National Institute of Standards & Technology

Certificate

Standard Reference Material® 2017

Multi-Angle White Reflectance Standard

Serial No.:

This Standard Reference Material (SRM) is intended for use in calibrating the reflectance factor scale of multi-angle reflectance instruments for an illumination angle of 45° and aspecular angles of 15°, 25°, 45°, 75°, and 110° at visible wavelengths. SRM 2017 is a polished white Russian opal glass with a diameter of 44 mm, mounted in a Delrin[1] holder with a diameter of 57 mm and a thickness of 13 mm. A mark in the holder indicates the direction of illumination. The serial number is located on the back of the holder.

Certified Values of Reflectance Factor: This SRM was individually calibrated using the NIST High Accuracy Reference Reflectometer [1,2], which determines bi-directional spectral reflectance with an absolute technique. Figure 1 shows typical reflectance factors as a function of wavelength for the reported aspecular geometries. The certified reflectance factor is given in Table 1 for wavelengths from 360 nm to 780 nm at an increment of 10 nm. This reflectance factor is valid for unpolarized light at an illumination angle of 45º from the sample normal and aspecular angles of 15°, 25°, 45°, 75°, and 110°, as shown in Figure 2, over the central 20 mm diameter of the sample. The uncertainty contributions and expanded uncertainty for the certified reflectance factors are given in Table 2.

Expiration of Certification: The certification of this SRM is deemed to be valid, within the uncertainties specified, for a period of **five years** from the date of certification specified in Table 1, provided the sample has been handled in accordance with the handling instructions given in this certificate. This SRM may be recertified if the sample surface has not been altered, contaminated, or damaged; however, acceptance for recertification is contingent upon inspection by NIST. For acceptance inspection and recertification information, contact M.E. Nadal of the NIST Optical Technology Division by phone (301) 975-4632; fax (301) 869-5700; or email maria.nadal@nist.gov.

Handling Instructions: When not in use, the sample should be properly stored in its original container. Improper handling will adversely affect the condition of the front surface. Lint-free gloves (nylon or latex) should be used when handling the sample to prevent fingerprints on the surface. Gently use a clean air bulb to remove dust from the front surface. The polished surface of the sample is very stable. However, care should be exercised while cleaning and handling the sample to avoid scratching the polished surface.

The overall direction and coordination leading to certification was provided by G.T. Fraser of the NIST Optical Technology Division. The initial research, development, and technical measurements leading to certification of this SRM were performed in the NIST Optical Technology Division by M.E. Nadal and E.A. Early.

Statistical consultation was provided by A.I. Aviles of the NIST Statistical Engineering Division.

The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the NIST Standard Reference Materials Group by J.W.L. Thomas.

Albert C. Parr, Chief
Optical Technology Division

Gaithersburg, MD 20899
Certificate Issue Date: 3 June 2002

John Rumble, Jr., Chief
Measurement Services Division

[11] Certain commercial equipment, instrumentation, or materials are identified in this certificate to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Source of Material: The samples were produced by the Hemmendinger Color Laboratory, Princeton, NJ.

Determination of Reflectance Factor: The bi-directional spectral reflectance measurements were made using the NIST High Accuracy Reference Reflectometer [1,2]. The sample was placed in a mount on the sample goniometer so that its front surface was on the axis of rotation. The collimated illumination beam, with less than 1º divergence, a 14.5 nm spectral bandwidth, and a diameter of 14 mm was centered on the front of the sample. The orientation of the mount was adjusted so that, at a goniometer angle of 0º, the illumination beam was retroreflected. This aligned the normal of the sample parallel to the illumination axis. The geometry is denoted by θ_i/θ_v with respect to the normal of the sample so that, for example, the specular condition $\theta_i = 45°$, $\theta_v = -45°$ is represented by 45°/–45°. The aspecular angle is the viewing angle measured from the specular angle toward the sample normal. Radiant flux was collected and measured using a receiver mounted on an arm of the goniometer. The distance from the center of the illuminated area to the center of the limiting aperture of the collector optics was 670.7 mm. The diameter of the limiting aperture was 31.85 mm. The sources of radiant flux into the monochromator were a xenon arc lamp for wavelengths less than 390 nm and a quartz-tungsten-halogen incandescent lamp for longer wavelengths. The optical detector was a silicon photodiode. During the measurements, the ambient temperature was 20 ºC ± 3 ºC and the relative humidity was 40 % ± 10 %.

