Designation: G183 – 15

Standard Practice for
Field Use of Pyranometers, Pyrheliometers and UV Radiometers[1]

This standard is issued under the fixed designation G183; 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 deployment conditions, maintenance requirements, verification procedures and calibration frequencies for use of pyranometers, pyrheliometers and UV radiometers in outdoor testing environments. This practice also discusses the conditions that dictate the level of accuracy required for instruments of different types.

1.2 While both pyranometers and UV radiometers may be employed indoors to measure light radiation sources, the measurement of ultraviolet and light radiation in accelerated weathering enclosures using manufactured light sources generally requires specialized radiometric instruments. Use of radiometric instrumentation to measure laboratory light sources is covered in ISO 9370.

NOTE 1—An ASTM standard that is similar to ISO 9370 is under development and deals with the instrumental determination of irradiance and radiant exposure in weathering tests.

1.3 The characterization of radiometers is outside the scope of the activities required of users of radiometers, as contemplated by this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology of Solar Energy Conversion
G7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
G24 Practice for Conducting Exposures to Daylight Filtered Through Glass
G90 Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight
G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

2.2 *ISO Standards:*[3]

ISO 877 Plastics—Methods of Exposure to Direct Weathering, Indirect Weathering Using Glass-Filtered Daylight and Indirect Weathering by Daylight Using Fresnel Mirrors
ISO 9060 Solar Energy—Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiation
ISO 9370 Plastics—Instrumental Determination of Radiant Exposure in Weathering Tests—General Guidance
ISO TR 9901 Solar Energy—Field Pyranometers—Recommended Practice for Use

2.3 *WMO Reference:*[4]

World Meteorological Organization (WMO), 1983 "Measurement of Radiation," *Guide to Meteorological Instruments and Methods of Observation*, seventh ed., WMO-No. 8, Geneva

3. Terminology

3.1 *Definitions*—The definitions given in Terminologies E772 and G113 are applicable to this practice.

4. Radiometer Selection

4.1 *Criteria for the Selection of Radiometers:*

4.1.1 There are several criteria that need to be considered for selection of the radiometer that will be used:

4.1.1.1 Function specific criteria, such as whether a pyranometer, pyrheliometer or UV radiometer is required,

4.1.1.2 Task specific criteria, such as the accuracy requirements for the selected incident angle and temperature ranges, and maximum response time,

4.1.1.3 Operational criteria, such as dimensions, weight, stability and maintenance, and

4.1.1.4 Economic criteria, such as when networks have to be equipped, or whether the instrument is being acquired for internal reference purposes, or for research purposes, etc.

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[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), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

[4] Available from World Meterological Organization, 7 bis, avenue de la Paix, CP. 2300, CH-1211 Geneva 2, Switzerland, http://www.wmo.int.

4.2 *Selection Related to Radiometer Type:*

4.2.1 Pyranometers, which measure global solar irradiance in the 300 to 2500 nm wavelength region, are required to assess the hemispherical solar irradiance on surfaces of test specimens mounted on weathering test racks that are used by the outdoor weathering exposure community. Typically, pyranometers are required to measure the exposure levels specified in the applicable ASTM and/or ISO outdoor weathering standards such as those described in Practices G7, G24, G90, and ISO 877.

4.2.2 Pyrheliometers, which measure direct (or, beam) solar irradiance in the 300 to 2500 nm wavelength region, are required to assess the solar irradiance reflected onto the target board by the mirrors of Fresnel Reflecting Concentrators used in outdoor accelerated tests specified by ASTM and ISO Standards described in Practice G90 and ISO 877.

4.2.3 Ultraviolet radiometers are either broad band or narrow band instruments covering defined wavelength regions of the solar ultraviolet spectrum.

4.2.3.1 Broad-band UV radiometers usually are designed to measure either UV-A, UV-B or some component of both UV-A and UV-B radiation.

NOTE 2—Certain UV radiometers that are designated as total ultraviolet radiometers are advertised to measure over the total wavelength range from the so called UV cutoff at approximately 300 nm to 385 or 400 nm, but in fact measure mostly UV-A radiation by virtue of their very low responsivity to wavelengths below 315 nm.

4.2.3.2 Narrow-band UV radiometers are essentially constructed using interference filters that isolate narrow bands of radiation having FWHM values of 20 nm, or less; their center wavelengths (CW) may reside anywhere in the UV spectrum from 280 to 400 nm wavelength—depending on the application for which they are intended.

NOTE 3—While the World Meteorological Organization (WMO) and the International Standards Organization (ISO) have established requirements for Secondary Standard and High, Good, and Moderate Quality pyranometers and pyrheliometers, specifications and required operational characteristics of different classes of ultraviolet radiometers have not been addressed by either organization.

NOTE 4—High Quality instruments are not necessary for all applications.

4.3 *Selection Related to Measuring Specifications:*

4.3.1 As a first step, all possible ranges of measuring parameters such as temperature, irradiance levels, angles of incidence, tilt angles, and station latitude, must be compiled.

4.3.2 Next, documentation must be compiled of available information about the technical characteristics, and the technical and physical specifications of the relevant radiometers given by:

4.3.2.1 The WMO and ISO classification of pyranometers given in the WMO Guide, and in ISO 9060 and ISO 9370 (which together define the specifications to be met by different categories of pyranometers and pyrheliometers),

4.3.2.2 The data specification sheets obtained from the manufacturer, and

4.3.2.3 Preferably, data on the technical characteristics and performance obtained from independent sources such as independent testing laboratories, research institutes and government laboratories.

