S. Department of Commerce
Philip M. Klutznick
Secretary

National Bureau of Standards
Ernest Ambler, Director

National Bureau of Standards Certificate

Standard Reference Materials 2021 and 2022

Black Porcelain Enamel for Directional-Hemispherical Reflectance from 250 to 2500 nm

V. R. Weidner and J. J. Hsia

These Standard Reference Materials (SRM's) are intended for use in calibrating the reflectance scale of integrating sphere reflectometers, such as those used in the evaluation of solar energy materials. SRM 2021 is 5.1 x 5.1 cm in size and SRM 2022 is 2.5 x 2.5 cm in size.

The reflectance of each piece was measured at 375, 550 and 2000 nm with a high-precision instrument to guarantee the homogeneity of these SRM's. The certified values for incidence at 6° from normal were determined in the following way. The reflectance of each of 25 pieces, selected at random, was measured at 10-nm intervals from 250 to 2500 nm with a high-precision reflectometer. The reflectance of five of the 25 pieces was also measured at 25-nm intervals from 250 to 800 nm and at 100-nm intervals from 800 to 2500 nm with the highly accurate NBS Reference Reflectometer. These accurate measurements were used to correct for systematic biases in the high-precision measurements which, after being corrected, provide the mean reflectance at each wavelength for this lot of material.

The mean values for 6° / hemispherical reflectance factor are given in Table 1. Starred values have an uncertainty of 0.015 or less, expressed as the coefficient of variation (the ratio of the standard deviation to the mean). This uncertainty applies to the difference between the value the NBS Reference Instrument would give for a single piece and the value given in this table. The errors for different wavelengths, however, are not independent. The uncertainties for unstarred values in the table cannot be fully assessed because they were obtained in part by interpolation of an additive correction. However, an indication of the maximum uncertainty is provided by the size of this correction, which ranged from 0.005 to 0.014. The research and development of these SRM's was supported by the DOE Solar Thermal Program through the Solar Energy Research Institute.

The overall direction and coordination of the preparation and technical measurements leading to certification were performed under the chairmanship of J.C. Richmond.

The technical and support aspects involved in the certification and issuance of these SRM's were coordinated through the Office of Standard Reference Materials by R.K. Kirby.

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George A. Uriano, Chief
Office of Standard Reference Materials

(over)

Table 1

6° / Hemispherical Reflectance Factor[t] (R)

λ (nm)	R	λ (nm)	R	λ (nm)	R	λ (nm)	R	λ (nm)	R	λ (nm)	R
250	0.059	650	0.063*	1050	0.097	1450	0.094	1850	0.106	2250	0.096
260	(.058)[+]	660	.063	1060	.095	1460	.095	1860	.106	2260	.097
270	(.058)	670	.063	1070	.092	1470	.097	1870	.105	2270	.096
280	.056	680	.064	1080	.090	1480	.098	1880	.105	2280	.096
290	.057	690	.064	1090	.087	1490	.100	1890	.104	2290	.096
300	.057*	700	.065*	1100	.085*	1500	.101*	1900	.104*	2300	.096*
310	.057	710	.065	1110	.083	1510	.102	1910	.104	2310	.096
320	.059	720	.065	1120	.081	1520	.104	1920	.103	2320	.096
330	.059	730	.065	1130	.079	1530	.105	1930	.103	2330	.096
340	.060	740	.065	1140	.077	1540	.106	1940	.102	2340	.096
350	.060*	750	.065*	1150	.076	1550	.107	1950	.102	2350	.096
360	.062	760	.065	1160	.075	1560	.108	1960	.102	2360	.096
370	.063	770	.065	1170	.074	1570	.108	1970	.102	2370	.096
380	.065	780	.065	1180	.073	1580	.109	1980	.101	2380	.096
390	.068	790	.065	1190	.072	1590	.109	1990	.101	2390	.096
400	.070*	800	.065*	1200	.072*	1600	.110*	2000	.101*	2400	.097*
410	.071	810	.065	1210	.072	1610	.110	2010	.101	2410	(.096)
420	.070	820	.066	1220	.072	1620	.111	2020	.100	2420	(.096)
430	.070	830	.067	1230	.072	1630	.111	2030	.100	2430	(.096)
440	.069	840	.067	1240	.072	1640	.111	2040	.100	2440	(.096)
450	.069*	850	.068	1250	.072	1650	.111	2050	.099	2450	(.096)
460	.069	860	.069	1260	.072	1660	.111	2060	.099	2460	(.095)
470	.069	870	.070	1270	.072	1670	.111	2070	.099	2470	(.095)
480	.069	880	.072	1280	.073	1680	.112	2080	.099	2480	(.095)
490	.068	890	.073	1290	.073	1690	.111	2090	.098	2490	(.095)
500	.068*	900	.074*	1300	.074*	1700	.111*	2100	.098*	2500	.095
510	.068	910	.077	1310	.075	1710	.111	2110	.098		
520	.067	920	.079	1320	.075	1720	.111	2120	.098		
530	.067	930	.082	1330	.076	1730	.111	2130	.097		
540	.066	940	.085	1340	.078	1740	.111	2140	.097		
550	.066*	950	.089	1350	.079	1750	.110	2150	.097		
560	.066	960	.092	1360	.080	1760	.110	2160	.096		
570	.065	970	.095	1370	.081	1770	.110	2170	.096		
580	.065	980	.097	1380	.083	1780	.109	2180	.095		
590	.064	990	.099	1390	.084	1790	.109	2190	.095		
600	.064*	1000	.100*	1400	.086*	1800	.109*	2200	.095*		
610	.064	1010	.100	1410	.087	1810	.108	2210	.097		
620	.064	1020	.100	1420	.089	1820	.108	2220	.097		
630	.064	1030	.099	1430	.090	1830	.107	2230	.097		
640	.063	1040	.098	1440	.092	1840	.107	2240	.096		

