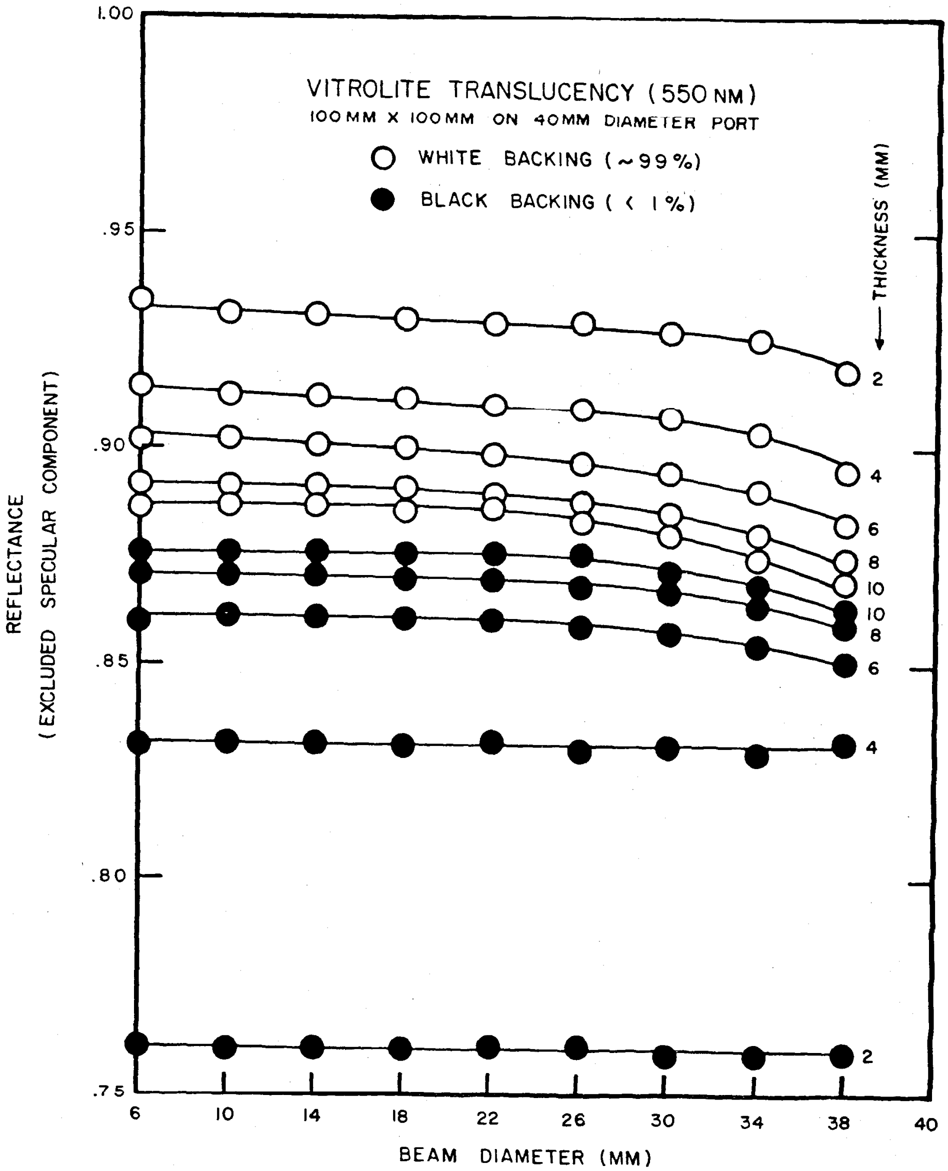

Figure 4. The reflectance of Vitrolite can be influenced by the backing, Vitrolite thickness, size of the Vitrolite, and size of the integrating sphere port on which the Vitrolite is mounted. The data in figure 4 should be compared with the data illustrated in figures 5 and 6 where the port size and Vitrolite size are changed. The data were obtained by means of the NBS hazemeter. This instrument has a visual response detector system with a peak response near 550 nanometers.