4.3.3 If the accuracy of the highest category of instrument is insufficient for the application contemplated, the following recommendations are given:

4.3.3.1 Hemispherical solar radiation may be measured by the simultaneous deployment of a pyrheliometer and a continuously shaded secondary standard pyranometer to achieve accuracies that are greater than can be achieved by a secondary standard pyranometer alone,

4.3.3.2 Direct (beam) solar radiation may be measured using an absolute cavity pyrheliometer employing electrical substitution of thermally absorbed radiation to achieve accuracies that are greater than can be achieved by a First-class pyrheliometer, and

4.3.3.3 Specific ultraviolet wavelength bands may be determined by integration of the selected wavelength bands using a scanning spectroradiometer possessing good slit function and narrow band pass characteristics to achieve accuracies that are greater than the most accurate narrow or broad band ultraviolet radiometers currently commercially available.

5. Practice for Use—General

5.1 *Installation of Radiometers:*

5.1.1 When performing measurements in support of testing, the test object and the field radiometer shall be equally exposed with respect to field of view, ground radiation and any stray light that may be present. This means that the test surface and the radiometer shall receive the same irradiance.

5.1.2 When used to determine the irradiance accumulated on solar concentrating devices such as the Fresnel reflecting concentrators used in Practice G90, and other types of solar concentrators, it is essential that the collection system of the solar concentrators, such as the flat mirrors used in Practice G90, do not receive direct irradiance that is unavailable to the optical system that connotes the pyrheliometer required.

5.1.3 The need for easy access to the radiometer for maintenance operations shall be considered in selecting the installation site, mount, etc.

5.2 *Electrical Installation:*

5.2.1 The electrical cable employed shall be secured firmly to the mounting stand to minimize the possibility of breakage or intermittent disconnection in severe weather.

5.2.2 Wherever possible, the electrical cable shall be protected and buried underground—particularly when recording devices, controllers, or converters are located at a distance. Use of shielded cable is highly recommended. The cable, recorder and other electronic devices, shall be connected by a very low resistance conductor to a common ground.

5.2.3 Contact the manufacturer of the radiometer being installed to establish the maximum allowable cable length permissible for the instrument's impedance so as to preclude significant signal loss (see 5.4.5.2 for additional requirements).

5.2.4 When hard wiring electrical connections, all exposed junctions shall be weatherproofed and protected from physical damage.

5.2.5 Establish and identify the polarity of all relevant connections prior to connecting to the recording device, converters, or controllers. Make all connections in accordance with the manufacturer's instructions.

5.3 *Required Maintenance Activities:*

5.3.1 *Inspection:*

5.3.1.1 Whenever possible, inspect radiometers employed in continuous operation at least once each day. Inspection and maintenance activities of specific attributes described in the following sections should be carried out daily, monthly and yearly as indicated.

NOTE 5—It should be noted that the quality of data obtained using total solar and solar ultraviolet radiometers depends strongly on the amount of personal attention given during the observation program.

5.3.2 *Daily Routine Inspection and Maintenance:*

5.3.2.1 The exterior glass domes and/or diffusers or windows, shall be inspected daily and cleaned at least once each week or more often whenever dust or other deposits are visible. Cleaning shall occur by spraying with deionized water and wiping dry with non-abrasive and lint-free cloth or tissue. It is recommended that this inspection and possible cleaning be performed early each day.

5.3.2.2 If frozen snow, glazed frost, hoar frost or rime is present, remove the deposit very gently, initially with the sparing use of a de-icing fluid or a warm lint-free cloth, appropriate for the type of glass dome, window, or diffuser, after which the glass dome, window, or diffuser shall be wiped clean and dry.

5.3.2.3 After heavy dew, rain, sleet, snow or frost buildup, check to determine if condensation is present inside the dome, or on the receptor or diffuser surface. If condensation is discovered inside the dome, on the receptor or diffuser surface of domed radiometers, the instrument's manufacturer shall be contacted to determine a course of action.

NOTE 6—The user may attempt to "dry out" the radiometer by elevating its temperature, either in natural sunlight or in the laboratory, to 50°C. If the condensation is eliminated, the radiometer's calibration constant shall be checked prior to being returned to service.

5.3.2.4 When hard-to-remove deposits of air pollution or local contamination is observed on a radiometer's exterior window, first apply deionized or distilled water on the surface. If the use of a detergent solution is indicated, a prepare a 2 % solution of a mild dish washing detergent and gently apply to the surface. Use a soft, lint-free muslin cloth to gently rub the surface if required. In either case, thoroughly rinse the surface with deionized or distilled water, after which it the window shall be wiped clean and dry. Water spots should not be evident on the surface. However, care should be exercised to avoid scratching the surface.

NOTE 7—The user may use optics cleaning compressed air to blow away all remaining water droplets from the surface after cleaning. Use small, controlled puffs of air, being careful not to discharge any propellant that may leave a residue on the window. Check for any streaking or lint left by the cleaning materials and repeat if necessary.

5.3.2.5 When used, check the operational state of the ventilator or air blower at least weekly and note any unusual noise for subsequent attention. Further, check the condition of ventillation unit filters and clean or replace as necessary.

5.3.2.6 Perform a cursory check of the output data on at least a weekly basis to determine if data being recorded are plausible in relation to the conditions being experienced.

5.3.3 *Monthly Routine Inspection and Maintenance:*

5.3.3.1 Examine the color-indicating desiccant for all instruments where the silica gel container is accessible. If moisture is indicated, replace the desiccant.

