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Standard Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37° Tilted Surface¹

This standard is issued under the fixed designation G177; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

^{ε1} NOTE—The title to **Table 2** was corrected editorially in August 2008.

INTRODUCTION

These tables of solar ultraviolet (UV) spectral irradiance values have been developed to meet the need for a standard ultraviolet reference spectral energy distribution to be used as a reference for the upper limit of ultraviolet radiation in the outdoor weathering of materials and related indoor exposure studies. A wide variety of solar spectral energy distributions occur in the natural environment and are simulated by artificial sources during product, material, or component testing. To compare the relative optical performance of spectrally sensitive products, or to compare the performance of products before and after being subjected to weathering or other exposure conditions, a reference standard solar spectral distribution is required. These tables were prepared using version 2.9.2 of the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS2) atmospheric transmission code **(1,2)**.² SMARTS2 uses empirical parameterizations of version 4.0 of the Air Force Geophysical Laboratory (AFGL) Moderate Resolution Transmission model, MODTRAN **(3,4)**. An extraterrestrial spectrum differing only slightly from the extraterrestrial spectrum in ASTM **E490** is used to calculate the resultant spectra. The hemispherical (2π steradian acceptance angle) spectral irradiance on a panel tilted 37° (average latitude of the contiguous United States) to the horizontal is tabulated. The wavelength range for the spectra extends from 280 to 400 nm, with uniform wavelength intervals. The input parameters used in conjunction with SMARTS2 for each set of conditions are tabulated. The SMARTS2 model and documentation are available as an adjunct **ADJG173CD**³ to this standard.

1. Scope

1.1 The table provides a standard ultraviolet spectral irradiance distribution that maybe employed as a guide against which manufactured ultraviolet light sources may be judged when applied to indoor exposure testing. The table provides a reference for comparison with natural sunlight ultraviolet spectral data. The ultraviolet reference spectral irradiance is provided for the wavelength range from 280 to 400 nm. The wavelength region selected is comprised of the UV-A spectral region from 320 to 400 nm and the UV-B region from 280 to 320 nm.

1.2 The table defines a single ultraviolet solar spectral irradiance distribution:

1.2.1 Total hemispherical ultraviolet solar spectral irradiance (consisting of combined direct and diffuse components) incident on a sun-facing, 37° tilted surface in the wavelength region from 280 to 400 nm for air mass 1.05, at an elevation of 2 km (2000 m) above sea level for the United States Standard Atmosphere profile for 1976 (USSA 1976), excepting for the ozone content which is specified as 0.30 atmosphere-centimeters (atm-cm) equivalent thickness.

1.3 The data contained in these tables were generated using the SMARTS2 Version 2.9.2 atmospheric transmission model developed by Gueymard **(1,2)**.

1.4 The climatic, atmospheric and geometric parameters selected reflect the conditions to provide a realistic maximum ultraviolet exposure under representative clear sky conditions.

1.5 The availability of the SMARTS2 model (as an adjunct **ADJG173CD**³) to this standard) used to generate the standard spectra allows users to evaluate spectral differences relative to the spectra specified here.

¹ These tables are under the jurisdiction of ASTM Committee G03 on Weathering and Durability and is the direct responsibility of Subcommittee G03.09 on Radiometry.

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.

³ Available from ASTM International Headquarters. Order Adjunct No. ADJG173CD. Original adjunct produced in 2005.

TABLE 2 Standard Ultraviolet Hemispherical Spectral Solar Irradiance for 37° Sun-Facing Tilted Surface

