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StandardTable for Reference Solar Spectral Distributions: Direct and Diffuse on 20° Tilted and Vertical Surfaces[1]

This standard is issued under the fixed designation G197; 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.

INTRODUCTION

This table of solar spectral irradiance distributions has been developed to meet the need for weighting functions to be used in evaluating the broadband transmittance of fenestration systems or the performance of technologies such as building-integrated photovoltaic devices. To compare the relative optical performance of spectrally sensitive products by theoretical simulation, or to compare the performance of products by actual testing under laboratory conditions, separate reference standard solar spectral distributions for direct and diffuse irradiance are required. This table was prepared using version 2.9.2 of the Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) atmospheric transmission code (**1, 2**).[2] SMARTS uses 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 directional beam and diffuse hemispherical (2π steradian acceptance angle) spectral irradiances on planes tilted 20° (representative of a pitched roof slope) and 90° (tilt of a typical wall) to the horizontal are tabulated. The wavelength range for the spectra extends from 280 nm to 4000 nm, covering the spectral range for which windows or solar collectors respond to shortwave energy. The input parameters used in conjunction with SMARTS for each set of conditions are tabulated. The SMARTS model and documentation are available as an adjunct to this standard.

1. Scope

1.1 This table provides terrestrial solar spectral irradiance distributions that may be employed as weighting functions to *(1)* calculate the broadband solar or light transmittance of fenestration from its spectral properties; or *(2)* evaluate the performance of building-integrated technologies such as photovoltaic electricity generators. Most of these systems are installed on vertical walls, but some are also installed on pitched roofs or on other tilted structures, such as sunspaces. Glazing transmittance calculations or measurements require information on both the direct and diffuse components of irradiance. The table provides separate information for direct and diffuse irradiance, and for two different tilt angles, 20° and 90° relative to the horizontal. All distributions are provided at 2002 wavelengths within the spectral range 280–4000 nm. The data contained in this table reflect reference spectra with uniform wavelength interval (0.5 nanometer (nm) below 400 nm, 1 nm between 400 and 1700 nm, an intermediate wavelength at 1702 nm, and 5 nm intervals from 1705 to 4000 nm). The data table represents reasonable cloudless atmospheric conditions favorable for the computerized simulation, comparative rating, or experimental testing of fenestration systems.

1.2 The data contained in this table were generated using the SMARTS version 2.9.2 atmospheric transmission model developed by Gueymard (**1, 2**).

1.3 The selection of the SMARTS radiative model to generate the spectral distributions is chosen for compatibility with previous standards (ASTM G173 and G177). The atmospheric and climatic conditions are identical to those in ASTM G173. The environmental conditions are also identical, with only one exception (see sections 4.3 and X1.2).

1.4 The table defines four solar spectral irradiance distributions:

1.4.1 Separate direct and diffuse solar spectral irradiance incident on a sun-facing, 20° tilted surface in the wavelength region from 280–4000 nm for air mass 1.5, at sea level.

[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.

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1.4.2 Separate direct and diffuse solar spectral irradiance incident on a sun-facing, 90° (vertical) tilted surface in the wavelength region from 280–4000 nm for air mass 1.5, at sea level.

1.5 The diffuse spectral distribution on a vertical surface facing away from the sun (i.e., shaded), or at any prescribed azimuth away from the sun, may be computed using the model to obtain representative results (i.e., results that fall within an acceptable range of variance).

1.6 The climatic, atmospheric, and geometric parameters selected reflect the conditions to provide a realistic set of spectral distributions appropriate for building applications under very clear-sky conditions, representative of near-maximum solar heat gains in buildings.

1.7 A wide variety of orientations or local environmental conditions is possible for exposed surfaces. The availability of the SMARTS model (as an adjunct to this standard) used to generate the standard spectra allows users to evaluate spectral differences relative to the spectra specified here.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

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

E772 Terminology of Solar Energy Conversion

G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

G177 Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37° Tilted Surface

2.2 *ASTM Adjuncts:*

ADJG173CD—SMARTS, Simple Model of the Atmospheric Radiative Transfer of Sunshine, Terrestrial Solar Spectral Modeling Code[4]

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 *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.

3.2.2 *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.

3.2.3 *albedo*—also called reflectance, a measure of the reflective characteristics of a surface relative to incident irradiance.

3.2.3.1 *Discussion*—For this standard, the albedo refers to the spectral reflectance of the ground relative to hemispherical irradiance. Two different albedos are considered by the model, and both only affect diffuse irradiance. The first albedo corresponds to the average surface reflectance of the far-field area around the site, within a radius of 5–50 km. The second albedo is that of the foreground (or near-field) immediately adjacent to the tilted surface, to a distance of 10–100 m. The two albedos can be identical or different, but the foreground albedo's effect significantly increases with tilt angle, whereas the far-field albedo's effect on diffuse irradiance decreases with tilt angle.

