Designation: G177 – 03 (Reapproved 2012)

Standard Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37° Tilted Surface[1]

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.

ε^1 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.

Current edition approved Nov. 1, 2012. Published November 2012. Originally approved in 2003. Last previous edition approved in 2008 as G177 – 03(2008) $^{\varepsilon1}$. DOI: 10.1520/G0177-03R12.

[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.

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 Sunshine[3]

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 $W \cdot m^{-2}$; 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-π 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, $W \cdot m^{-2} \cdot nm^{-1}$)

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

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

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 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://rredc.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] 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.

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 (ADJG173CD[5]) for SMARTS2 allows one to (*1*) reproduce the reference spectra, using the above input parameters; (*2*) compute test spectra to attempt to match measured data at a specified FWHM, and evaluate atmospheric conditions; and (*3*) compute test spectra representing specific conditions for analysis vis-à-vis any one or all of the reference spectra.

6. Solar Spectral Irradiance

6.1 Table 2 presents the reference spectral irradiance data global hemispherical solar irradiance on a plane tilted at 37° toward the equator, for the conditions specified in Table 1.

6.2 The table contains:

6.2.1 Hemispherical solar spectral irradiance incident on an equator-facing[5] plane tilted to 37° from the horizontal in the wavelength range from 280 to 400 nm.

6.2.2 The columns in each table contain:

6.2.2.1 Column 1: Wavelength in nanometers (nm).

6.2.2.2 Column 2: Mean hemispherical spectral irradiance incident on surface tilted 37° toward the equator. E_λ, $W \cdot m^{-2} \cdot nm^{-1}$.

7. Validation

7.1 In part of the spectral region of interest, (295 to 400 nm) the SMARTS2 model has been verified against experimental data. SMARTS2 performance is adequate for the region from 295 to 400 nm. No reliable experimental data has been found to verify performance below 295 nm.

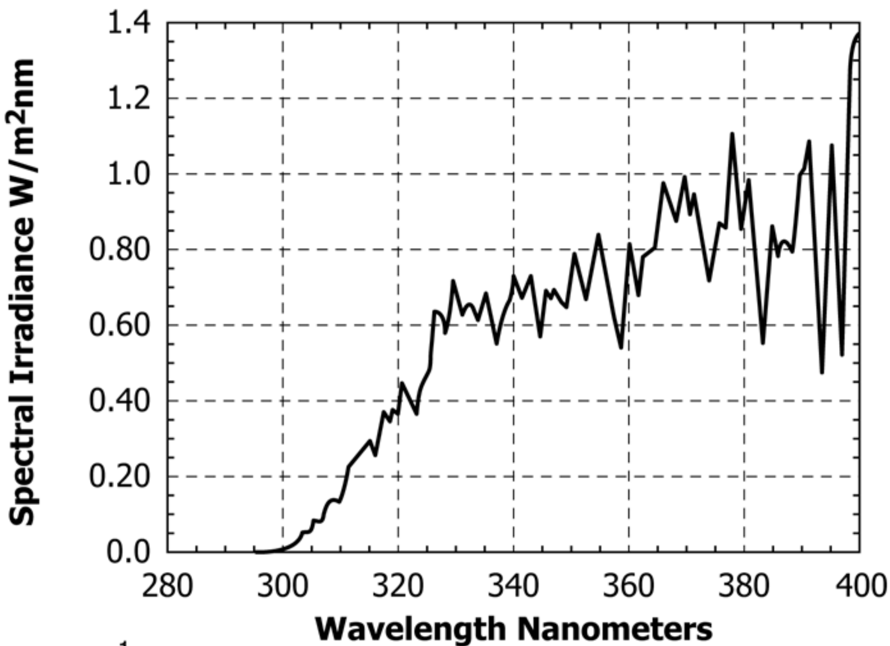
7.2 Comparisons of the SMARTS2 computer model with both MODTRAN model results and measured spectral data and other rigorous spectral models are reported in (**1,2**). Fig. 2 is a plot of the relative magnitude of the spectral differences observed between MODTRAN version 4.0 and SMARTS2 for identical conditions. Results indicate that the various models are within ~5 % in spectral regions where significant energy is present.