NOTE 8—If desiccant is consumed rapidly, the cause might be a defective seal of the instrument's window, a defective electrical connection into the instrument case, or a defective O-ring associated with the desiccant chamber.

5.3.3.2 Attention should be paid to the transmission and amplification of signals. Perform both visual and electrical checks of the cable and amplifier (when used). These inspections shall also be performed when any component of a measuring system has been replaced, or after any anomalies have been detected in the data.

5.3.4 *Quarterly Inspection and Maintenance:*

5.3.4.1 In those radiometers where the desiccant is not visible, remove the desiccant cover and inspect the desiccant for dryness. If moisture is indicated, replace the desiccant. Care should be exercised to ensure that the desiccant container's cover is closed completely (manufacturer's instructions should be followed with respect to ensuring the tightness of the cover, or cap).

5.3.4.2 Verify that the responsivities of all radiometers have not changed to the extent that they are out of tolerance. This can be done by comparison to another radiometer that has the same spectral response function[5] or by determination that the ratio of, for example, UV-B to UV-A irradiance has remained essentially the same (if both measurements are being performed), or, as will usually be the case, if the ratio of total solar UV irradiance to total solar irradiance has remained essentially the same for clear day solar noon conditions.

5.3.5 *Semi-annual Inspection and Maintenance:*

5.3.5.1 Use an inclinometer[6] to determine the inclination of all radiometers mounted at tilts from the horizontal. Inspect the inclination angles of all pyranometers and UV-radiometers including the spirit level of all horizontally mounted radiometers.

5.3.6 *Yearly Inspection and Maintenance:*

5.3.6.1 When calibration schedules do not require annual re calibration, special attention should be paid to the possibility of drift in the sensitivity (that is, the calibration factor) of the radiometer. This shall be accomplished by use of either a field re calibrator (in the case of certain UV-A and UV-B radiometers) or a field reference radiometer maintained by the testing/measuring facility for that purpose.

5.3.6.2 Inspect all radiometers for general deterioration of the instrument—including domes and windows (to detect chips, cracks, or the development of any optical disparity), the receiver coating (to detect discoloration, loss of material, checking, or cracks), and seals (to detect severe discoloration, cracking, degradation, etc.).

5.3.6.3 When either drift in sensitivity greater than the tolerance established by the testing/measuring facility, or greater than permitted by the applicable standards or specifications, or when any degradation of instrument components is noted, the manufacturer should be contacted to

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[5] This is most easily achieved by comparing with a UV radiometer of the same model.

[6] A protractor scale equipped with a rotatable spirit level.

determine the advisability of either replacing the instrument or returning the instrument for refurbishment.

NOTE 9—In the event that component degradation is observed, a field sensitivity check should be performed prior to contacting the manufacturer.

5.3.6.4 When used, inspect the air channels of ventilators or blowers and remove any dirt and debris that may have collected.

5.4 *Recording of Measured Data:*

5.4.1 Recording systems fall into three principal classes:

5.4.1.1 Those providing a series of individual values,

5.4.1.2 Continuous-line or intermittent-dot recorders providing autographic traces, and,

NOTE 10—Potentiometric strip-chart recorders with integration and voltage time integrators are in wide use.

5.4.1.3 Automatic data acquisition systems which can deliver either individual values or integrated totals over a specified period of time.

NOTE 11—Microprocessor controlled data loggers using a variety of support systems for data storage have become common.

5.4.2 *Sampling Rate:*

5.4.2.1 When making instantaneous individual readings, choose the length of the interval over which the series of readings extends and the number of readings comprising the measurement so as to ensure that the derived mean affords a representative value for the desired time interval. This applies equally to a series of readings recorded by means of a fast response multi-channel automatic data logging system and to a series of measurements recorded manually using a millivoltmeter or potentiometer.

5.4.2.2 The frequency of the readings depends on the application and the system characteristics as illustrated by the following questions:

(a) What is the smallest time interval of interest?

(b) What are the response time and accuracy of the radiometer being used?

(c) Are the measurements to be instantaneous values obtained from a sample-hold instrument or short time integrated values obtained with an integrator (that is, a voltage/frequency converter and a counter)?

(d) Does the data acquisition system compress data?

5.4.2.3 Depending on the answers to these questions, the sampling rate can range from one sample measurement per minute to one sample per second, or faster. Generally, for the calculation of average values over periods of between 0.1 and 1.0 h, 100 samples allow the average values to be estimated with sufficient accuracy.

NOTE 12—In solar energy applications, a pyranometer or pyrheliometer signal output is only one of several parameters being measured. Special attention must be given to ensure that all measurements are made simultaneously, or at a time interval much shorter than the rate of change of the irradiance and the response time of the radiometer.

5.4.2.4 The recommended method is to take readings with a short-term integration, to apply a data check and then to perform data compression corresponding to a suitable interval.

NOTE 13—This is only possible with complex data acquisition systems.

5.4.3 *Integration of Data:*

5.4.3.1 There are two systems of data integration: *(1)* Analog using an operational amplifier connected to the integrator, and *(2)* digital by sampling the voltage output from the pyranometer.

5.4.3.2 When using analog integration, check the precision and linearity of the integration system on a monthly basis.

5.4.3.3 When using digital sampling, check the precision of the analog/digital converter, as well as the validity of the sampling frequency, at appropriate intervals (e.g. use Nyquist criterion). Follow the manufacturer's instructions for sampling frequency.