3.2.4 *integrated irradiance* $E_{\lambda 1\text{-}\lambda 2}$—spectral irradiance integrated over a specific wavelength interval from λ_1 to λ_2, measured in $W \cdot m^{-2}$; mathematically:

$$E_{\lambda 1-\lambda 2} = \int_{\lambda 1}^{\lambda 2} E_\lambda \, d\lambda \tag{1}$$

3.2.5 *shading*—condition that results in partial obscuration of the sky, including the sun or not.

3.2.5.1 *Discussion*—For this standard, no shading of the sky is considered. However, the standard also applies to cases when the 20° or 90° tilted surfaces are shaded from the sun only, due to their relative geometry or other circumstances. This cancels the direct irradiance component, so that the total hemispherical irradiance reduces to the diffuse component.

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

$$E_\lambda = \frac{dE}{d\lambda} \tag{2}$$

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

3.2.8 *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.

3.2.8.1 *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.

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

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

3.2.10 *spectral solar irradiance, diffuse* $E_{d\lambda}$—on a given plane, the solar radiant flux at wavelength λ received from within the 2π 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, excluding direct solar radiation.

[3] 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] Available on CD-ROM from ASTM International Headquarters. Order Adjunct No. ADJG173CD.

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3.2.11 *spectral solar irradiance, direct* $E_{D\lambda}$—on a given plane, the solar radiant flux at wavelength λ received directly from the sun, excluding diffuse solar radiation.

3.2.11.1 *Discussion*—In practice, instruments measuring direct solar irradiance have a larger acceptance angle than the apparent diameter of the sun. Consequently, it is virtually impossible to measure $E_{D\lambda}$ without the contribution of diffuse radiation emanating from the sun's aureole. This contribution is referred to as "circumsolar radiation." Contrarily to ASTM G173, the data in Table 3 use the ideal definition of direct irradiance, and therefore ignore the circumsolar contribution. The sum of direct and diffuse irradiance is the hemispherical solar irradiance, $E_{H\lambda}$.

3.2.12 *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)

3.2.13 *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)

3.2.14 *wavenumber*—a unit of frequency, í, in units of reciprocal centimeters (symbol cm^{-1}) commonly used in place of wavelength, λ (units of length, typically nanometers). To convert wavenumbers to nanometers, $\lambda\ nm = 1 \cdot 10^7/í\ cm^{-1}$.

4. Technical Bases 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**), and the SMARTS version 2.9.2 radiative transfer code. Further details are provided in ASTM G173.

4.2 The 20° tilted surface closely represents the geometry of pitched roofs or tilted glazed structures, which are common elements of buildings. The 90° (vertical) surface represents the norm for building walls.

4.3 The tabulated diffuse irradiance is a combination of scattered irradiance from the sky and reflected irradiance from far-field and near-field ground surfaces. Dry soil conditions have been chosen for both surfaces. This is a darker, less reflective surface than what was used in ASTM G173 or G177.

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

4.5 To provide spectral data with a uniform spectral step size, the AM0 spectrum used in conjunction with SMARTS to generate the terrestrial spectrum is slightly different from the ASTM extraterrestrial spectrum, ASTM E490. Because ASTM E490 and SMARTS both use the data of Kurucz (**5**), the SMARTS 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 to 5 nm (see 1.1).

4.8 The SMARTS model code and documentation is available as an adjunct standard. Request ASTM Stock number ADJG173CD.

5. Significance and Use

5.1 This standard does not purport to address the mean spectral irradiance incident on tilted or vertical fenestration or building-integrated systems over a day, a season, or a year. The spectral irradiance distributions have been chosen to represent a reasonable near-upper limit for solar radiation when these systems are exposed to clear-sky conditions similar to those used to calculate solar heat loads of buildings. The diffuse spectral irradiance distributions can also be used to represent conditions when these systems are shaded from the direct sun.

5.2 Absorptance, reflectance, and transmittance of solar radiation are important factors in studies of light transmission through semi-transparent plates. 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 To compare the relative performance of competitive products by computerized simulations, or to compare the performance of products subjected to experimental tests in laboratory conditions, a reference standard solar spectral distribution for both direct and diffuse irradiance is desirable.

5.4 The table provides appropriate standard spectral irradiance distributions for determining the relative optical performance of semi-transparent materials and other systems. The table may be used to evaluate components and materials for the purpose of solar simulation where the direct and the diffuse spectral solar irradiances are needed separately.

5.5 The selected air mass value of 1.5 for a plane-parallel atmosphere above a flat earth corresponds to a zenith angle of 48.19°. The SMARTS2 computation of air mass accounts for atmospheric curvature and the vertical density profile of molecules, which results in a solar zenith angle of 48.236°, or an equivalent plane-parallel-atmosphere air mass of 1.50136. The angle of incidence computed by SMARTS for the direct beam irradiance incident on a 20°-tilted plane facing the sun is thus 28.236°. It is 41.764° for a 90°-tilted surface facing the sun.

5.6 A plot of the SMARTS model output for the reference direct radiation on a 20° and 90° tilted surfaces is shown in Fig. 1. A similar plot, but for diffuse radiation, is shown in Fig. 2.