7.3 Comparison of these reference spectra with clear sky solar spectral irradiance data from various spectrometers under various atmospheric conditions approximating those chosen for this data are in reasonable agreement (**8**).

8. Keywords

8.1 global hemispherical; materials exposure; terrestrial; ultraviolet solar spectral irradiance

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



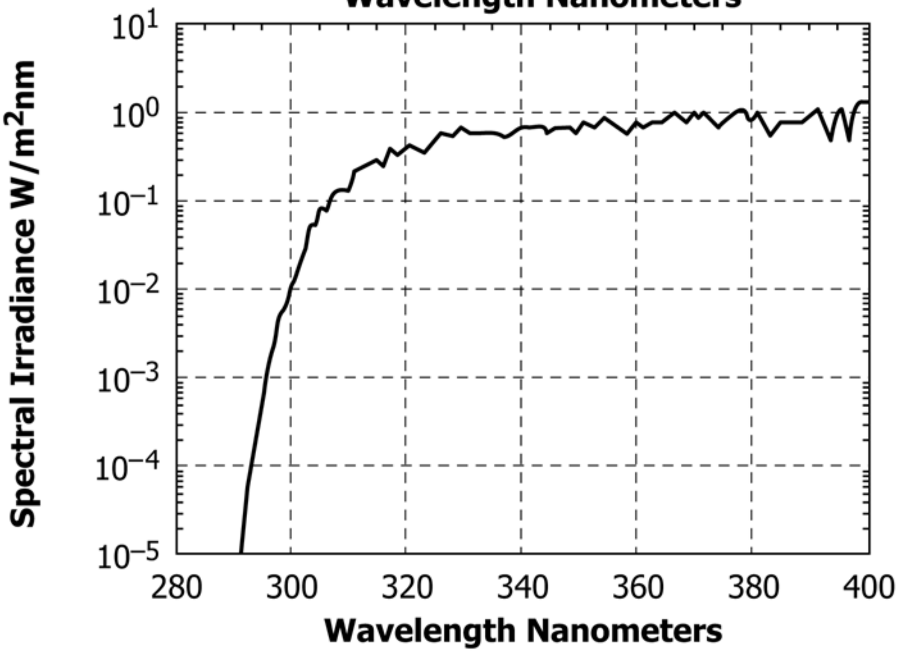


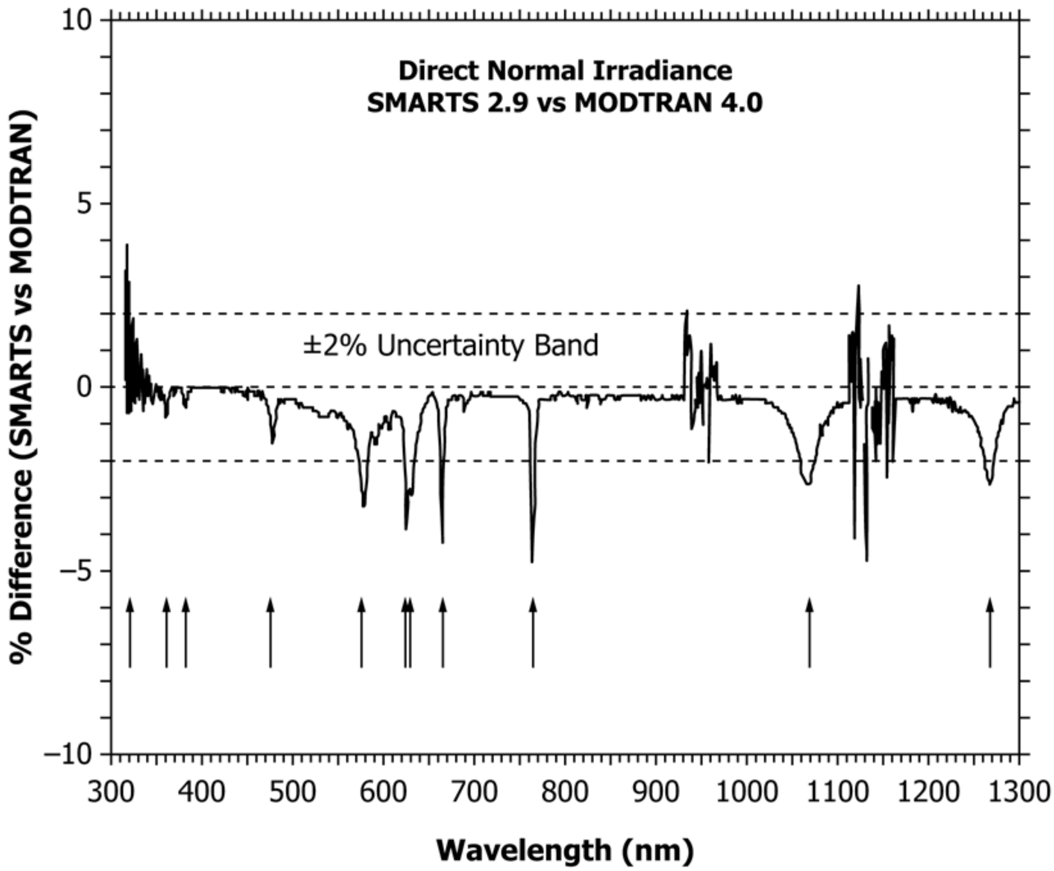
FIG. 1 Total Hemispherical Ultraviolet Reference Spectra Based on SMARTS2 Runs for AM1.05 UV Spectral Profile (a) Linear Scale; (b) Logarithmic Scale

TABLE 1 SMARTS Version 2.9.2 Input File to Generate the Reference Spectra

Card ID	Value	Parameter/Description/Variable Name
1	'ASTM UV_Std_Spectra'	Header
2	1	Pressure input mode (1 = pressure and altitude): ISPR
2a	820.0 2.0.	Station Pressure (mb) and altitude (km): SPR, ALT
3	1	Standard Atmosphere Profile Selection (1 = use default atmosphere): IATM1
3a	'USSA'	Default Standard Atmosphere Profile: ATM
4	1	Water Vapor Input (1 = default from Atmospheric Profile): IH2O
5	0	Ozone Calculation (0 = user input concentariont and altitude): IO3
5a	1 0.3	Ozone Atltitude correctiom (IALT = 1 = > correct from sea level), Ozone Concentration (AbO3 = 0.30 atm cm)
6	1	Pollution level mode (1 = standard conditions/no pollution): IGAS (see X1.3)