5.4.4 *Time Base:*

5.4.4.1 Time accuracy shall be linked to a recognized universal time reference and should be better than 1 min., and should be better than 1 s for users that are interested in measuring solar irradiance with high accuracy by correcting for solar zenith angle dependence. It is therefore necessary to check the reference time at appropriate intervals.

NOTE 14—GPS or Reference to Radio Station WWVB, 60kHz, Ft. Collins, CO, which is operated by the National Institute of Standards and Technology, is recommended. It is noted that inexpensive GPS or quartz-crystal single-frequency radios set to this frequency are available from various sources.

5.4.4.2 When comparing solar and ultraviolet irradiance data between weathering sites, the data should be referenced to solar time to facilitate analysis. The equation-of-time may be used to compute the solar time from local time.

5.4.5 *Impedance Considerations:*

5.4.5.1 The input impedance of the amplifier, recorder, or data logger, shall be at least 1000 times the value of the output impedance of the radiometer being used. If this is not the case, corrections must be applied.

5.4.5.2 The length of the cable and its cross-section must be such that the resistance of the cable will not be greater than the output impedance of the radiometers in use. The total impedance of the radiometer and cabling shall in any case be less than one-one-thousandths of the input impedance of the recording device employed.

5.4.5.3 To minimize any effects of impedance mismatch, position voltage/current converters as close as possible to the radiometer.

5.4.6 *Accuracy of the Electronics:*

5.4.6.1 Radiometer outputs are usually of the order of millivolts. Although electrical instrumentation is usually shielded, the radiometer's sensor, the body of the radiometer, and the cabling are nonetheless vulnerable to electromagnetic noise, or interference (EMI), which can produce very-short-term voltage changes. For this reason, it is preferable to integrate the output signal electronically using an appropriate voltage/frequency converter employing an integration time of at least 1 s for each reading. This can be programmed internally for digital recorders.

5.4.6.2 The resolving power of the data acquisition system shall be at least a factor of 100 (two orders magnitude) better than that of the radiometer's output signal (in terms of millivolts). Attention should be given to the fact that a radiometer's millivolt signal can vary over two to three orders of magnitude—particularly in the case of UV radiometers.

5.4.6.3 Temperature is a source of deviation in data acquisition systems, and may be a source of significant error for very hot climates. The temperature response of the various components of the measuring system, which includes the radiometer and the data acquisition system, should be known.

NOTE 15—For example, the system drift can be determined as the square root of the sum of the squares of the individual component drifts.

5.4.6.4 As an alternative to use of an external calibration service whose calibrations are traceable to the International System of Units (SI), the following procedure may be used: Remove the radiometer from the measurement circuit. Then, using a calibrated and traceable DC voltage source having very low output impedance, check the data acquisition system on an annual basis to determine any differences between input values and recorded signals. Extend this check over the anticipated range of outputs of the radiometer being used.

5.5 *Characterization of Radiometers:*

5.5.1 It is recommended that the users of all radiometers covered by this practice *(1)* understand the characterized behavior of the radiometers employed, and *(2)* apply the characterizations as algorithms in the analysis of their data wherever practical and whenever required by the applications for which the radiometric measurements are performed.

5.5.2 The characterized behavior of radiometers include the following: Linearity of output over the range of irradiance values being measured, temperature dependence of the output of the radiometer over the range of temperatures to which the radiometer is subjected during deployment, angular response of the radiometer through all azimuth and cosine angles that the radiometer will be required to perform throughout the year, and spectral responsivity of the radiometer in the spectral band in which it is designed to operate.

5.5.2.1 Spectral responsivity of radiometers are critical for UV-A and UV-B measurements. Not only do they determine the wavelength band that is being measured, but the shape, cut-on and cut-off of, for example, two different UV radiometers (whether UV-A or UV-B) determine the degree to which they will agree at the same site on a seasonal basis.

5.5.2.2 Spectral responsivity is extremely important for UV-B radiometers, since it defines the so-called spectral mismatch behavior of these instruments.[7] A discussion of spectral mismatch errors is presented in Appendix X1.

5.5.3 The characterization of radiometers covered by this practice is nearly always determined by the manufacturers themselves, and the characterized behavior of the class, or type, is either provided by, or may be obtained from, the manufacturer.[8] The characterized behavior is also sometimes available from national and international organizations who have been chartered to perform certain measurements as independent organizations. In any case, these characterized data are usually available as plots of instrument sensitivity for a parameter of interest.

NOTE 16—For sensitive and critical measurements, it is usually mandatory that corrections for linearity, temperature, tilt and cosine/azimuth angles be applied to the data.

5.6 *Quality Control Procedures:*

5.6.1 A simple method of quality control in outdoor applications is to periodically note the solar noon irradiance value during clear sky conditions and compare it against a stable and calibrated reference radiometer. Records of these values should be plotted, showing any long term drifts in sensitivity, as well as cross correlation with calibration results. If a significant drift is detected, the radiometer will require re calibration.

NOTE 17—Clear sky conditions are indicated by the absence of clouds and observable haze within ±30° of the solar disk.

5.6.2 Another method of quality control is to compare the totally cloudy day values of hemispherical irradiance measured by pyranometers and UV radiometers with those measured by a diffuse radiometer[9] mounted in the same orientation.

NOTE 18—All radiometers will occasionally register elevated irradiance spikes as a result of cloud-edge reflections during intermittently cloudy conditions.

5.6.3 Quality checks should also include ensuring that the irradiance of interest does not:

5.6.3.1 Exceed the historical maximum for clear days, and

5.6.3.2 Exceed the theoretical maximum for the time of year, and for the matching integral of reference spectral distributions (for UV measurements).