5.7 The input needed by SMARTS to generate the spectra for the prescribed conditions and the 20°-tilted surface is provided in Table 1. The input file for the 90°-tilted surface differs only by one line. This modified line appears in Table 2.

5.8 The total irradiance, integrated over the spectral range 280–4000 nm, is 791.07 and 97.96 $W \cdot m^{-2}$ for direct and diffuse radiation incident on the 20° tilted surface, respectively. It is 669.74 and 140.56 $W \cdot m^{-2}$ for direct and diffuse radiation incident on the 90° tilted surface, respectively.

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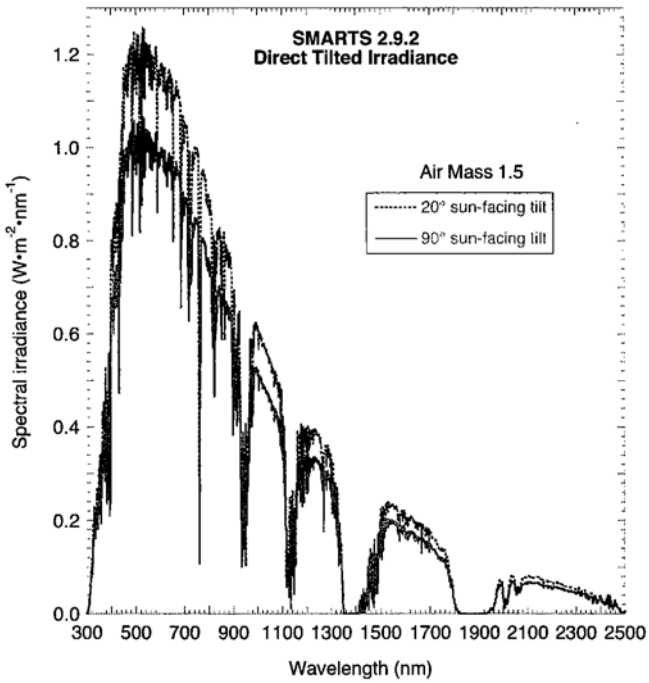

FIG. 1 Plot of Direct Spectral Irradiance on 20° Tilted Sun-Facing Surface (Dotted Line) and 90° Tilted Sun-Facing Surface (Solid Line) Computed Using SMARTS Version 2.9.2 Model with Input File in Tables 1 and 2

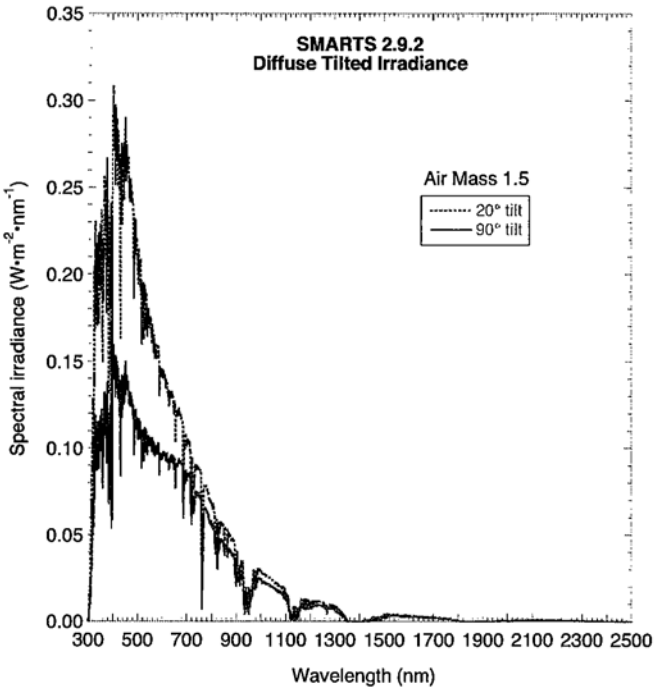

FIG. 2 Plot of Diffuse Spectral Irradiance on 20° Tilted Sun-Facing Surface (Dotted Line) and 90° Tilted Sun-Facing Surface (Solid Line) Computed Using SMARTS Version 2.9.2 Model with Input File in Tables 1 and 2

5.9 The availability of the adjunct standard computer software for SMARTS allows one to *(a)* reproduce the reference spectra, using the above input parameters; *(b)* compute test spectra to attempt to match measured data at a specified FWHM, and evaluate atmospheric conditions; *(c)* compute test spectra representing specific conditions for analysis vis-à-vis any one or all of the reference spectra; *(d)* obtain the sky diffuse and the ground-reflected diffuse spectra (whose sum

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TABLE 1 SMARTS Version 2.9.2 Input File to Generate the Reference Spectra for a 20° Tilt