7	370	Carbon Monoxide volume mixing ratio (ppm): qCO2 (see X1.3)
7a	1	Extraterrestrial Spectrum (1 = SMARTS/Gueymard): ISPCTR
8	'S&F_RURAL'	Aerosol Profile to Use: AEROS
9	0	Specification for aerosol optical depth/turbidity input (0 = AOD at 500 nm): ITURB
9a	0.05	Aerosol Optical Depth at 500 nm: TAU5
10	38	Far field Spectral Albedo file to use (38 = Light Sandy Soil): IALBDX
10b	1	Specify tilt calculation (1 = yes): ITILT
10c	38 37 180	Albedo and Tilt variables—Albedo file to use for near field, Tilt, and Azimuth: IALBDG, TILT, WAZIM
11	280 400 1.0 1367.0	Wavelength Range—start, stop, mean radius vector correction, integrated solar spectrum irradiance: WLMN, WLMX, SUNCOR, SOLARC
12	2	Separate spectral output file print mode (2 = yes): IPRT
12a	280 400 0.5	Output file wavelength-Print limits, start, stop, minimum step size: WPMN, WPMX, INTVL
12b	1	Number of output variables to print: IOTOT
12c	8	Code relating output variables to print [8 = Hemispherical tilt, OUT(8)]
13	1	Circumsolar calculation mode (1 = yes): ICIRC
13a	0 2.9 0	Receiver geometry-Slope, View, Limit half angles: SLOPE, APERT, LIMIT
14	0	Smooth function mode (0 = none): ISCAN
15	0	Illuminance calculation mode (0 = none): ILLUM
16	0	UV calculation mode (0 = none): IUV
17	2	Solar Geometry mode (2 = Air Mass): IMASS
17a	1.05	Air mass value: AMASS