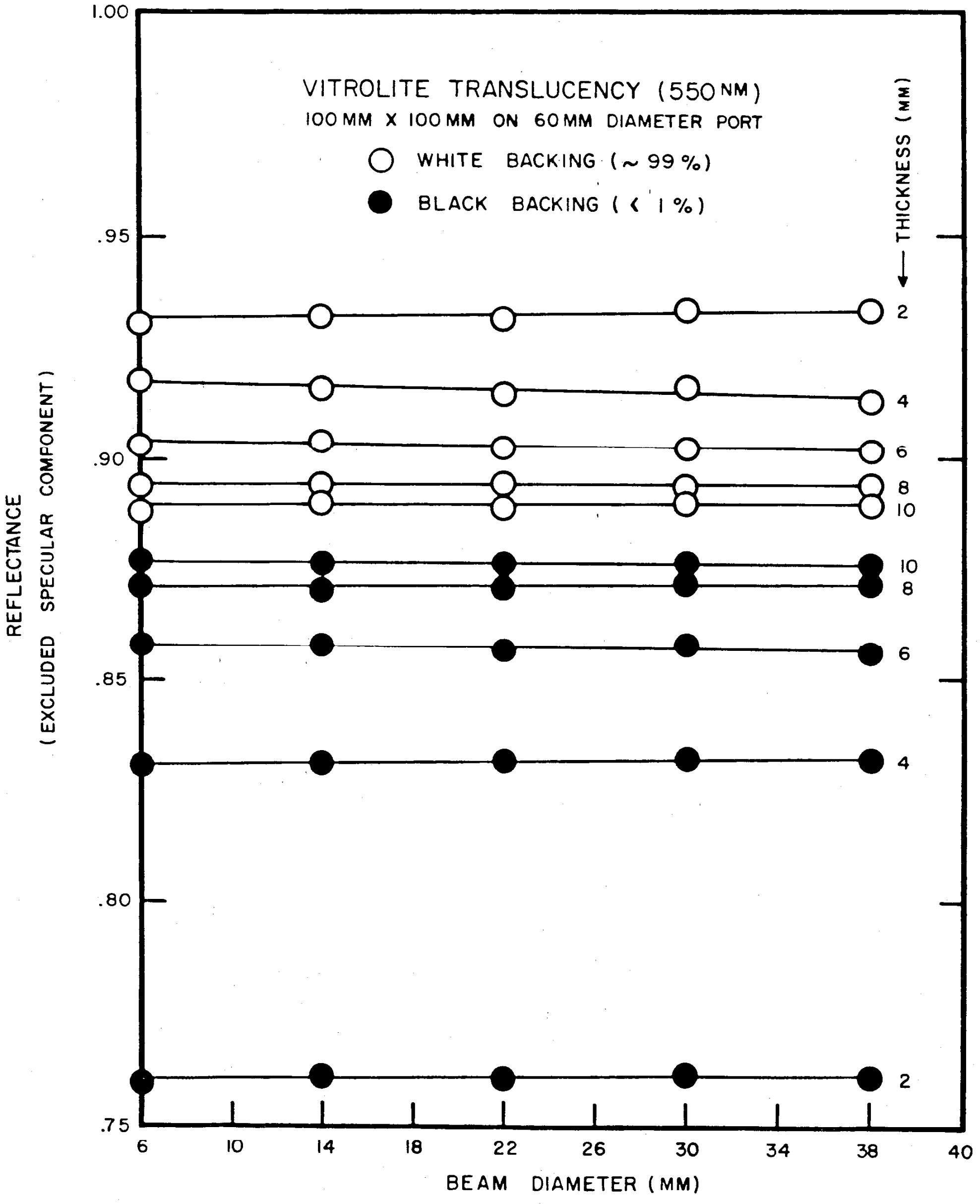

Figure 5. The reflectance of Vitrolite can be influenced by the backing, Vitrolite thickness, size of the Vitrolite, and size of the integrating sphere port on which the Vitrolite is mounted. The data in figure 5 should be compared with the data illustrated in figures 4 and 6 where the port size and Vitrolite size are changed. The data were obtained by means of the NBS hazemeter. This instrument has a visual response detector system with a peak response near 550 nanometers.