Card ID	Value	Parameter/Description/Variable Name
1	'ASTM_Tilted_Std_Spectra'	Header
2	1	Pressure input mode (1 = pressure and altitude): ISPR
2a	1013.25 0.0.	Station Pressure (mb) & 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	1	Ozone Calculation (1 = default from Atmospheric Profile): IO3
6	1	Pollution level mode (1 = standard conditions/no pollution): IGAS (see Appendix C)
7	370	Carbon Dioxide volume mixing ratio (ppm): qCO2 (see Appendix C)
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	0.084	Aerosol Optical Depth @ 500 nm: TAU5
10	37	Far field Spectral Albedo file to use (38= Light Sandy Soil): IALBDX
10b	1	Specify tilt calculation (1 = yes): ITILT
10c	37 20 180	Albedo and Tilt variables—Albedo file to use for near field, Tilt, and Azimuth: IALBDG, TILT, WAZIM
11	280 4000 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 4000 0.5	Output file wavelength—Print limits, start, stop, minimum step size: WPMN, WPMX, INTVL
12b	2	Number of output variables to print: IOTOT
12c	6 7	Code relating output variables to print [6 = Direct tilt, OUT(6); 7 = Diffuse tilt, OUT(7)]
13	0	Circumsolar calculation mode (1 = yes): ICIRC
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	1.5	Air mass value: AMASS

TABLE 2 Modification to Table 1 to Generate the Reference Spectra for a 90° Tilt

Card ID	Value	Parameter/Description/Variable Name
10c	37 90 180	Albedo and Tilt variables—Albedo file to use for near field, Tilt, and Azimuth:IALBDG, TILT, WAZIM

appears in the table) separately; and *(e)* smooth the spectral results to different resolution and wavelength step by using the postprocessing options.

6. Solar Spectral Irradiance

6.1 Table 3 presents the reference direct and diffuse solar irradiance on two sun-facing planes, tilted at 20° and 90° from the horizontal, for the conditions specified in Tables 1 and 2.

6.2 The table contains:

6.2.1 Direct and diffuse solar spectral irradiance incident on a sun-facing plane tilted to 20° from the horizontal in the wavelength range from 280 nm to 4000 nm.

6.2.2 Direct and diffuse solar spectral irradiance incident on a sun-facing plane tilted to 90° from the horizontal in the wavelength range from 280 nm to 4000 nm.

6.2.3 The columns in each table contain:

6.2.3.1 Column 1: wavelength in nanometers (nm).

6.2.3.2 Column 2: direct spectral irradiance incident on a sun-facing surface tilted 20°. $E_{D\lambda}$, $W \cdot m^{-2} \cdot nm^{-1}$.

6.2.3.3 Column 3: diffuse spectral irradiance incident on a sun-facing surface tilted 20°. $E_{d\lambda}$, $W \cdot m^{-2} \cdot nm^{-1}$.

6.2.3.4 Column 4: direct spectral irradiance incident on a sun-facing surface tilted 90°. $E_{D\lambda}$, $W \cdot m^{-2} \cdot nm^{-1}$.

6.2.3.5 Column 5: direct spectral irradiance incident on a sun-facing surface tilted 90°. $E_{d\lambda}$, $W \cdot m^{-2} \cdot nm^{-1}$.

7. Validation

7.1 In part of the spectral region of interest (280–4000 nm), the SMARTS model has been verified against experimental data. SMARTS performance is adequate for the region from 295–2500 nm. No reliable experimental data has been found to verify performance below 295 nm or above 2500 nm.

7.2 Comparisons of the SMARTS computer model with advanced radiative transfer models such as MODTRAN and measured spectral data, including measured spectra on tilted and vertical surfaces, are reported in (**1**, **2**, **11**).

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 shows reasonable agreement (**8**, **11**).

8. Keywords

8.1 albedo; building; collector; daylight; diffuse radiation; direct radiation; fenestration; glazing; photovoltaic; reflectance; skylight; solar energy; solar spectral irradiance; terrestrial; transmittance; window

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TABLE 3 Standard Direct and Diffuse Spectral Solar Irradiance for 20º and 90° Sun-Facing Tilted Surfaces

