Designation: G222 – 21

Standard Practice for
Estimation of UV Irradiance Received by Field-Exposed Products as a Function of Location[1]

This standard is issued under the fixed designation G222; 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.

1. Scope

1.1 This practice describes methods to estimate the total solar ultraviolet irradiance on a horizontal surface as a function of Air Mass and geographic location.

1.2 This practice provides a mathematical model for calculating Global Horizontal Ultraviolet irradiance (GHUV) from Global Horizontal Irradiance (GHI) data for a specific location.

1.3 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D7869 Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings

E772 Terminology of Solar Energy Conversion

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

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

G183 Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers

2.2 *ISO Standards:*[3]

ISO/TR 17801 Standard Table for Reference Global Solar Spectral Irradiance at Sea Level — Horizontal, Relative Air Mass 1

ISO 9060:2018 Solar Energy — Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiation

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions applicable to this practice can be found in Terminologies E772 and G113.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *Diffuse Horizontal Irradiance (DHI), $W \cdot m^{-2}$, n*—the total solar irradiance received on a horizontal plane that has been scattered or diffused by the atmosphere.

3.2.2 *Direct Normal Irradiance (DNI), $W \cdot m^{-2}$, n*—the total solar irradiance received on a plane normal to the sun within a 5° concentric field of view around the sun.

3.2.3 *Global Horizontal Irradiance (GHI), $W \cdot m^{-2}$, n*—the total solar irradiance received on a horizontal plane measured directly using a pyranometer with a hemispherical view, or calculated as the sum of Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) each measured or modeled independently:

$GHI = DHI + DNI * \cos(\theta_z)$ where θ_z is the solar zenith angle.

3.2.3.1 *Discussion*—The wavelength range reported for field measurements of GHI varies with the pyranometer design and application. Commercial pyranometers generally measure over the 300–3000 nm range, from near the solar cut-on and cut-off (see ISO 9060). This is sufficient for weathering and durability testing applications because 95 % of the solar irradiance on a surface is from wavelengths < 1800 nm. Standard reference spectra for different applications vary in the

[1] This practice is 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] 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] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

wavelength range they report. For example, ISO 17801 reports values from 285–2400 nm, whereas ASTM G173, which was developed primarily for photovoltaic energy applications, reports from 280–4000 nm.

3.2.4 *Global Horizontal UV irradiance (GHUV), W·m^{-2}, n*—the ultraviolet solar irradiance received on a horizontal plane for wavelengths shorter than those for visible irradiance and longer than the solar cut-on where the upper limit varies with the ultraviolet radiometer design. GHUV shall be reported using the following format designating the wavelength range over which it is valid: GHUV(X–Y) where X is the minimum wavelength and Y is the maximum.

3.2.4.1 *Discussion*—GHUV values for the range 295–385 nm, denoted as GHUV(295–385), have historically been measured and reported by solar radiation monitoring stations, especially from outdoor exposure testing service suppliers. This range traces back to the early use of spectroradiometers with a spectral range of 295–385 nm. Another commonly reported value is GHUV(280–400) that combines the UVA and UVB ranges of solar ultraviolet irradiance (see Terminology G113). Some radiometers measure the total UVA and UVB irradiance directly while others measure them independently; GHUV(280–400) is then calculated as the sum of the values obtained.

3.2.5 *Solar cut-on, n*—the wavelength at which the solar irradiance on a plane is greater than 0.001 W/m^2/nm. For practical weathering and durability exposure testing purposes, the lowest wavelength at which this value can occur is 295 nm under ideal conditions (for example, ASTM G177); see Appendix X3 (**1**).[4]

4. Summary of Practice

4.1 The mathematical model described in this practice provides a simple way to estimate the representative contribution of UV to the total solar irradiance on a horizontal surface through the ratio GHUV/GHI.

4.2 Data for GHI may be obtained from measurements or modeled datasets (**2**).

4.3 The method requires GHI input of good quality. Practice G183 provides details about standard practice of field measurements of solar radiometric data. If GHI is not reliably measured on site, low-uncertainty modeled estimates should be used instead.

4.4 The Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) atmospheric transmission code was used to generate ratios of ultraviolet to total solar radiation, as a function of air mass for multiple locations with site specific surface albedo, and atmospheric constituents such as aerosols, water vapor or ozone. The mathematical model described in this practice generalizes these ratios to any geographical location with an estimation of accuracy.

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

5. Significance and Use

5.1 Products exposed outdoors degrade due to primarily three stress factors: sunlight, temperature and moisture. The rate of property change is a function of time and stressors' intensity.

5.2 Whereas the UV irradiance calculated in this practice is independent of material, it is especially relevant to polymeric materials exposed outdoors as the combined action of UV radiation and oxygen is often the dominant factor leading to their degradation. Therefore, estimating UV irradiance is an important parameter to assess the service life of products.

5.3 UV radiant dosage is often more important to determine in the correlation with the amount of degradation than total solar radiant dosage or duration of time. The comparison of UV radiant dosage from one location to another may be used to normalize degradation results.

5.4 Measured UV irradiance data are scarce compared to total solar irradiance data. Many locations that monitor solar resource data only collect data for total solar radiation. This practice allows the user to estimate the amount of UV irradiance from the amount of total solar irradiance for any site.

6. Estimating the Contribution of UV Light to the Solar Irradiance on a Horizontal Surface

6.1 Under clear-sky conditions, GHUV and GHI can be simulated using the SMARTS spectral radiation model, as described by Gueymard (**3-5**). This practice is based on version 2.9.8 of SMARTS (**5**).

6.2 Eq 1, as described by Habte et al. (**6**), was created by fitting GHUV and GHI data as a function of air mass for multiple SMARTS simulations and for different locations, surface albedo, and atmospheric constituents such as aerosols, water vapor or ozone. The SMARTS outputs can be directly compared to what would be obtained under the conditions pertaining to the ASTM G177 standard spectrum, since the latter was developed with SMARTS.

$$\frac{GHUV}{GHI} = \sum_{i=0}^{4} m_i AM^i \tag{1}$$

where:

$GHUV$ = global horizontal UV irradiance, W/m^2
GHI = global horizontal irradiance, W/m^2
m_i = location-specific numerical coefficients
AM = air mass coefficient

Eq 1 can be directly used with AM values obtained from climate data files with hourly, or more frequent, data. Most data sources will include a measure of the solar zenith angle (θ_z); see 3.2.3. The solar zenith angle should be obtained from a solar geometry calculator. The air mass may also be calculated from the value of the solar zenith angle using equation for solar zenith angles below 80° (**7**).

$$AM = \frac{1}{\left[\cos\ (\theta_z) + 0.48353 \times \theta_z^{0.09585} / (96.741\ -\ \theta_z\ )^{1.754}\right]} \tag{2}$$

where θ_z is the solar zenith angle, with $\theta_z < 80$.

6.3 The m_i coefficients used in Eq 1 are location specific. A set of m_i coefficients for 15 locations are proposed by Habte et