6. Practice for Use—Specific

6.1 *General:*

6.1.1 Pyranometers and UV radiometers may be mounted in either horizontal or inclined orientations, or on follow-the-sun mounts. Pyrheliometers may only be mounted on follow the sun devices whose tracking accuracy is generally greater than required for pyranometers and UV radiometers that are mounted to track the sun.

6.2 *Pyranometers:*

6.2.1 *Mounting Platform, Leveling and Mounting:*

6.2.1.1 The use of blackened versus white sun exposed surfaces of radiometer mounts must be weighed carefully. White surfaces are indicated for hot climatic regions to minimize the heating effect of sunlight and the concomitant heating of radiometers mounted thereupon. On the other hand, black surfaces should be used for instrumentation setups employing mounts upon which several radiometers of different heights are mounted in order to avoid accumulation of inter- and intra-reflected solar radiation.

6.2.1.2 Radiometers shall not be mounted flush to the mounting surface. Radiometers in common use are provided with adjustable leveling and standoff screws, which provide for air flow between the radiometer and the mounting surface that

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[7] Although spectral mismatch is a problem in the measurement of UV-A radiation, mismatch errors are somewhat less than for UV-B radiometers.

[8] The characterization of radiometers, which should be the responsibility of instrument manufacturers, is the subject of on-going activities of Subcommittee SC-1 of ISO/TC180 on Solar Energy.

[9] A radiometer that is provided with a shading disk to occlude the direct beam. Use of a shade ring rather than a disk requires corrections to account for the occulting of that portion of the hemispherical sky radiation intercepted by the ring.

minimizes heating of the radiometer body and concomitant effects on the instrument's calibration constant.

6.2.1.3 Radiometers equipped with radiation shields shall be calibrated with the shield in place.

6.2.1.4 Horizontal platforms shall be of metal fabrication and shall be of sufficient strength to withstand heat distortion and strong wind. Plastic and/or wood structures shall not be used. The mounting surface shall be adjusted using spirit levels to within ±1.0° of true horizontal.

6.2.1.5 Mounting platforms constructed for mounting radiometers at tilts from the horizontal shall be of like construction and shall be provided with a tilting mechanism to permit their adjustment to within ±1.0° of the required tilt angle. They shall be provided with a sighting mechanism that facilitates their alignment to true south (180°) at solar noon using the equation of time. Alternatively, a transit may be used to align tilted platforms to true south.

6.2.1.6 Follow-the-sun mounts, whether altazimuthal (using bi-directional control) or equatorial, shall be constructed to follow the sun to within ±2° of the direct (beam) component of sunlight.

6.2.2 *Alignment and Leveling of Pyranometers and UV Radiometers:*

6.2.2.1 The spirit level should be checked on initial installation and thereafter on an annual basis. This is most easily accomplished by mounting the radiometer on a carefully adjusted horizontal platform and plotting irradiance continuously throughout a clear day from sunrise to sunset as a function of solar time. If the plot is even slightly nonsymmetrical, the spirit level and the plane of the receiver are most likely not in parallel planes. If this occurs, the spirit level should then be adjusted to indicate the horizontal plane or the instrument should be returned to the manufacturer for adjustment. A more rigorous method is presented in Appendix X2 for radiometer manufacturers or users who wish to use a more precise method.

NOTE 19—For most cases, a difference of 2 to 3 % in the irradiance recorded at, for example, 10:30 AM and 1:30 PM Solar Time can be tolerated. This equates to 15 to 23 $W{\cdot}m^{-2}$ on a clear day at mid latitudes during the summer months.

6.2.2.2 When mounting radiometers on a tilt table, the radiometer shall first be leveled on a horizontal surfaces that meets the requirements of 6.2.1.2. After adjustment of the leveling legs provided on most radiometers, the instrument shall be mounted on the tilted platform, or on the follow-the-sun tracking mount, either of which have been previously aligned to meet the requirements of 6.2.1.3 or 6.2.1.4, as applicable.

6.2.2.3 After alignment and mounting, the radiometer shall be tightly secured to the platform using bolts or other means provided.

6.2.2.4 Wherever possible, horizontally mounted radiometers should be oriented so that the cable or connectors are located in the polar direction of the receiving surface (that is, north in the northern hemisphere) to minimize radiant heating of the electrical connectors. When the radiometer is mounted in an inclined position, the cable and electrical connectors should be pointed to the equator (that is, downward) to limit both radiant heating and rain intrusion.

6.2.2.5 The user should specify to the calibration agency employed the intended orientation of the radiometer, and should request that the cable/electrical connectors are positioned during calibration as noted in 6.2.2.4.

6.3 *Pyrheliometers:*

6.3.1 Pyrheliometers used to measure the direct component of solar radiation in support of the outdoor intensified exposures required by G90 require special follow-the-sun mounting platforms. Use platforms that are either of the equatorial or altazimuthal type.

6.3.2 *Equatorial Mounts, Mounting and Alignment:*

6.3.2.1 Equatorial follow-the-sun trackers are typically driven by a stepping motor and a gear system that rotates a disk to which the radiometer is mounted through exactly one revolution per twenty four hours. The pyrheliometer mount is adjustable to permit tilting to the latitude of the exposure site. The platform is also equipped with an adjustable mount to permit alignment to the declination of the sun at the time the facility is set up. This alignment is performed by adjusting both the declination and azimuth—with the platform permanently set to the latitude angle—such that the pyrheliometer's alignment target is precisely illuminated.