[t]Relative to a perfect diffuser.

[+]The values in parentheses are not certified but are for information only.

*The uncertainty of the starred values (as expressed as the coefficient of variation) is less than 0.015. The uncertainties of all values not starred cannot be fully assessed.

Normalized directional/hemispherical reflectances at nine wavelengths and four angles of incidence are provided in Table 2 for information only. (These values are not certified.) These reflectances are the average values obtained on five pieces of porcelain normalized to the 6°/hemispherical reflectance factors given in Table 1 for radiant flux polarized in both the parallel (p) and perpendicular (s) directions as well as for unpolarized radiant flux.

These SRM's can be cleaned with a mild liquid soap and warm water followed by a rinse with distilled water. Care should be taken to avoid scratching the front surface.

Table 2

Directional/Hemispherical Reflectance Normalized to the 6° Angle of Incidence

(These values are not certified)

Wavelength Angle of Incidence	Parallel (p) Polarized	Perpendicular (s) Polarized	Unpolarized (Ordinary)	STDM*
250 nm				
15°	(0.942)	(1.078)	(1.011)	0.09%
30°	(.702)	(1.369)	(1.041)	.20
45°	(.329)	(2.038)	(1.197)	.64
60°	(.096)	(3.585)	(1.868)	1.04
300 nm				
15°	(.945)	(1.076)	(1.011)	0.07
30°	(.712)	(1.361)	(1.041)	.15
45°	(.354)	(2.023)	(1.201)	.49
60°	(.149)	(3.571)	(1.887)	.59
350 nm				
15°	(.947)	(1.069)	(1.009)	.04
30°	(.735)	(1.335)	(1.039)	.08
45°	(.410)	(1.951)	(1.191)	.24
60°	(.236)	(3.410)	(1.844)	.57
450 nm				
15°	(.956)	(1.058)	(1.007)	.02
30°	(.782)	(1.284)	(1.036)	.06
45°	(.519)	(1.814)	(1.172)	.18
60°	(.392)	(3.066)	(1.742)	.30
600 nm				
15°	(.952)	(1.061)	(1.007)	.03
30°	(.767)	(1.302)	(1.037)	.08
45°	(.488)	(1.870)	(1.185)	.25
60°	(.359)	(3.219)	(1.803)	.35
750 nm				
15°	(.953)	(1.060)	(1.007)	.03
30°	(.774)	(1.295)	(1.037)	.09
45°	(.503)	(1.851)	(1.183)	.28
60°	(.382)	(3.175)	(1.792)	.40
1000 nm				
15°	(.970)	(1.078)	(1.022)	3.14
30°	(.907)	(1.224)	(1.065)	2.98
45°	(.738)	(1.651)	(1.190)	2.10
60°	(.677)	(2.365)	(1.515)	2.58
1500 nm				
15°	(.963)	(1.059)	(1.010)	1.34
30°	(.860)	(1.234)	(1.043)	2.15
45°	(.720)	(1.586)	(1.145)	2.24
60°	(.683)	(2.390)	(1.521)	1.22
2000 nm				
15°	(1.000)	(1.006)	(0.993)	6.62
30°	(0.931)	(1.249)	(1.080)	9.29
45°	(.788)	(1.572)	(1.165)	9.51
60°	(.722)	(2.289)	(1.506)	5.14

*Percent Standard Deviation of the Mean