Wavelength nm	Hemispherical W/m ² /nm	Wavelength nm	Hemispherical W/m ² /nm	Wavelength nm	Hemispherical W/m ² /nm	Wavelength nm	Hemispherical W/m ² /nm	Wavelength nm	Hemispherical W/m ² /nm
λ	E_{λ}	λ	E_{λ}	λ	E_{λ}	λ	E_{λ}	λ	E_{λ}
1	2	1	2	1	2	1	2	1	2
280.0	2.320E-16	307.5	0.1277	335.0	0.6826	362.5	0.7823	390.0	0.9986
280.5	2.453E-15	308.0	0.1334	335.5	0.6628	363.0	0.8033	390.5	1.0061
281.0	7.972E-15	308.5	0.1406	336.0	0.6063	363.5	0.7799	391.0	1.0646
281.5	9.229E-14	309.0	0.1334	336.5	0.5615	364.0	0.8065	391.5	1.0788
282.0	4.085E-13	309.5	0.1310	337.0	0.5517	364.5	0.7979	392.0	0.9923
282.5	1.081E-12	310.0	0.1482	337.5	0.5914	365.0	0.8274	392.5	0.8262
283.0	2.948E-12	310.5	0.1867	338.0	0.6325	365.5	0.9094	393.0	0.5975
283.5	4.660E-12	311.0	0.2288	338.5	0.6587	366.0	0.9729	393.5	0.4747
284.0	3.901E-11	311.5	0.2283	339.0	0.6684	366.5	0.9732	394.0	0.6162
284.5	8.723E-11	312.0	0.2380	339.5	0.6836	367.0	0.9539	394.5	0.8493
285.0	1.794E-10	312.5	0.2420	340.0	0.7261	367.5	0.9349	395.0	1.0022
285.5	5.618E-10	313.0	0.2564	340.5	0.7226	368.0	0.8791	395.5	1.0667
286.0	1.452E-09	313.5	0.2608	341.0	0.6754	368.5	0.8720	396.0	0.9371
286.5	5.743E-09	314.0	0.2768	341.5	0.6697	369.0	0.9103	396.5	0.6807
287.0	1.354E-08	314.5	0.2842	342.0	0.6968	369.5	0.9767	397.0	0.5268
287.5	3.518E-08	315.0	0.2926	342.5	0.7212	370.0	0.9889	397.5	0.7774
288.0	1.168E-07	315.5	0.2604	343.0	0.7314	370.5	0.8928	398.0	1.0521
288.5	2.398E-07	316.0	0.2589	343.5	0.6903	371.0	0.9057	398.5	1.2416
289.0	5.837E-07	316.5	0.3026	344.0	0.5971	371.5	0.9402	399.0	1.3169
289.5	1.539E-06	317.0	0.3446	344.5	0.5718	372.0	0.8791	399.5	1.3562
290.0	3.403E-06	317.5	0.3693	345.0	0.6476	372.5	0.8365	400.0	1.3701
290.5	6.192E-06	318.0	0.3463	345.5	0.6883	373.0	0.8046		
291.0	1.192E-05	318.5	0.3480	346.0	0.6704	373.5	0.7244		
291.5	2.602E-05	319.0	0.3733	346.5	0.6813	374.0	0.7217		
292.0	4.777E-05	319.5	0.3699	347.0	0.6915	374.5	0.7155		
292.5	6.429E-05	320.0	0.3889	347.5	0.6665	375.0	0.7626		
293.0	1.052E-04	320.5	0.4423	348.0	0.6623	375.5	0.8425		
293.5	2.055E-04	321.0	0.4323	348.5	0.6724	376.0	0.8716		
294.0	3.080E-04	321.5	0.4091	349.0	0.6464	376.5	0.8568		
294.5	4.169E-04	322.0	0.3969	349.5	0.6627	377.0	0.9181		
295.0	6.400E-04	322.5	0.3863	350.0	0.7307	377.5	1.0232		
295.5	1.137E-03	323.0	0.3664	350.5	0.7842	378.0	1.1015		
296.0	1.650E-03	323.5	0.4085	351.0	0.7620	378.5	1.0727		
296.5	2.088E-03	324.0	0.4483	351.5	0.7326	379.0	0.9559		
297.0	2.489E-03	324.5	0.4682	352.0	0.7136	379.5	0.8563		
297.5	3.984E-03	325.0	0.4748	352.5	0.6731	380.0	0.8990		
298.0	5.347E-03	325.5	0.5390	353.0	0.7140	380.5	0.9619		
298.5	5.899E-03	326.0	0.6128	353.5	0.7841	381.0	0.9772		
299.0	7.299E-03	326.5	0.6400	354.0	0.8279	381.5	0.8794		
299.5	0.0108	327.0	0.6287	354.5	0.8358	382.0	0.7485		
300.0	0.0116	327.5	0.6121	355.0	0.8346	382.5	0.6466		
300.5	0.0130	328.0	0.5744	355.5	0.8043	383.0	0.5788		
301.0	0.0177	328.5	0.5860	356.0	0.7535	383.5	0.5597		
301.5	0.0222	329.0	0.6486	356.5	0.7058	384.0	0.6469		
302.0	0.0229	329.5	0.7136	357.0	0.6201	384.5	0.7779		
302.5	0.0307	330.0	0.7201	357.5	0.6268	385.0	0.8530		
303.0	0.0459	330.5	0.6647	358.0	0.5826	385.5	0.8141		
303.5	0.0546	331.0	0.6283	358.5	0.5404	386.0	0.7846		
304.0	0.0556	331.5	0.6420	359.0	0.6349	386.5	0.8148		
304.5	0.0646	332.0	0.6560	359.5	0.7643	387.0	0.8213		
305.0	0.0798	332.5	0.6540	360.0	0.8074	387.5	0.8086		
305.5	0.0848	333.0	0.6413	360.5	0.7621	388.0	0.8000		
306.0	0.0819	333.5	0.6154	361.0	0.7001	388.5	0.7935		
306.5	0.0892	334.0	0.6275	361.5	0.6842	389.0	0.8606		
307.0	0.1080	334.5	0.6615	362.0	0.7157	389.5	0.9529		