NOTE 20—If the latitude, azimuth and declination adjustments are correctly made, the pyrheliometer will track accurately throughout the day.

6.3.2.2 Daily inspection and adjustment of pyrheliometers affixed to equatorial mounts is mandatory. Since most equatorial mounts do not reverse to their starting position, but continually revolve day-after-day, it is necessary that the system be inspected to determine if the cabling has entangled during the night. Also, the declination must be re-set each day to account for the changing zenith angle of the sun throughout the year.

NOTE 21—The greatest rate of daily change in the sun's zenith angle occurs at the two equinoxes, and the lowest rate occur at the two solstices. Therefore, it is usually not necessary to change the pyrheliometer's declination angle every day. However, since the cabling and transmitting window must be inspected each day, the focus of the pyrheliometer should be at least checked on a daily basis.

6.3.3 *Altazimuth Mounts, Mounting and Alignment:*

6.3.3.1 Altazimuth follow-the-sun mounts track in both azimuth and altitude directions. The earliest altazimuth mounts, some of which are still in use at outdoor weathering exposure stations, consist of platforms equipped with two pairs of partially shaded solar cells. The differential signal resulting from the sun's travel, which differentially illuminates the two cells, provides the stimulus to the tracking stepping motors that position the platform in the tilt-from-the-horizontal (altitude) from one pair, and the stimulus to move the platform in the azimuth direction (east-to-west in the northern hemisphere) from a pair of solar cells mounted at right angles to each other.

6.3.3.2 One problem with solar-cell-response activated tracking is clouds. Therefore, it is essential that these trackers be closely monitored during cloudy weather to eliminate the possibility of complete loss of sun acquisition.

6.3.3.3 Commercially available altazimuth trackers are controlled, in most cases with an associated computer, or microprocessor) using an algorithm that maintains the pyrheliometer exactly focused on the sun throughout the day. These trackers also possess a pair of solar cells mounted at right angles to each other to either occasionally, or continuously, update the system's computerized tracking capabilities.

6.3.3.4 These trackers are not generally susceptible to cloud interference due to the fact that the algorithm tells the computer-operated drive system where the sun is located at all times—and, on re-acquiring the sun after clouds pass, the tracking algorithm is then up-dated and maintained by the system's software.

6.4 *UV Radiometers:*

6.4.1 Generally, the same care and inspection, and inspection frequency, applies to UV radiometers, regardless of whether the UV-A or UV-B or narrow-band type, that is required for pyranometers.

6.4.2 Nearly all UV radiometers are equipped with Teflon® diffusing windows. Although several UV radiometers are also equipped with quartz glass domes to improve cosine response and improve their thermal characteristics, at least one UV radiometer in wide use has its Teflon® window directly exposed to the elements.

6.4.3 It is essential that the domed UV radiometers be regularly inspected for accumulation of moisture between the Teflon® diffuser and the inside of the dome.

6.4.4 It is also essential that the Teflon® windows be inspected at least quarterly for physical damage to the diffuser itself. Damaged diffuser windows shall be replaced.

6.5 *Tracking, Shaded UV Radiometers—Practice G90:*

6.5.1 UV Radiometers, principally UV-A and total ultraviolet (TUVR) ultraviolet radiometers are provided with a shading mechanism to measure the diffuse component of UV radiation. By subtraction of the diffuse component from the total ultraviolet radiation measured with a tracking un-shaded radiometer of the same model and manufacture, the direct component of ultraviolet radiation is computed. The resultant irradiance is used to define the irradiance received in the plane of the mirror bed, and concomitantly that received in the target plane of the Fresnel-reflector solar concentrators used in Practice G90.

6.5.2 The design and construction of the shade ring assembly used to occult the direct beam is completely described in Practice G90. No further admonitions are required here with respect to the care, inspection and use of shaded ultraviolet radiometers used for this purpose.

APPENDIXES

(Nonmandatory Information)

X1. THE MEASUREMENT OF SOLAR UV RADIATION

X1.1 UV radiometers are designed to measure either UV-A, UV-B, or some narrow portion of the ultraviolet spectrum. Regardless of the spectral region they are designed to measure, they typically consist of a photoreceptor, spectrum shaping filters, a cosine-correcting diffuser and associated electronics. The more sophisticated instruments employ chemical fluorescing films and operational amplifiers to increase the signal-to-noise ratio, plus temperature-compensation circuits and quartz-glass domes to insulate the receiver from convective air currents as well as to provide additional cosine-correction.

X1.2 Commonly, the irradiance *I* measured in solar and solar-ultraviolet radiometry is directly proportional to the output signal *E* from the radiometer as shown in Eq X1.1, where *k*, the proportionally factor, is the calibration constant. The value of *k* is a precise measure of the sensitivity of the radiometer.

$$I = kE \tag{X1.1}$$

X1.2.1 When considering the spectral dependency of a radiometer, Eq X1.1 is expressed as shown in Eq X1.2:

$$\int_B I_\lambda d\lambda = k\int I_\lambda D_\lambda d\lambda \tag{X1.2}$$

where I_λ is the spectral irradiance to be measured and D_λ is the spectral response function of the ultraviolet radiometer. The left term in Eq X1.2 represents integration of the spectral irradiance in the range from 315 to 400-nm for UV-A and from 280 to 315-nm wavelength for UV-B ultraviolet radiometers. The right term represents the product of the instrument