Wavelength, nm	Direct 20°, W·m^{-2}·nm^{-1}	Diffuse 20°, W·m^{-2}·nm^{-1}	Direct 90°, W·m^{-2}·nm^{-1}	Diffuse 90°, W·m^{-2}·nm^{-1}	Wavelength, nm	Direct 20°, W·m^{-2}·nm^{-1}	Diffuse 20°, W·m^{-2}·nm^{-1}	Direct 90°, W·m^{-2}·nm^{-1}	Diffuse 90°, W·m^{-2}·nm^{-1}
λ	$E_{D\lambda}$	$E_{d\lambda}$	$E_{D\lambda}$	$E_{d\lambda}$	λ	$E_{D\lambda}$	$E_{d\lambda}$	$E_{D\lambda}$	$E_{d\lambda}$
1	2	3	4	5	1	2	3	4	5
280.0	2.20E-26	5.09E-23	1.86E-26	2.62E-23	1161.0	0.2919	0.0092	0.2471	0.0076
280.5	9.47E-25	1.32E-21	8.02E-25	6.82E-22	1162.0	0.2940	0.0092	0.2489	0.0076
281.0	5.31E-24	6.12E-21	4.50E-24	3.15E-21	1163.0	0.3929	0.0128	0.3326	0.0105
281.5	2.38E-22	1.68E-19	2.02E-22	8.68E-20	1164.0	0.3373	0.0107	0.2856	0.0088
282.0	2.46E-21	1.28E-18	2.08E-21	6.61E-19	1165.0	0.3263	0.0103	0.2763	0.0085
282.5	1.15E-20	4.88E-18	9.75E-21	2.51E-18	1166.0	0.3149	0.0099	0.2666	0.0081
283.0	5.87E-20	1.98E-17	4.97E-20	1.02E-17	1167.0	0.3441	0.0109	0.2914	0.0090
283.5	1.27E-19	3.79E-17	1.07E-19	1.95E-17	1168.0	0.3522	0.0111	0.2982	0.0092
284.0	4.33E-18	7.77E-16	3.66E-18	4.01E-16	1169.0	0.3551	0.0113	0.3006	0.0093
284.5	1.88E-17	2.65E-15	1.59E-17	1.37E-15	1170.0	0.3848	0.0123	0.3258	0.0101
285.0	7.82E-17	8.54E-15	6.62E-17	4.40E-15	1171.0	0.3762	0.0119	0.3185	0.0098
285.5	5.60E-16	4.52E-14	4.74E-16	2.33E-14	1172.0	0.3817	0.0121	0.3231	0.0100
286.0	2.04E-15	1.45E-13	1.73E-15	7.47E-14	1173.0	0.3830	0.0121	0.3243	0.0100
286.5	1.60E-14	8.83E-13	1.36E-14	4.55E-13	1174.0	0.2833	0.0086	0.2399	0.0071
287.0	6.30E-14	2.87E-12	5.34E-14	1.48E-12	1175.0	0.3797	0.0120	0.3214	0.0099
287.5	3.18E-13	1.14E-11	2.69E-13	5.86E-12	1176.0	0.4000	0.0128	0.3386	0.0105
288.0	2.44E-12	6.42E-11	2.06E-12	3.31E-11	1177.0	0.3964	0.0125	0.3356	0.0103
288.5	7.88E-12	1.75E-10	6.67E-12	9.04E-11	1178.0	0.3027	0.0092	0.2562	0.0076
289.0	3.04E-11	5.69E-10	2.57E-11	2.94E-10	1179.0	0.4058	0.0129	0.3436	0.0106
289.5	1.34E-10	2.07E-09	1.13E-10	1.07E-09	1180.0	0.3701	0.0115	0.3133	0.0095
290.0	4.47E-10	5.94E-09	3.79E-10	3.06E-09	1181.0	0.3821	0.0119	0.3235	0.0098
290.5	1.16E-09	1.35E-08	9.79E-10	6.94E-09	1182.0	0.2720	0.0081	0.2303	0.0067
291.0	3.39E-09	3.37E-08	2.87E-09	1.74E-08	1183.0	0.3683	0.0115	0.3118	0.0095
291.5	1.25E-08	1.03E-07	1.06E-08	5.28E-08	1184.0	0.3528	0.0109	0.2987	0.0089
292.0	3.55E-08	2.46E-07	3.00E-08	1.27E-07	1185.0	0.3424	0.0105	0.2899	0.0086
292.5	6.12E-08	3.86E-07	5.19E-08	1.99E-07	1186.0	0.4006	0.0125	0.3391	0.0103
293.0	1.37E-07	7.67E-07	1.16E-07	3.95E-07	1187.0	0.3828	0.0118	0.3241	0.0098
293.5	4.10E-07	1.95E-06	3.47E-07	1.01E-06	1188.0	0.2820	0.0084	0.2387	0.0069
294.0	8.23E-07	3.51E-06	6.96E-07	1.81E-06	1189.0	0.3493	0.0107	0.2957	0.0088
294.5	1.39E-06	5.43E-06	1.18E-06	2.80E-06	1190.0	0.3883	0.0120	0.3288	0.0099
295.0	2.81E-06	9.87E-06	2.38E-06	5.09E-06	1191.0	0.3752	0.0115	0.3177	0.0095
295.5	6.98E-06	2.16E-05	5.91E-06	1.11E-05	1192.0	0.3975	0.0123	0.3366	0.0101