2. Referenced Documents

2.1 ASTM Standards:⁴

E490 Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables

E772 Terminology of Solar Energy Conversion

2.2 ASTM Adjuncts:

ADJG173CD Simple Model for Atmospheric Transmission of Sunshine³

⁴ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary Page on the ASTM website.

3. Terminology

3.1 *Definitions*—Definitions of terms used in this specification not otherwise described below may be found in Terminology **E772**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *air mass zero (AM0)*—describes solar radiation quantities outside the Earth’s atmosphere at the mean Earth-Sun distance (1 Astronomical Unit). See ASTM E490.

3.2.2 *integrated irradiance* $E_{\lambda_1-\lambda_2}$ —spectral irradiance integrated over a specific wavelength interval from λ_1 to λ_2 , measured in $\text{W}\cdot\text{m}^{-2}$; mathematically:

$$E_{\lambda_1-\lambda_2} = \int_{\lambda_1}^{\lambda_2} E_{\lambda} d\lambda \quad (1)$$

3.2.3 *solar irradiance, hemispherical* E_H —on a given plane, the solar radiant flux received from the within the $2\text{-}\pi$ steradian field of view of a tilted plane from the portion of the sky dome and the foreground included in the plane’s field of view, including both diffuse and direct solar radiation.

3.2.3.1 *Discussion*—For the special condition of a horizontal plane the hemispherical solar irradiance is properly termed global solar irradiance, E_G . Incorrectly, global tilted, or total global irradiance is often used to indicate hemispherical irradiance for a tilted plane. In case of a sun-tracking receiver, this hemispherical irradiance is commonly called global normal irradiance. The adjective global should refer only to hemispherical solar radiation on a horizontal, not a tilted, surface.

3.2.4 *aerosol optical depth (AOD)*—the wavelength-dependent total extinction (scattering and absorption) by aerosols in the atmosphere. This optical depth (also called “optical thickness”) is defined here at 500 nm.

3.2.4.1 *Discussion*—See X1.1.

3.2.5 *solar irradiance, spectral* E_{λ} —solar irradiance E per unit wavelength interval at a given wavelength λ . (Unit: Watts per square meter per nanometer, $\text{W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$)

$$E_{\lambda} = \frac{dE}{d\lambda} \quad (2)$$

3.2.6 *spectral passband*—the effective wavelength interval within which spectral irradiance is allowed to pass, as through a filter or monochromator. The convolution integral of the spectral passband (normalized to unity at maximum) and the incident spectral irradiance produces the effective transmitted irradiance.

3.2.6.1 *Discussion*—Spectral passband may also be referred to as the spectral bandwidth of a filter or device. Passbands are usually specified as the interval between wavelengths at which one half of the maximum transmission of the filter or device occurs, or as full-width at half-maximum, FWHM.