The bi-directional spectral reflectance was measured at wavelengths from 360 nm to 780 nm at a 10 nm increment for polarizations of the illumination beam both parallel and perpendicular to the plane of illumination, an illumination angle of 45°, and aspecular angles of 15°, 25°, 45°, 75°, and 110°. As shown in Figure 2, the sample was positioned so that the projection of the illumination axis onto the surface was aligned with the mark on the Delrin holder. For each wavelength and polarization, the following measurement sequence was followed. With the sample translated out of the illumination beam, a signal proportional to the incident radiant flux was measured by the receiver, termed the incident signal. The reflected radiant flux was measured by centering the sample in the illumination beam and rotating it with the goniometer to obtain a 45º angle of illumination. The receiver was rotated so that the viewing angle was in the desired aspecular direction, and a signal proportional to the reflected radiant flux was measured, termed the reflected signal. The sequence was completed by again measuring the incident signal. Also, after each signal reading, a shutter was closed on the monochromator and a dark signal was measured.

For each wavelength and polarization, the reflectance factor was calculated by subtracting the dark signals from the incident and reflected signals to yield net signals, dividing the net reflected signal by the average of the net incident signals and the projected solid angle of the limiting aperture, and multiplying by the constant π. The reflectance factor for unpolarized incident light was calculated by averaging the reflectance factors of both polarizations.

Discussion of Uncertainties: Uncertainties were calculated according to the procedures outlined in Reference [3]. Type A uncertainty components due to random effects include source stability and detector noise. The uncertainty contribution caused by these effects was evaluated from the standard deviation of repeat measurements (three scans with ten measurements each) of each sample.

Type B uncertainty components due to systematic effects include those that depend on the scattering properties of the sample (wavelength, uniformity, illumination, and viewing angle) and those that are independent of the sample (solid angle and viewing angle). The uncertainty contribution for the solid angle includes the standard uncertainty in the distance from the illuminated area to the center of the limiting aperture of the collector optics and the standard uncertainty in the diameter of the limiting aperture. The standard uncertainties in distance, diameter, wavelength, and angles are given in Reference [2]. The uncertainty contribution for wavelength was evaluated from the derivative of the reflectance factor. The uncertainty contributions for illumination and viewing angles were evaluated from reflectance factors measured at angles differing from the nominal angles by 0.1º. The uncertainty contribution for uniformity was evaluated from reflectance factors measured at 5 mm displacements, both horizontal and vertical, from the center of the sample. All uncertainty components were assumed to have normal probability distributions.

The sources of uncertainty and uncertainty contributions are given in Table 2, categorized by effect and dependence on sample. The expanded uncertainty in reflectance factor is obtained from the root-sum-square of the uncertainty contributions multiplied by a coverage factor $k = 2$.

REFERENCES

[1] Proctor, J.E.; Barnes, P.Y.; *NIST High Accuracy Reference Reflectometer-Spectrophotometer*; J. Res. Natl. Inst. Stand. Technol. **101**, p. 619 (1996).

[2] Barnes, P.Y.; Early, E.A.; Parr, A.C.; *NIST Measurement Services: Spectral Reflectance*; NIST Special Publication 250-48, U.S. Government Printing Office, Washington, DC (1998).

[3] *Guide to the Expression of Uncertainty in Measurement*, ISBN 72-67-10188-9, lst Ed., ISO, Geneva, Switzerland, 1993; see also Taylor, B.N.; Kuyatt, C.E.; *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*; NIST Technical Note 1297, U.S. Government Printing Office, Washington, DC; 1994; available at http://physics.nist.gov/Pubs.

Users of this SRM should ensure that the certificate in their possession is current. This can be accomplished by contacting SRM at: telephone (301) 975-6776; fax (301) 926-4751; e-mail srminfo@nist.gov; or via the internet http://www.nist.gov/srm.