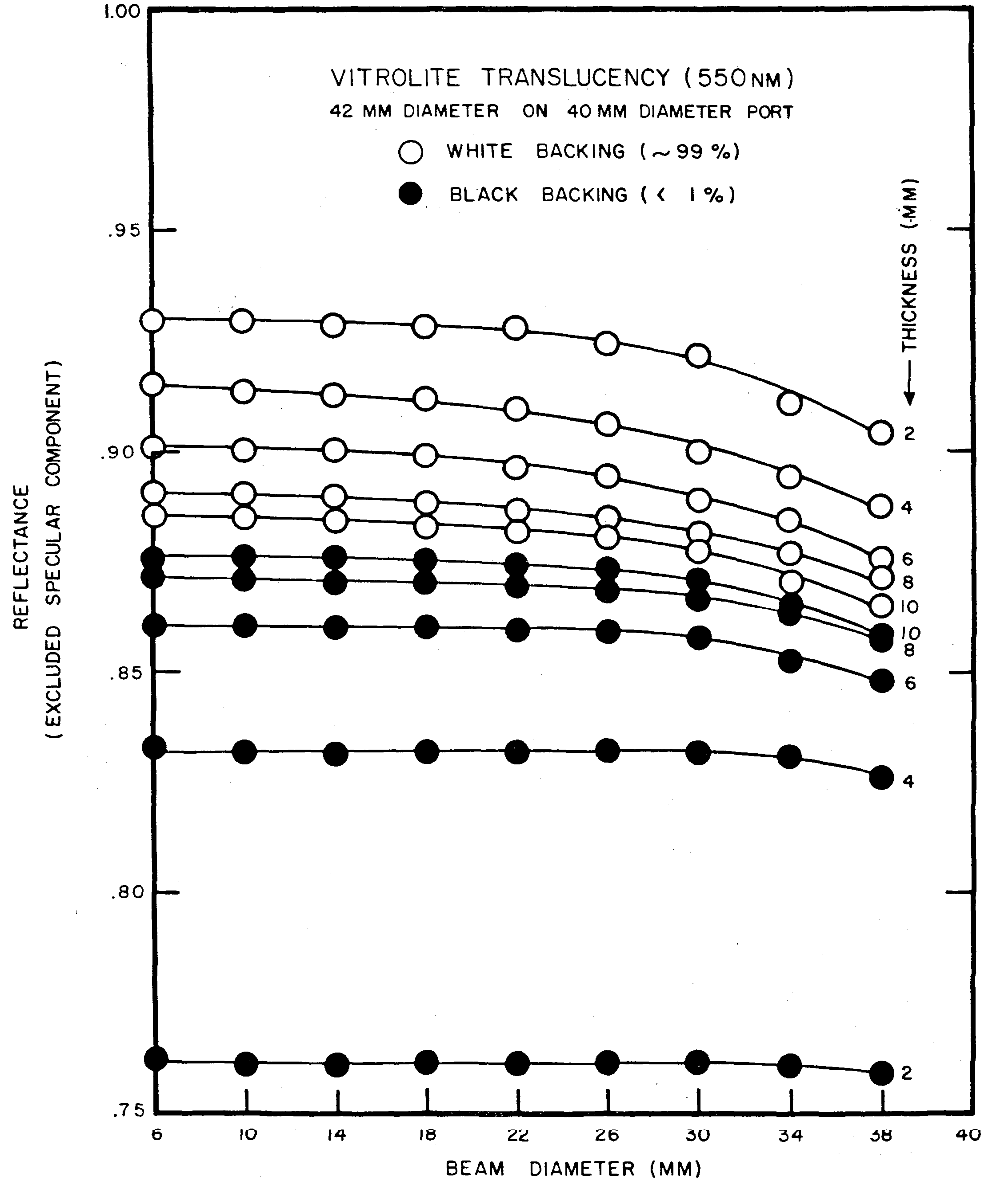

Figure 6. The reflectance of Vitrolite can be influenced by the backing, Vitrolite thickness, size of the Vitrolite, and size of the integrating sphere port on which the Vitrolite is mounted. The data in figure 6 should be compared with the data illustrated in figures 4 and 5 where the port size and Vitrolite size are changed. The data were obtained by means of the NBS hazemeter. This instrument has a visual response detector system with a peak response near 550 nanometers.