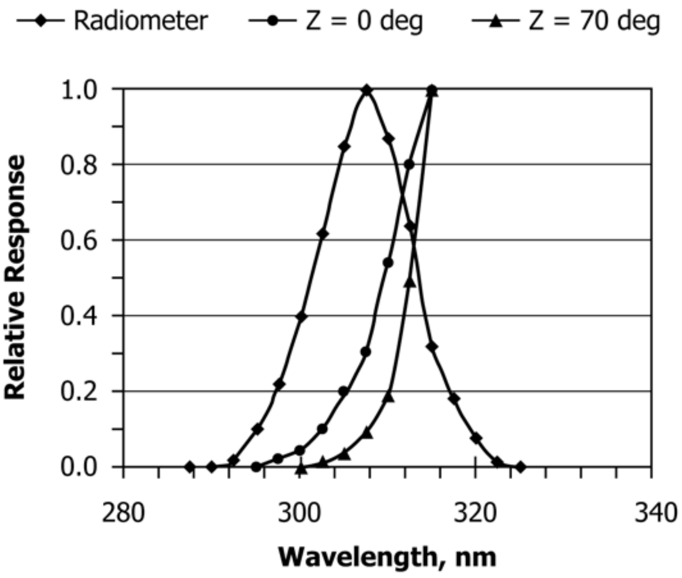

FIG. X1.1 UV-B Radiometer Response and UV-B Solar Spectral Distribution at Two Zenith Angles

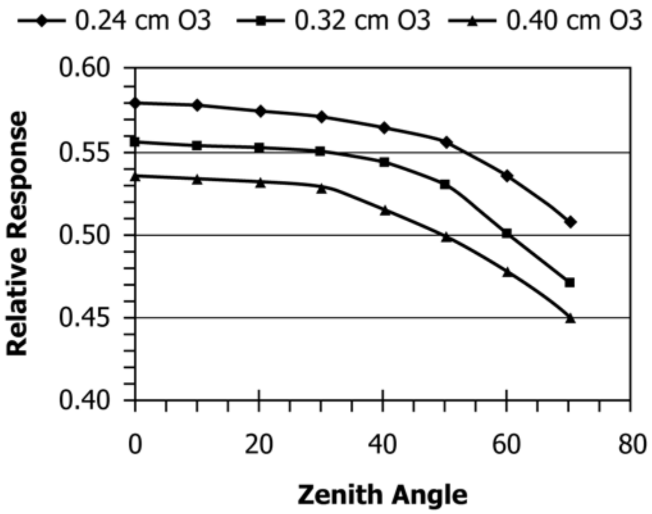

FIG. X1.2 Instrument Constant (Relative Response) of a UV-B Radiometer as a Function of Solar Zenith Angle for Three Different Atmospheric Ozone Levels

sensitivity *k* and the integrand obtained by convoluting (multiplying) the spectral irradiance I_λ with the spectral response D_λ of the respective radiometer. The sensitivity constant of ultraviolet radiometers is determined by solving Eq X1.2 for *k*, yields Eq X1.3.

$$k = \frac{\int_B I_\lambda d\lambda}{\int I_\lambda D_\lambda d\lambda} \quad (X1.3)$$

X1.3 Although ultraviolet radiometers' spectral responsivity functions D_λ are constant, that is, they do not change except as functions of long-term ageing, the solar spectral irradiance I_λ changes throughout the day, and from day-to-day, and from season-to-season, both spectrally proportionately and spectrally disproportionately—depending on the air mass and atmospheric conditions. Air mass changes throughout the day and season as a direct function of the secant of the sun's zenith angle (that is, 90° less the sun's altitude).

X1.4 If an ultraviolet radiometer's spectral response function were ideally flat throughout the relevant ultraviolet region rather than representing a Gaussian-like distribution, and if it exhibited perfectly abrupt cut-on and cut-off limits (with zero response below 280 nm and above 315 nm for UV-B radiometers, as an example), the radiometer's sensitivity factor would remain constant regardless of the atmospheric conditions, the air mass (time of day), or time of year. However, UV-B and UV-A ultraviolet radiometers with such ideal response functions cannot be realized in actuality.

X1.5 Fig. X1.1 shows a typical response of a UV-B radiometer and the UV-B spectral distribution for solar radiation at two zenith angles and illustrates the concept of spectral mismatch error.

X1.5.1 In optically designing a UV-B radiometer, one can compute *k* for various spectral irradiance distributions based on, for example, data given by Bener[10] for three different concentrations of stratospheric ozone. One can then calculate *k* as a function of changing the profile of the filter's transmittance spectrum, principally its peak wavelength, to select a filter that results in minimum spectral mismatch errors.

X1.6 Fig. X1.2 shows the instrument constant *k* (relative response) for a radiometer designed so that the worst case scenario from the combine effects of a 67 % increase in stratospheric ozone and an increase of the sun's zenith angle from 0 to 70° results in a spectral mismatch error of 10 %.

X1.6.1 Since the bulk of ultraviolet radiant exposure results from the higher zenith angles, and from much smaller changes in ozone levels than shown in Fig. X1.2, the actual mismatch error for most of the UV-B ultraviolet collected will be from 5 to 7 %.

X1.7 Spectral mismatch errors account for approximately 80 % of the uncertainties associated with ultraviolet UV-B measurements.[11] This is illustrated in Fig. X1.3 for measurements of global UV-B irradiance in Hiratsuka, Japan, made over a two year period with a UV-B radiometer having a peak wavelength at 305-nm and a 20-nm band pass (that is, the entire UV-B region).