296.0	1.28E-05	3.62E-05	1.09E-05	1.87E-05	1193.0	0.3817	0.0117	0.3232	0.0097
296.5	2.03E-05	5.25E-05	1.72E-05	2.71E-05	1194.0	0.3938	0.0121	0.3334	0.0100
297.0	2.89E-05	6.96E-05	2.45E-05	3.59E-05	1195.0	0.3755	0.0115	0.3179	0.0095
297.5	5.91E-05	1.30E-04	5.01E-05	6.68E-05	1196.0	0.3625	0.0110	0.3069	0.0091
298.0	9.69E-05	1.96E-04	8.20E-05	1.01E-04	1197.0	0.4007	0.0123	0.3392	0.0102
298.5	1.24E-04	2.37E-04	1.05E-04	1.22E-04	1198.0	0.3646	0.0111	0.3087	0.0091
299.0	1.77E-04	3.18E-04	1.50E-04	1.64E-04	1199.0	0.3069	0.0091	0.2598	0.0075
299.5	3.26E-04	5.37E-04	2.76E-04	2.77E-04	1200.0	0.3766	0.0114	0.3188	0.0094
300.0	3.97E-04	6.23E-04	3.36E-04	3.21E-04	1201.0	0.3673	0.0111	0.3110	0.0091
300.5	4.98E-04	7.43E-04	4.22E-04	3.83E-04	1202.0	0.3674	0.0110	0.3110	0.0091
301.0	8.01E-04	1.12E-03	6.78E-04	5.76E-04	1203.0	0.3647	0.0110	0.3088	0.0091
301.5	1.15E-03	1.52E-03	9.73E-04	7.83E-04	1204.0	0.3049	0.0089	0.2581	0.0074
302.0	1.27E-03	1.62E-03	1.07E-03	8.36E-04	1205.0	0.3671	0.0110	0.3108	0.0091
302.5	1.91E-03	2.32E-03	1.62E-03	1.20E-03	1206.0	0.4037	0.0123	0.3418	0.0101
303.0	3.25E-03	3.74E-03	2.75E-03	1.93E-03	1207.0	0.3612	0.0108	0.3058	0.0089
303.5	4.19E-03	4.64E-03	3.54E-03	2.39E-03	1208.0	0.3642	0.0109	0.3083	0.0090
304.0	4.44E-03	4.87E-03	3.76E-03	2.51E-03	1209.0	0.3480	0.0104	0.2947	0.0086
304.5	5.64E-03	6.11E-03	4.77E-03	3.15E-03	1210.0	0.3808	0.0114	0.3224	0.0094
305.0	7.78E-03	8.38E-03	6.59E-03	4.32E-03	1211.0	0.3548	0.0106	0.3004	0.0087
305.5	8.88E-03	9.50E-03	7.52E-03	4.90E-03	1212.0	0.3571	0.0106	0.3023	0.0087
306.0	8.85E-03	9.39E-03	7.49E-03	4.84E-03	1213.0	0.3943	0.0118	0.3338	0.0098
306.5	1.01E-02	1.06E-02	8.54E-03	5.48E-03	1214.0	0.3647	0.0108	0.3088	0.0089
307.0	1.33E-02	1.40E-02	1.13E-02	7.24E-03	1215.0	0.3595	0.0106	0.3044	0.0087
307.5	1.70E-02	1.80E-02	1.44E-02	9.28E-03	1216.0	0.3917	0.0117	0.3316	0.0097
308.0	1.81E-02	1.90E-02	1.53E-02	9.81E-03	1217.0	0.3825	0.0114	0.3238	0.0094
308.5	0.0198	0.0208	0.0168	0.0107	1218.0	0.3858	0.0115	0.3267	0.0095
309.0	0.0194	0.0203	0.0165	0.0105	1219.0	0.3753	0.0111	0.3177	0.0092
309.5	0.0206	0.0219	0.0175	0.0113	1220.0	0.3848	0.0114	0.3258	0.0094
310.0	0.0243	0.0257	0.0205	0.0133	1221.0	0.3909	0.0116	0.3309	0.0096
310.5	0.0313	0.0330	0.0265	0.0170	1222.0	0.3793	0.0112	0.3211	0.0092
311.0	0.0396	0.0418	0.0335	0.0215	1223.0	0.3732	0.0110	0.3159	0.0091
311.5	0.0403	0.0422	0.0341	0.0218	1224.0	0.3766	0.0111	0.3188	0.0091
312.0	0.0444	0.0473	0.0376	0.0244	1225.0	0.3885	0.0115	0.3289	0.0095
312.5	0.0469	0.0503	0.0397	0.0259	1226.0	0.3934	0.0116	0.3330	0.0096
313.0	0.0509	0.0545	0.0431	0.0281	1227.0	0.3640	0.0106	0.3082	0.0088
313.5	0.0515	0.0541	0.0436	0.0279	1228.0	0.3920	0.0116	0.3319	0.0095
314.0	0.0569	0.0605	0.0482	0.0312	1229.0	0.3926	0.0116	0.3324	0.0095
314.5	0.0615	0.0668	0.0521	0.0345	1230.0	0.3866	0.0113	0.3273	0.0093
315.0	0.0643	0.0696	0.0544	0.0359	1231.0	0.3966	0.0117	0.3358	0.0096