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		



Conditions with Aerosol Optical depth at 500 nm = 0.27. Arrows indicate absorption by gases not treated in MODTRAN but included in the SMARTS2 model.

FIG. 2 Atmospheric Transmittance Predicted by SMARTS2 and MODTRAN4 for AM 1.5 USSA 1976

APPENDIX

(Nonmandatory Information)

X1. Description of Parameters Affecting Ultraviolet Spectral Transmission

X1.1 Aerosol Optical Depth

X1.1.1 *Discussion*—Aerosol optical depth is sometimes incorrectly referred to as "turbidity." Technically, "turbidity" is defined as the number of clean, dry atmospheres required to produce the same extinction of solar radiation as observed. Thus "turbidity" is actually a number greater than 1. The expression for extinction of solar radiation by aerosols in the atmosphere is:

$$\tau(\lambda) = \beta\ (\lambda/\lambda_o)^{-\alpha} \qquad (X1.1)$$

where τ(λ) is the extinction coefficient, or optical depth, at wavelength λ. β (approximately 0.05 to 0.45 for clean and "turbid" atmospheres, respectively) is an extinction coefficient, related to the total atmospheric loading of the aerosols, generally called the "Ångström turbidity coefficient." α, generally called the "Ångström turbidity exponent" is related to the size of the aerosol particles and normally ranges from −0.2 (very large particles) to +2.0 (very small particles) with values of 1.0 to 1.5 typical for a rural atmosphere. For $\lambda = \lambda_o$ = 1 µm, τ(λ) equals the turbidity coefficient β, which is therefore identical to the AOD at 1 µm. Typical values for AOD are thus 0.05 for very clean, and 1.0 for very "turbid" or "hazy" cloudless skies. The value 0.08 selected is representative of clean, clear desert sky conditions.

X1.2 Atmospheric Constituents and Absorbers

X1.2.1 The 1976 U.S. Standard Atmosphere Model (**6**) with the rural Shettle and Fenn Aerosol (**7**) was used to produce the data in this standard. The atmospheric model exhibits the following parameters for a vertical path from sea level to the top of the atmosphere is shown in Table X1.1.

X1.2.2 Atmospheric parameters, such as temperature, pressure, relative humidity, air density, and the density of nine molecular species are defined at 33 levels in the atmosphere. Atmospheric parameters vary exponentially between the 33 levels. The total abundance of all absorbing gases are obtained by integrating their concentrations throughout the 33 levels, from sea level to an altitude of 120 km.

TABLE X1.1 U.S. Standard Atmosphere 1976 Constituents

Standard	Aerosol Optical Depth at 500 nm	Total Precipitable Water Vapor, cm	Total Ozone, atm-cm	Carbon Dioxide Volume Concentration, ppm
Present Standard	0.05	1.4164	0.30	370

X1.2.3 The USSA 1976 concentration of Ozone is 0.3438 atm-cm. The concentration of Ozone is reduced to 0.30 atm-cm and corrected for an altitude of 2.0 km (2000 m) to represent a reasonable maximum UV spectral dose that could be obtained under natural conditions.

X1.2.4 The USSA 1976 concentration of Carbon Dioxide (CO_2) is 330 parts per million (ppm). The value of this concentration in 2002 is known to be about 370 ppm. In order to accurately represent the current state of the atmosphere, the 370 ppm value is used to generate the reference spectra, as noted for cards 6 and 7 in Table 1.