X1.7.1 The spectral response of the UV-B radiometer was measured using a wide-beam spectrograph, both initially and periodically during the exposure. Detailed information about the methodologies used are found in the cited paper. Spectral mismatch, or spectral uncertainty (plot b in Fig. X1.3) was computed based on well-known spectral models for time of day and season of the year.

X1.7.2 The angular uncertainty (plot c in Fig. X1.3) was determined in a similar manner. Likewise, the temperature uncertainty (plot d in Fig. X1.3) was determined from daily temperature measurements using the known temperature dependence of the instruments calibration constant.

X1.7.3 Plot a of Fig. X1.3 shows the total uncertainty of the radiometer and is simply the additive uncertainties shown in plots b, c, and d of Fig. X1.3. Note that the range of spectral mismatch error is about 11 percent over a year.

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[10] Bener, P., *Approximate Values of Intensity of Natural Ultraviolet Radiation for Different Amounts of Stratospheric Ozone, Final Technical Report*, European Research Office, United States Army, London, Contract Number DAJA37-68-C-1017.

[11] Takeshita, S., Sasaki, M., Sakata, T., Miyake, Y., and Zerlaut, G., *Uncertainty in the Measurement of Global UV-B Irradiance Using a Narrow-Band Filter Radiometer*, Proceedings, Eighth Conference on Atmospheric Radiation, January 23-28, Nashville, TN, Am. Met. Soc., 1994.

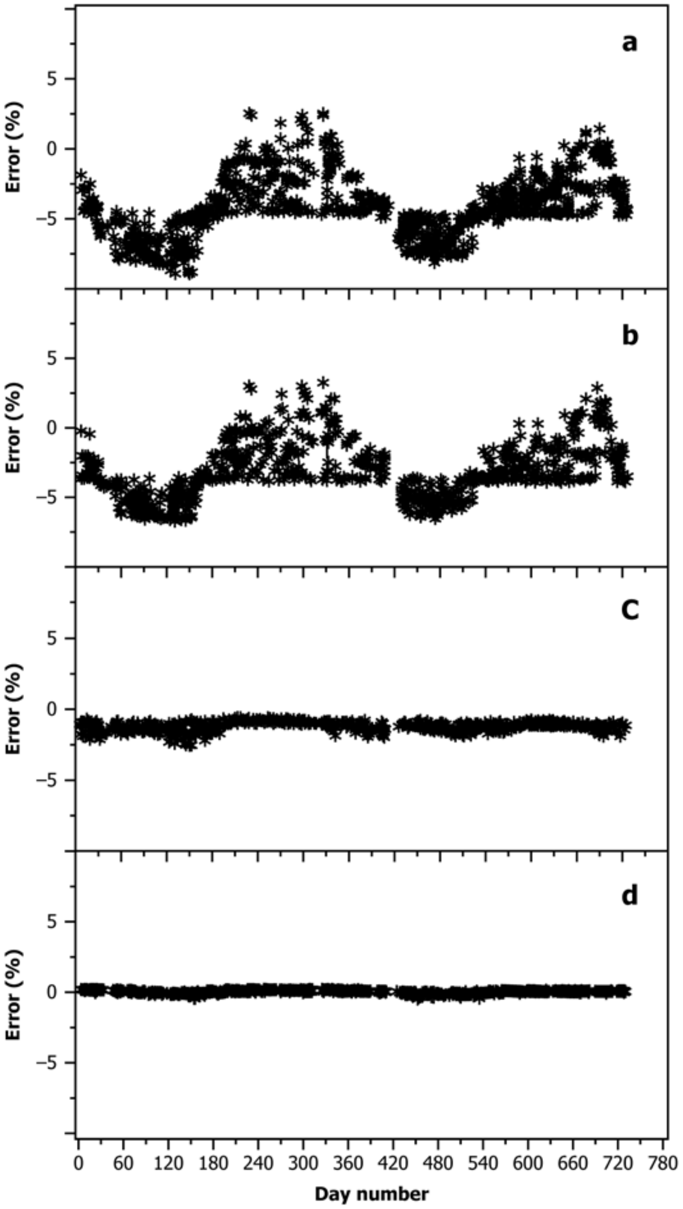

FIG. X1.3 Extent of Spectral Mismatch Error Contribution to the Total Uncertainty of UV-B Measurements

X2. MEASURING THE DEGREE OF PARALLELISM BETWEEN THE PLANE OF A SENSOR AND THE SPIRIT LEVEL

X2.1 The degree of parallelism between the plane of a sensor and the spirit level can be determined by placing the pyranometer on an optical leveling table with the sun at an elevation of about 20°, or indoors by using a collimated beam at about 20° elevation. The leveling screws are then adjusted until the variation in response is a minimum during rotation of the sensor in the azimuthal plane. The spirit level should then indicate the horizontal plane. If it does not, adjust the spirit level to indicate the horizontal plane or return the instrument to the manufacturer for adjustment. Data should be taken in no larger than 30 degree increments (at least 12 incremental measurements as the device is rotated through 360 degrees), and the time between measurements should be at least 5 instrument time constants (1/*e*).

NOTE X2.1—If it is determined that the thermopile sensor is not co-planar with the plane of the spirit level, the pyranometer should be returned to the manufacturer for adjustment or repair. However, it should be noted that variations in azimuthal response are typically 1 to 3 % and may be due to factors other than leveling. During this exercise, a second pyranometer should be used as a reference to determine the source (lamp or sun) irradiance during the test.

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