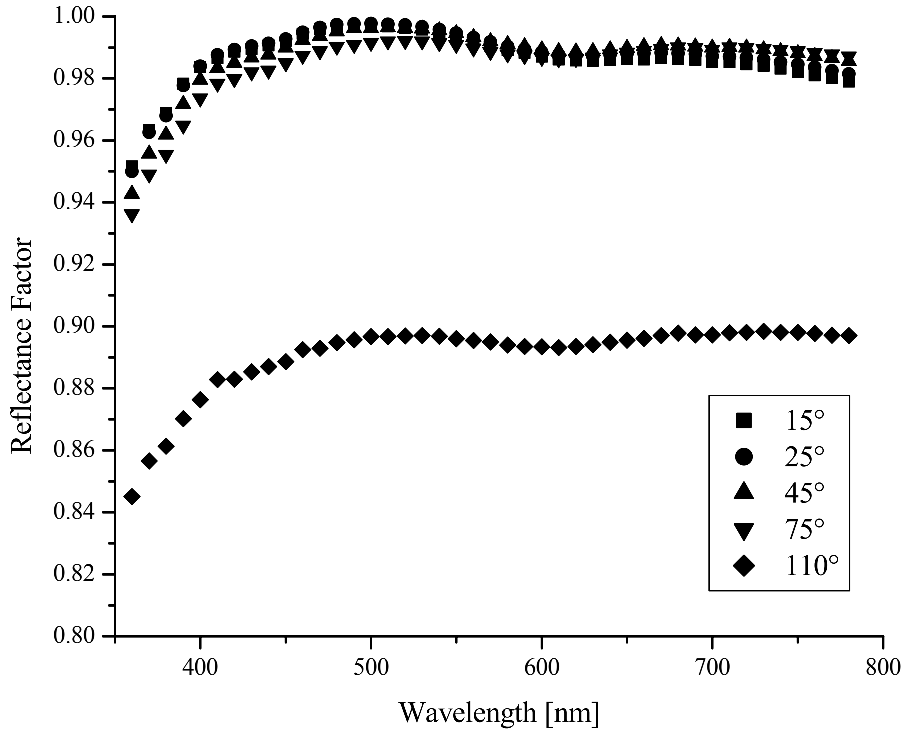

Figure 1. Reflectance factor of SRM 2017 as a function of wavelength for an illumination angle of 45° and aspecular angles of 15°, 25°, 45°, 75°, and 110° at visible wavelengths.

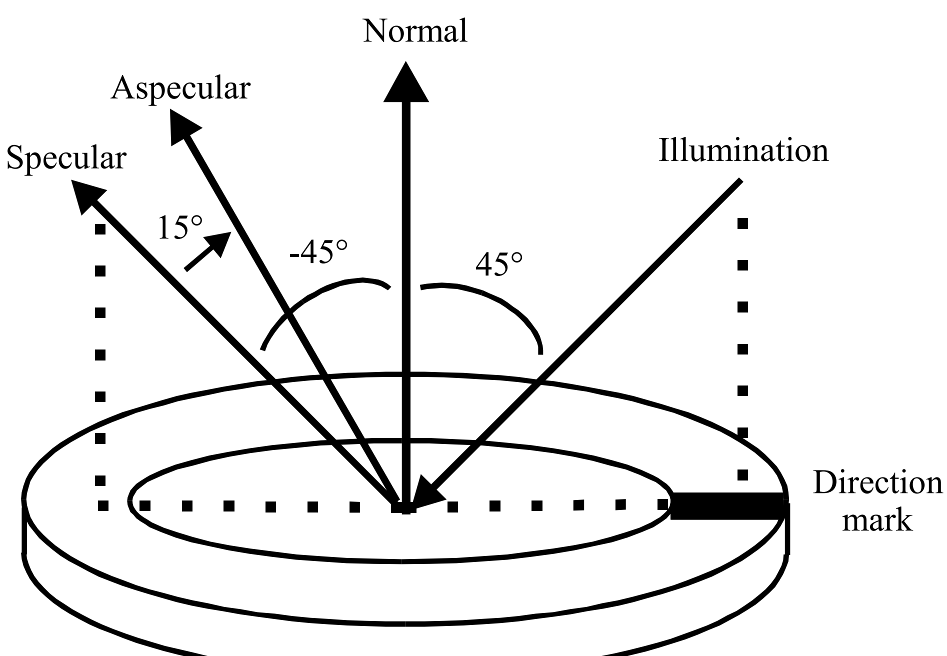

Figure 2. Schematic of sample orientation and angles. The illuminator axis is 45° from the sample normal, and its projection onto the surface is aligned with the mark in the Delrin holder. The aspecular angle is measured from the normal in the illuminator plane.