X1.2.5 The SMARTS version 2.9.2 model calculates absorption for a total of 19 gases, some of which are not included in USSA, nor treated in MODTRAN4 or the previous versions of the reference spectra. The SMARTS model allows the user to specify the relative loading of some of these gases at default concentrations representing standard, pristine, light pollution, moderate pollution, or severe pollution conditions. As noted in Table 1, conditions for the reference spectra were chosen to be for a standard atmosphere, that is, USSA without pollution. The total columnar abundances (in atm-cm) of all gases (except water vapor, see Table X1.1) treated in the standard spectra are shown in Table X1.2.

X1.2.6 The absorption and scattering properties of the aerosol are calculated based on parameterizations of the data from the Shettle and Fenn model (**7**), which is also used in the MODTRAN spectral modeling code developed at the Air Force Geophysical Laboratory (**9,10**). Complete input parameters for the spectral model are listed in Table 1.

X1.3 Spectral Reflectance

X1.3.1 To generate the spectra, the present standards utilize wavelength-dependent values of ground reflectance, representative of a light soil, combined with a slightly forward-enhanced reflectance pattern. Fig. X1.1 is a plot of the data, which have been slightly modified from the Jet Propulsion Laboratory ASTER Spectral Library.

TABLE X1.2 Gaseous Abundances for Standard Conditions Used to Compute Standard Spectra

Gas	Ammonia	Bromine monoxide	Carbon monoxide	Carbon dioxide	Chlorine nitrate	Formal-dehyde	Methane	Nitric acid	Nitric oxide
Symbol	NH3	BrO	CO	CO2	ClNO3	CH2O	CH4	HNO3	NO
Standard Abundance, atm-cm	0.00013	0.0000025	0.08747	297.1	0.00012	0.0003	1.285	0.0003811	0.0003211
Gas	Nitrogen	Nitrogen dioxide	Nitrogen trioxide	Nitrous acid	Nitrous oxide	Oxygen	Colliding Oxygen	Ozone	Sulfur dioxide
Symbol	N2	NO2	NO3	HNO2	N2O	O2	O2-O2 / O2-N2	O3	SO2
Standard Abundance, atm-cm	3.719	0.0002044	0.00005	0.0001	0.2385	16780	16780	0.3438	0.0001071