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TABLE 3 *Continued*

Wavelength, nm	Direct 20°, W·m^{-2}·nm^{-1}	Diffuse 20°, W·m^{-2}·nm^{-1}	Direct 90°, W·m^{-2}·nm^{-1}	Diffuse 90°, W·m^{-2}·nm^{-1}	Wavelength, nm	Direct 20°, W·m^{-2}·nm^{-1}	Diffuse 20°, W·m^{-2}·nm^{-1}	Direct 90°, W·m^{-2}·nm^{-1}	Diffuse 90°, W·m^{-2}·nm^{-1}
λ	$E_{D\lambda}$	$E_{d\lambda}$	$E_{D\lambda}$	$E_{d\lambda}$	λ	$E_{D\lambda}$	$E_{d\lambda}$	$E_{D\lambda}$	$E_{d\lambda}$
1	2	3	4	5	1	2	3	4	5
315.5	0.0566	0.0596	0.0479	0.0307	1232.0	0.3919	0.0115	0.3318	0.0095
316.0	0.0585	0.0627	0.0496	0.0323	1233.0	0.3816	0.0111	0.3231	0.0092
316.5	0.0708	0.0769	0.0599	0.0397	1234.0	0.3951	0.0116	0.3345	0.0096
317.0	0.0812	0.0872	0.0687	0.0450	1235.0	0.3908	0.0114	0.3309	0.0094
317.5	0.0870	0.0919	0.0737	0.0474	1236.0	0.3942	0.0115	0.3338	0.0095
318.0	0.0836	0.0889	0.0708	0.0458	1237.0	0.3895	0.0113	0.3298	0.0094
318.5	0.0873	0.0951	0.0739	0.0490	1238.0	0.3933	0.0115	0.3330	0.0094
319.0	0.0958	0.1052	0.0811	0.0542	1239.0	0.3889	0.0113	0.3293	0.0093
319.5	0.0933	0.0986	0.0790	0.0508	1240.0	0.3873	0.0112	0.3279	0.0093
320.0	0.0984	0.1024	0.0833	0.0528	1241.0	0.3884	0.0112	0.3288	0.0093
320.5	0.1161	0.1241	0.0983	0.0640	1242.0	0.3888	0.0113	0.3292	0.0093
321.0	0.1171	0.1282	0.0991	0.0661	1243.0	0.3847	0.0111	0.3257	0.0092
321.5	0.1119	0.1217	0.0947	0.0628	1244.0	0.3828	0.0110	0.3241	0.0091
322.0	0.1065	0.1105	0.0902	0.0570	1245.0	0.3839	0.0111	0.3250	0.0091
322.5	0.1045	0.1076	0.0885	0.0555	1246.0	0.3864	0.0111	0.3271	0.0092
323.0	0.1015	0.1060	0.0859	0.0546	1247.0	0.3847	0.0110	0.3257	0.0091
323.5	0.1169	0.1263	0.0990	0.0651	1248.0	0.3857	0.0110	0.3266	0.0091
324.0	0.1297	0.1396	0.1098	0.0720	1249.0	0.3866	0.0111	0.3273	0.0091
324.5	0.1351	0.1415	0.1143	0.0730	1250.0	0.3845	0.0110	0.3255	0.0091
325.0	0.1354	0.1365	0.1146	0.0704	1251.0	0.3807	0.0108	0.3223	0.0089
325.5	0.1566	0.1596	0.1326	0.0823	1252.0	0.3794	0.0108	0.3212	0.0089
326.0	0.1822	0.1896	0.1543	0.0978	1253.0	0.3767	0.0107	0.3189	0.0088
326.5	0.1935	0.2038	0.1639	0.1051	1254.0	0.3733	0.0105	0.3161	0.0087
327.0	0.1907	0.1973	0.1615	0.1017	1255.0	0.3792	0.0107	0.3211	0.0089
327.5	0.1859	0.1886	0.1574	0.0972	1256.0	0.3705	0.0104	0.3137	0.0086
328.0	0.1727	0.1685	0.1462	0.0869	1257.0	0.3664	0.0103	0.3102	0.0085
328.5	0.1806	0.1809	0.1529	0.0932	1258.0	0.3745	0.0105	0.3170	0.0087
329.0	0.2035	0.2075	0.1723	0.1070	1259.0	0.3597	0.0100	0.3045	0.0083
329.5	0.2259	0.2301	0.1913	0.1186	1260.0	0.3629	0.0101	0.3073	0.0083
330.0	0.2288	0.2294	0.1937	0.1182	1261.0	0.3465	0.0096	0.2934	0.0079
330.5	0.2106	0.2047	0.1783	0.1056	1262.0	0.3333	0.0091	0.2822	0.0075
331.0	0.1995	0.1908	0.1689	0.0984	1263.0	0.3371	0.0092	0.2854	0.0076
331.5	0.2065	0.1988	0.1748	0.1025	1264.0	0.3130	0.0085	0.2650	0.0070
332.0	0.2141	0.2089	0.1813	0.1077	1265.0	0.3333	0.0091	0.2822	0.0075