Table 1. Reflectance factor as a function of wavelength of SRM 2017

Serial No: 2017-02-2 Calibration Date: September 8, 2004

	Aspecular Angle [deg]				
	15	25	45	75	110
Wavelength [nm]	Reflectance Factor				
360	0.944	0.939	0.936	0.927	0.843
370	0.956	0.951	0.947	0.939	0.852
380	0.962	0.957	0.954	0.945	0.857
390	0.972	0.968	0.965	0.955	0.865
400	0.979	0.974	0.969	0.960	0.871
410	0.982	0.979	0.973	0.963	0.873
420	0.984	0.980	0.977	0.966	0.876
430	0.985	0.981	0.977	0.968	0.877
440	0.986	0.982	0.979	0.968	0.877
450	0.988	0.984	0.981	0.970	0.879
460	0.991	0.988	0.983	0.974	0.882
470	0.993	0.989	0.985	0.975	0.885
480	0.994	0.991	0.986	0.977	0.885
490	0.995	0.991	0.987	0.978	0.886
500	0.995	0.992	0.987	0.978	0.887
510	0.995	0.992	0.988	0.979	0.887
520	0.995	0.992	0.988	0.979	0.887
530	0.994	0.992	0.987	0.979	0.888
540	0.994	0.991	0.987	0.978	0.888
550	0.993	0.991	0.986	0.977	0.887
560	0.992	0.990	0.986	0.976	0.885
570	0.991	0.989	0.984	0.975	0.885
580	0.990	0.988	0.983	0.975	0.885
590	0.989	0.987	0.983	0.974	0.884
600	0.988	0.986	0.982	0.974	0.884
610	0.988	0.986	0.982	0.974	0.884
620	0.987	0.986	0.982	0.973	0.884
630	0.988	0.986	0.982	0.974	0.884
640	0.988	0.986	0.983	0.975	0.885
650	0.989	0.987	0.983	0.975	0.886
660	0.989	0.987	0.984	0.976	0.887
670	0.990	0.988	0.984	0.977	0.887
680	0.990	0.988	0.984	0.977	0.887
690	0.989	0.988	0.984	0.977	0.888
700	0.989	0.988	0.984	0.977	0.888
710	0.988	0.987	0.984	0.977	0.888
720	0.988	0.987	0.984	0.977	0.888
730	0.988	0.986	0.984	0.977	0.888
740	0.988	0.986	0.983	0.977	0.888
750	0.987	0.985	0.983	0.976	0.887
760	0.985	0.984	0.982	0.975	0.887
770	0.984	0.983	0.981	0.975	0.887
780	0.984	0.982	0.980	0.974	0.886

Table 2. Uncertainty Contributions and Expanded Uncertainty (k = 2) of the Reflectance Factor of SRM 2017 at Each Aspecular Angle

Source of Uncertainty	Aspecular Angle (deg)				
	15	25	45	75	110
	Uncertainty Contribution (%)				
Systematic Effects					
Sample-Independent					
Distance	0.15	0.15	0.15	0.15	0.15
Aperture Area	0.1	0.1	0.1	0.1	0.1
Viewing Angle	0.1	0.06	0	0.1	0.37
Wavelength					
360 nm – 390 nm	0.1	0.1	0.1	0.1	0.1
400 nm – 780 nm	0	0	0	0	0
Sample-Dependent					
Uniformity	0.1	0.1	0.1	0.1	0.1
Illumination Anlge	0.1	0.1	0.1	0.1	0.1
Viewing Angle	0	0	0	0	0
Random Effects					
Repeatability	0.2	0.2	0.2	0.2	0.4
Wavelength Range	**Expanded Uncertainty (k = 2) (%)**				
360 nm – 390 nm	0.67	0.65	0.64	0.67	1.20
400 nm – 780 nm	0.64	0.62	0.61	0.64	1.18