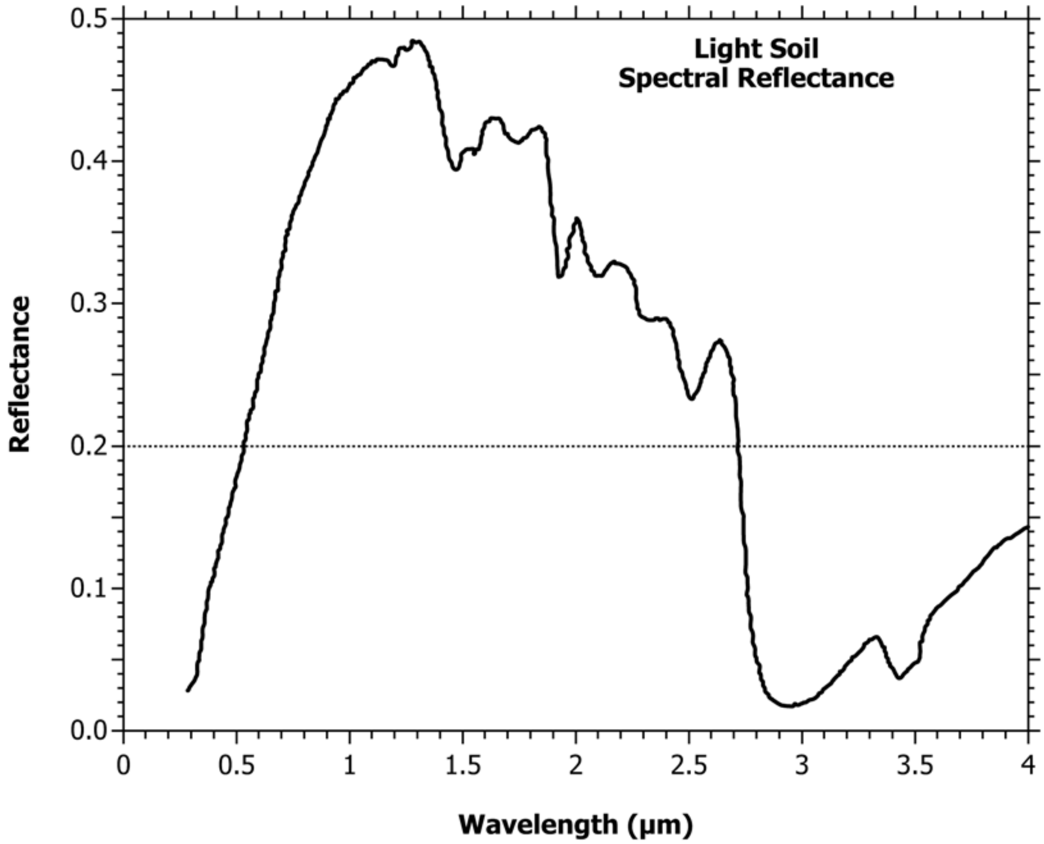


FIG. X1.1 Plot of the Data in the Albedo File (LITESOIL.DAT) Used to Compute the Standard Spectra

REFERENCES

(1) Gueymard, C., " Parameterized Transmittance Model for Direct Beam and Circumsolar Spectral Irradiance," *Solar Energy*, Vol 71, No. 5, 2001, pp. 325-346.

(2) Gueymard, C., " SMARTS22, A Simple Model of the Atmospheric Radiative Transfer of Sunshine: Algorithms and Performance Assessment," Professional Paper FSEC-PF-270-95. Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, FL 32922, 1995.

(3) Berk, A., Bernstein, L. S., and Robertson, D. C., "MODTRAN: A Moderate Resolution Model for LOWTRAN7," Rep. GL-TR-89-0122, Air Force Geophysics Lab., Hanscom AFB, MA, 1989.

(4) Berk, A., Anderson, G. P., Acharya, P. K., Chetwynd, J. H., Bernstein, L. S., Shettle, E. P., Matthew, M. W., and Adler-Golden, S. M., "MODTRAN4 User's Manual," Air Force Research Lab., Hanscom AFB, MA, 1999.

(5) Kurucz, R. L., " ATLAS9 Stellar Atmosphere Programs and 2 km/s Grid," Harvard-Smithsonian Center for Astrophysics, CD-ROM No. 13, 1993.

(6) Anderson, G. P., Clough, S. A., Kneizys, F. X., Chetwynd, J. H., and Shettle, E. P., "AFGL Atmospheric Constituent Profiles (0-120 km)," Tech. Report AFGL-TR-86-0110, Air Force Geophysics Lab., Hanscom AFB, MA, 1968.

(7) Shettle, E. P. and Fenn, R. W., "Models for the Aerosols of the Lower Atmosphere and the Effects of Humidity Variations on their Optical Properties," Rep. AFGL-TR-79-0214, Air Force Geophysics Lab., Hanscom AFB, MA, 1979.

(8) Gueymard, C. and Myers, D. R. and Emery, K., "Proposed Reference Irradiance Spectra for Solar Energy Systems Testing," *Solar Energy*, Vol 73, No.6, pp. 443–467, 2002.

(9) Anderson, G. P., et al., "Reviewing Atmospheric Radiative Transfer Modeling: New Developments in High and Moderate Resolution FASCODE/FASE and MODTRAN," *Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research II*, Society of Photo-Optical Instrumentation Engineers, 1996.

(10) Anderson, G. P., et al., "History of One Family of Atmospheric Radiative Transfer Codes," *Passive Infrared Remote Sensing of Clouds and the Atmosphere II*, Society of Photo-optical Instrumentation Engineers, 1994.