3.2.7 *spectral interval*—the distance in wavelength units between adjacent spectral irradiance data points.

3.2.8 *spectral resolution*—the minimum wavelength difference between two wavelengths that can be identified unambiguously.

3.2.8.1 *Discussion*—In the context of this standard, the spectral resolution is simply the interval, $\Delta\lambda$, between spectral data points, or the *spectral interval*.

3.2.9 *total precipitable water*—the depth of a column of water (with a section of 1 cm^2) equivalent to the condensed

water vapor in a vertical column from the ground to the top of the atmosphere. (Unit: cm or g/cm^2)

3.2.10 *total ozone*—the depth of a column of pure ozone equivalent to the total of the ozone in a vertical column from the ground to the top of the atmosphere. (Unit: atmosphere-cm)

3.2.11 *wavenumber*—a unit of frequency, ν , in units of reciprocal centimeters (symbol cm^{-1}) commonly used in place of wavelength, λ . The relationship between wavelength and frequency is defined by $\lambda\nu = c$, where c is the speed of light in vacuum. To convert wavenumber to nanometers, $\lambda\cdot\text{nm} = 1\cdot 10^7/\nu\cdot\text{cm}^{-1}$.

4. Technical Basis for the Tables

4.1 These tables are modeled data generated using an air mass zero (AM0) spectrum based on the extraterrestrial spectrum of Gueymard (1,2) derived from Kurucz (5), the United States Standard Atmosphere of 1976 (USSA) reference Atmosphere (6), the Shettle and Fenn Rural Aerosol Profile (7), the SMARTS2 V. 2.9.2 radiative transfer code. Further details are provided in X1.3.

4.2 The 37° tilted surface was selected as it represents the average latitude of the contiguous forty-eight states of the continental U.S., and outdoor exposure testing often takes place at latitude tilt.

4.3 The documented USSA atmospheric profiles utilized in the MODTRAN spectral transmission model (6) have been used to provide atmospheric properties and concentrations of absorbers.

4.4 The SMARTS model Version 2.9.2 is available at Internet URL: <http://redc.nrel.gov/solar/models/SMARTS>.

4.5 To provide spectral data with a uniform spectral step size, the AM0 spectrum used in conjunction with SMARTS2 to generate the terrestrial spectrum is slightly different from the ASTM extraterrestrial spectrum, ASTM E490. Because ASTM E490 and SMARTS2 both use the data of Kurucz (5), the SMARTS2 and E490 spectra are in excellent agreement although they do not have the same spectral resolution.

4.6 The current spectra reflect improved knowledge of atmospheric aerosol optical properties, transmission properties, and radiative transfer modeling (8).

4.7 The terrestrial solar spectral in the tables have been computed with a spectral bandwidth equivalent to the spectral resolution of the tables, namely 0.5 nm.

5. Significance and Use

5.1 This standard does not purport to address the mean level of solar ultraviolet spectral irradiance to which materials will be subjected during their useful life. The spectral irradiance distributions have been chosen to represent a reasonable upper limit for natural solar ultraviolet radiation that ought to be considered when evaluating the behavior of materials under various exposure conditions.

5.2 Absorptance, reflectance, and transmittance of solar energy are important factors in material degradation studies. These properties are normally functions of wavelength, which

require that the spectral distribution of the solar flux be known before the solar-weighted property can be calculated.

5.3 The interpretation of the behavior of materials exposed to either natural solar radiation or ultraviolet radiation from artificial light sources requires an understanding of the spectral energy distribution employed. To compare the relative performance of competitive products, or to compare the performance of products before and after being subjected to weathering or other exposure conditions, a reference standard solar spectral distribution is desirable.

5.4 A plot of the SMARTS2 model output for the reference hemispherical UV radiation on a 37° south facing tilted surface

is shown in Fig. 1. The input needed by SMARTS2 to generate the spectrum for the prescribed conditions are shown in Table 1.

5.5 SMARTS2 Version 2.9.2 is required to generate AM 1.05 UV reference spectra.

5.6 The availability of the adjunct standard computer software (ADJG173CD⁵) for SMARTS2 allows one to (1) reproduce the reference spectra, using the above input parameters;

⁵ South facing for the northern hemisphere, north facing for the southern hemisphere.