332.5	0.2154	0.2104	0.1824	0.1085	1266.0	0.3246	0.0088	0.2748	0.0072
333.0	0.2120	0.2040	0.1795	0.1052	1267.0	0.3270	0.0089	0.2769	0.0073
333.5	0.2033	0.1907	0.1721	0.0983	1268.0	0.3122	0.0084	0.2643	0.0069
334.0	0.2082	0.1930	0.1762	0.0995	1269.0	0.2082	0.0053	0.1763	0.0044
334.5	0.2223	0.2081	0.1882	0.1073	1270.0	0.3264	0.0088	0.2763	0.0073
335.0	0.2314	0.2170	0.1959	0.1119	1271.0	0.3438	0.0093	0.2911	0.0077
335.5	0.2263	0.2116	0.1916	0.1091	1272.0	0.3442	0.0093	0.2914	0.0077
336.0	0.2081	0.1928	0.1762	0.0994	1273.0	0.3421	0.0093	0.2897	0.0076
336.5	0.1931	0.1755	0.1635	0.0905	1274.0	0.3420	0.0093	0.2896	0.0076
337.0	0.1902	0.1700	0.1611	0.0876	1275.0	0.3472	0.0094	0.2940	0.0077
337.5	0.2048	0.1809	0.1734	0.0933	1276.0	0.3511	0.0095	0.2973	0.0078
338.0	0.2213	0.1968	0.1874	0.1015	1277.0	0.3537	0.0096	0.2995	0.0079
338.5	0.2321	0.2063	0.1965	0.1064	1278.0	0.3601	0.0098	0.3049	0.0080
339.0	0.2369	0.2093	0.2005	0.1079	1279.0	3.58E-01	9.66E-03	3.03E-01	7.97E-03
339.5	0.2434	0.2129	0.2061	0.1097	1280.0	3.55E-01	9.59E-03	3.01E-01	7.91E-03
340.0	0.2593	0.2228	0.2195	0.1149	1281.0	3.48E-01	9.39E-03	2.95E-01	7.75E-03
340.5	0.2594	0.2214	0.2196	0.1141	1282.0	3.14E-01	8.49E-03	2.66E-01	7.00E-03
341.0	0.2442	0.2084	0.2067	0.1074	1283.0	3.43E-01	9.25E-03	2.90E-01	7.62E-03
341.5	0.2435	0.2069	0.2062	0.1067	1284.0	3.54E-01	9.53E-03	3.00E-01	7.86E-03
342.0	0.2546	0.2147	0.2156	0.1107	1285.0	3.57E-01	9.59E-03	3.02E-01	7.91E-03
342.5	0.2649	0.2218	0.2243	0.1143	1286.0	3.60E-01	9.66E-03	3.05E-01	7.97E-03
343.0	0.2698	0.2235	0.2284	0.1152	1287.0	3.56E-01	9.50E-03	3.01E-01	7.84E-03
343.5	0.2557	0.2096	0.2165	0.1081	1288.0	3.54E-01	9.44E-03	2.99E-01	7.79E-03
344.0	0.2217	0.1785	0.1877	0.0920	1289.0	3.45E-01	9.15E-03	2.92E-01	7.54E-03
344.5	0.2137	0.1717	0.1809	0.0885	1290.0	3.48E-01	9.26E-03	2.94E-01	7.64E-03
345.0	0.2436	0.1951	0.2062	0.1006	1291.0	3.52E-01	9.36E-03	2.98E-01	7.72E-03
345.5	0.2602	0.2072	0.2203	0.1068	1292.0	3.34E-01	8.78E-03	2.83E-01	7.24E-03
346.0	0.2548	0.2015	0.2157	0.1039	1293.0	3.48E-01	9.19E-03	2.94E-01	7.58E-03
346.5	0.2601	0.2042	0.2202	0.1053	1294.0	3.41E-01	8.98E-03	2.88E-01	7.41E-03
347.0	0.2651	0.2060	0.2245	0.1062	1295.0	3.41E-01	8.98E-03	2.89E-01	7.40E-03
347.5	0.2567	0.1977	0.2173	0.1019	1296.0	3.28E-01	8.56E-03	2.78E-01	7.06E-03
348.0	0.2563	0.1964	0.2170	0.1012	1297.0	3.13E-01	8.09E-03	2.65E-01	6.67E-03
348.5	0.2614	0.1989	0.2213	0.1026	1298.0	3.30E-01	8.61E-03	2.80E-01	7.10E-03
349.0	0.2524	0.1908	0.2137	0.0983	1299.0	3.44E-01	9.02E-03	2.92E-01	7.44E-03
349.5	0.2599	0.1948	0.2201	0.1004	1300.0	2.98E-01	7.60E-03	2.52E-01	6.27E-03
350.0	0.2879	0.2141	0.2437	0.1104	1301.0	3.06E-01	7.82E-03	2.59E-01	6.45E-03
350.5	0.3103	0.2290	0.2627	0.1180	1302.0	3.30E-01	8.56E-03	2.80E-01	7.06E-03

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