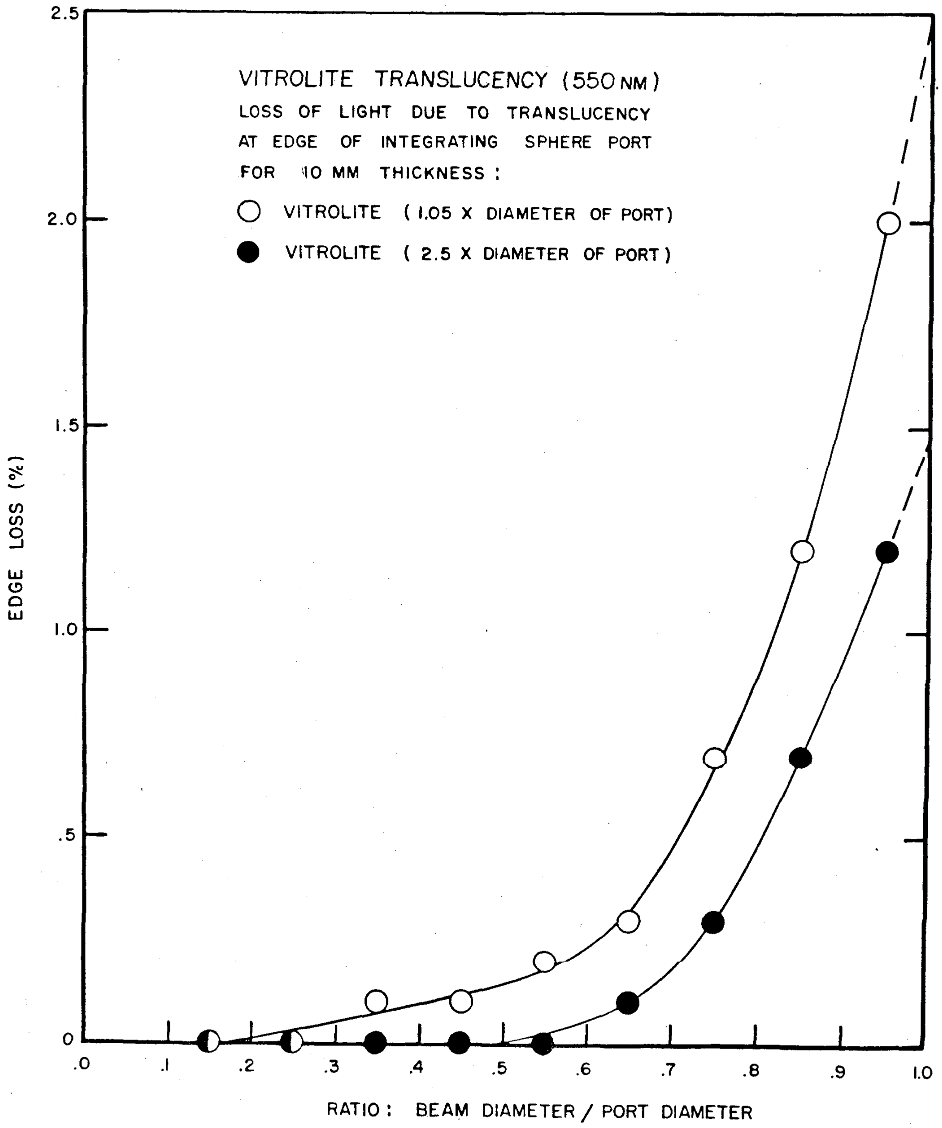

Figure 7. The percentage of incident light beam that is lost out the edge of the Vitrolite near the edge of the integrating sphere post. The data were obtained for a Vitrolite of 10 mm thickness. The light lost from the measurement is due to the Vitrolite translucency. The amount of light lost depends on the dimensions of the Vitrolite and the ratio of the sample beam diameter to the port diameter. The data were obtained by means of the NBS hazemeter. This instrument has a visual response detector system with a peak response near 550 nanometers.

diameter should not be greater than 50 percent of the port diameter in order to avoid edge losses. The data shown in figure 7 should not be used as a correction factor but only as a guideline to point out possible instrumental problems related to translucency.

In summary it is clearly shown in figure 7 that edge loss errors can be greater than 1 percent if the Vitrolite is illuminated with a beam having a diameter nearly the same as the port diameter. Therefore, the user should make certain that the beam diameter is small enough in relation to the port diameter to avoid edge losses. The user should also make certain that the Vitrolite is covered by draping an opaque cloth over it to prevent room light from diffusing in through the Vitrolite edges and into the integrating sphere. It is also important that the Vitrolite be backed by the black felt-covered plate supplied with each standard.