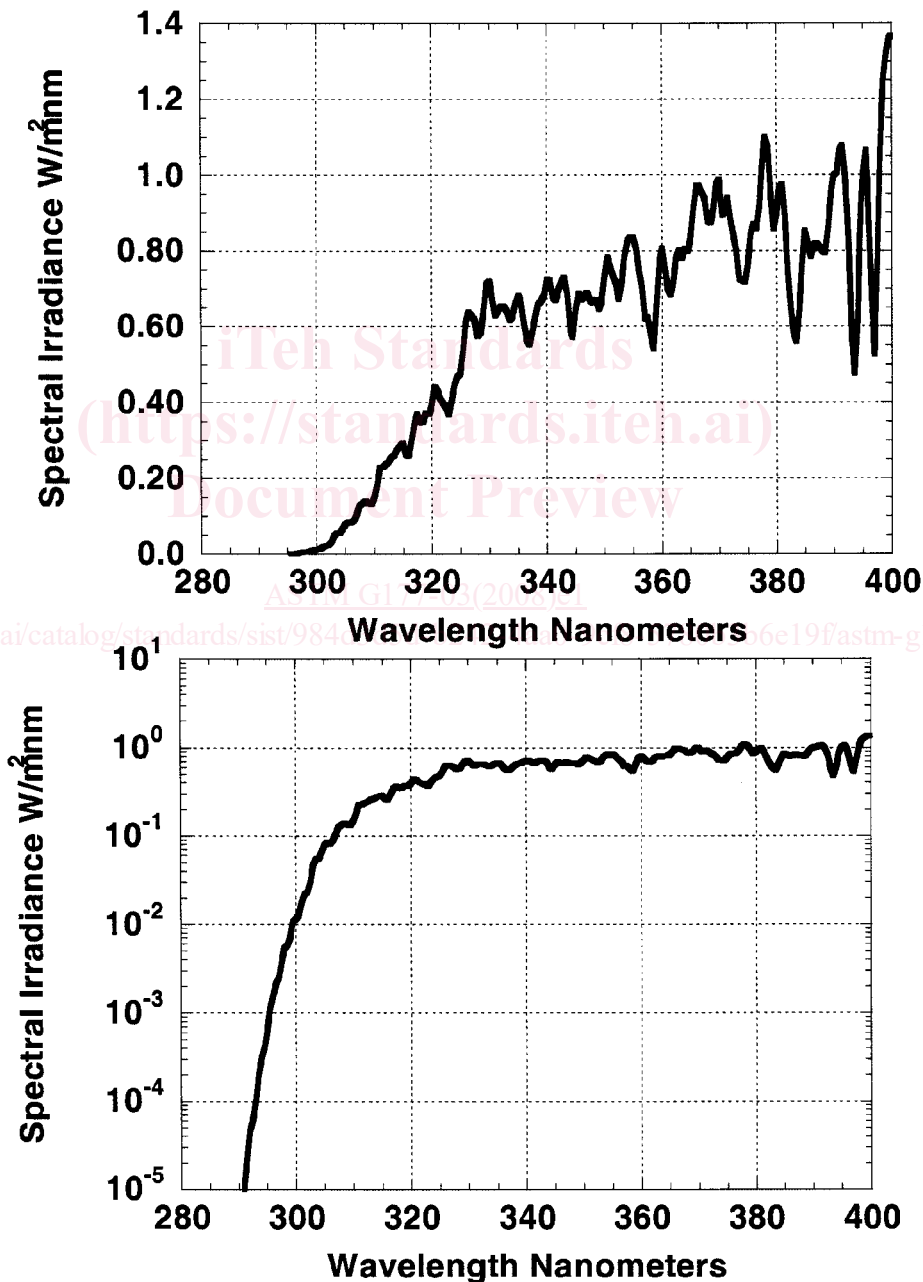


FIG. 1 Total Hemispherical Ultraviolet Reference Spectra Based on SMARTS2 Runs for AM1.05 UV Spectral Profile (a) Linear Scale; (b) Logarithmic Scale