The results of the translucency studies shown in figures 2 through 7 are representative of what a user will encounter in using Vitrolite reflectance standards with integrating spheres having circular ports and sample beams that are collimated and circular. Obviously, there are integrating spheres with rectangular ports or ports that are not circular and reflectometers that do not have collimated circular beams. Where these geometrical conditions exist, it is still a good rule to avoid illuminating the Vitrolite with a beam that is greater in width or height than 50 percent of the port width or height. In reflectometers in which the sphere is illuminated by an uncollimated source and the Vitrolite is diffusely illuminated, then viewed by some limiting aperture such as a monochromator slit, the Vitrolite calibration is still valid as long as the viewed area of the Vitrolite is in a central area of the port, not exceeding 50 percent of the port diameter.

5. Cleaning and Storing Vitrolite Reflectance Standards

Vitrolite can be cleaned with soap and water. Mild liquid soap or plain white hand soap will do. After washing, the standard should be rinsed with warm water and dried with a soft tissue or cotton cloth which is free of grit that might scratch the surface. Never clean with strong detergents or solvents. These may permanently alter the Vitrolite surface through repeated use. The best way to store a Vitrolite reflectance standard is to place it in a desiccator or glass container so that the standard reflecting surface is in contact with air only.

6. References

[1] Vitrolite is a trade name for an opal glass that was manufactured by the Libby Owens Ford Glass Company.

[2] Goebel, David G.; Caldwell, B. Patrick; Hammond, Harry K. III; Use of an auxiliary sphere with a spectrophotometer to obtain absolute reflectance, J. Opt. Soc. Am. 56, 783 (1966).

[3] Venable, William H., Jr.; Hsia, Jack J.; Weidner, Victor R.; Development of an NBS reference spectrophotometer for diffuse transmittance and reflectance, Nat. Bur. Stand. (U.S.) Tech Note 594-11, October 1976. 47 pages.

[4] Venable, William H., Jr.; Hsia, Jack J.; Weidner, Victor R.; Establishing a scale of directional-hemispherical reflectance factor I: The Van den Akker Method, J. Res. Nat. Bur. Stand. (U.S.) 82, 1, p. 29 (July-August 1977).

[5] Weidner, Victor R.; Hsia, Jack J.; NBS hazemeter, its development and testing, Appl. Opt. 18, 1619 (May 15, 1979).

U. S. Department of Commerce
Malcolm Baldrige
Secretary

National Bureau of Standards
Ernest Ambler, Director

Appendix I

National Bureau of Standards

Certificate

Standard Reference Material 2015

White Opal Glass Diffuse Spectral Reflectance

Standard for the Visible Spectrum

V. R. Weidner

This Standard Reference Material (SRM) is intended for use in calibrating the photometric scale of integrating sphere reflectometer-spectrophotometers used in the measurement of spectral 6°/hemispherical reflectance. SRM 2015 is a 5.1-cm x 3.8-cm, fire-polished, white opal glass (vitrolite).

This SRM was measured at 10-nm intervals from 400 to 750 nm. The certified values were determined in the following way. The 6°/hemispherical diffuse reflectance factor of a master plate was measured on the NBS High Accuracy Reference Spectrophotometer for diffuse reflectance, using techniques for determining absolute reflectance values (reflectance relative to a perfect diffuser). This master plate was then used to transfer the absolute reflectance scale to the reflectance SRM through the use of a working plate and a high-precision recording spectrophotometer. The uncertainty in the values of absolute diffuse reflectance assigned to the master plate is 0.15 percent. The total uncertainty of the certified values of absolute diffuse reflectance is ± 1.0 percent at the 95 percent confidence level. the certified values for the "included specular component" are given in Table 1. Uncertified values for the "excluded specular component" are given for information only in Table 2.

The white opal glass can be cleaned with a mild liquid soap and warm water, followed by a rinse in distilled water. The fire-polished surface and the reflectance of the standard are very stable. However, care should be exercised in cleaning and handling to avoid scratching the polished surface. The standard should be stored in a covered glass enclosure when not in use.

This SRM is issued with a black felt covered aluminum plate. This black felt is to be placed against the back of the SRM when measuring its reflectance. The same black backing was used in calibrating the SRM at NBS. This white glass is translucent and may not be suitable as a reflectance standard for some reflectometers.

The calibration of this diffuse spectral reflectance standard was done in the Radiometric Physics Division of the Center for Radiation Research at NBS.

The technical and support aspects involved in the certification and issuance of SRM 2015 was coordinated through the Office of Standard Reference Materials by R.K. Kirby.

Washington, D.C. 20234
May 5, 1982

George A. Uriano, Chief
Office of Standard Reference Materials

THIS IS A SAMPLE

6°/Hemispherical Reflectance Factor (Relative to a Perfect Diffuser)

White Opal Glass Serial No. V6-G2001

Wavelength (nm)	TABLE 1 INCLUDED SPECULAR COMPONENT	TABLE 2 EXCLUDED SPECULAR COMPONENT
400	0.905	0.864
410	.896	.857
420	.892	.852
430	.892	.852
440	.890	.852
450	.898	.860
460	.908	.869
470	.911	.872
480	.911	.872
490	.915	.875
500	.916	.878
510	.919	.880
520	.921	.882
530	.922	.882
540	.922	.884
550	.922	.883
560	.922	.882
570	.920	.882
580	.918	.881
590	.916	.879
600	.914	.877
610	.913	.875
620	.910	.873
630	.908	.870
640	.906	.869
650	.906	.868
660	.905	.867
670	.903	.865
680	.904	.865
690	.902	.864
700	.901	.863
710	.899	.860
720	.897	.858
730	.894	.857
740	.892	.854
750	.890	.853

U. S. Department of Commerce
Malcolm Baldrige
Secretary
National Bureau of Standards
Ernest Ambler, Director

Appendix II

National Bureau of Standards

Certificate

Standard Reference Material 2016

White Opal Glass Diffuse Spectral Reflectance Standard for the Visible Spectrum

V. R. Weidner

This Standard Reference Material (SRM) is intended for use in calibrating the photometric scale of integrating sphere reflectometer-spectrophotometers used in the measurement of spectral 6°/hemispherical reflectance. SRM 2016 is a 10-cm x 10-cm, fire-polished, white opal glass (vitrolite).

This SRM was measured at 10-nm intervals from 400 to 750 nm. The certified values were determined in the following way. The 6°/hemispherical diffuse reflectance factor of a master plate was measured on the NBS High Accuracy Reference Spectrophotometer for diffuse reflectance, using techniques for determining absolute reflectance values (reflectance relative to a perfect diffuser). This master plate was then used to transfer the absolute reflectance scale to the reflectance SRM through the use of a working plate and a high-precision recording spectrophotometer. The uncertainty in the values of absolute diffuse reflectance assigned to the master plate is 0.15 percent. The total uncertainty of the certified values of absolute diffuse reflectance is ± 1.0 percent at the 95 percent confidence level, the certified values for the "included specular component" are given in Table 1. Uncertified values for the "excluded specular component" are given for information only in Table 2.

The white opal glass can be cleaned with a mild liquid soap and warm water, followed by a rinse in distilled water. The fire-polished surface and the reflectance of the standard are very stable. However, care should be exercised in cleaning and handling to avoid scratching the polished surface. The standard should be stored in a covered glass enclosure when not in use.

This SRM is issued with a black felt covered aluminum plate. This black felt is to be placed against the back of the SRM when measuring its reflectance. The same black backing was used in calibrating the SRM at NBS. This white glass is translucent and may not be suitable as a reflectance standard for some reflectometers.

The calibration of this diffuse spectral reflectance standard was done in the Radiometric Physics Division of the Center for Radiation Research at NBS.

The technical and support aspects involved in the certification and issuance of SRM 2016 was coordinated through the Office of Standard Reference Materials by R.K. Kirby.

Washington, D.C. 20234
May 5, 1982

George A. Uriano, Chief
Office of Standard Reference Materials

THIS IS A SAMPLE

6°/Hemispherical Reflectance Factor (Relative to a Perfect Diffuser)

White Opal Glass Serial No. V6-G4001

Wavelength (nm)	TABLE 1 INCLUDED SPECULAR COMPONENT	TABLE 2 EXCLUDED SPECULAR COMPONENT
400	0.906	0.864
410	.896	.858
420	.892	.852
430	.892	.853
440	.890	.852
450	.899	.861
460	.908	.868
470	.911	.872
480	.911	.873
490	.914	.876
500	.916	.879
510	.919	.882
520	.922	.882
530	.923	.884
540	.922	.884
550	.922	.883
560	.922	.883
570	.921	.883
580	.918	.881
590	.916	.879
600	.915	.877
610	.913	.875
620	.910	.873
630	.907	.870
640	.905	.869
650	.905	.868
660	.904	.867
670	.903	.866
680	.902	.865
690	.901	.864
700	.901	.863
710	.898	.862
720	.896	.859
730	.894	.857
740	.892	.854
750	.890	.852