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Standard Test Method for Transfer of Calibration From Reference to Field Radiometers[1]

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INTRODUCTION

Accurate and precise measurements of total solar and solar ultraviolet irradiance are required in: *(1)* the determination of the energy incident on surfaces and specimens during exposure outdoors to various climatic factors that characterize a test site, *(2)* the determination of solar irradiance and radiant exposure to ascertain the energy available to solar collection devices such as flat-plate collectors, and *(3)* the assessment of the irradiance and radiant exposure in various wavelength bands for meteorological, climatic and earth energy-budget purposes. The solar components of principal interest include total solar radiant exposure (all wavelengths) and various ultraviolet components of natural sunlight that may be of interest, including both total and narrow-band ultraviolet radiant exposure.

This test method for transferring calibration from reference to field instruments is only applicable to pyranometers and radiometers whose field angles closely approach 180° ... instruments which therefore may be said to measure hemispherical radiation, or all radiation incident on a flat surface. Hemispherical radiation includes both the direct and sky (diffuse) geometrical components of sunlight, while global solar irradiance refers only to hemispherical irradiance on a horizontal surface such that the field of view includes all of the hemispherical sky dome.

For the purposes of this test method, the terms pyranometer and radiometer are used interchangeably.

1. Scope

1.1 The method described in this standard applies to the transfer of calibration from reference to field radiometers to be used for measuring and monitoring outdoor radiant exposure levels. This standard has been harmonized with ISO 9847.

1.2 This test method is applicable to field radiometers regardless of the radiation receptor employed, but is limited to radiometers having approximately 180° (2π Steradian), field angles.

1.3 The calibration covered by this test method employs the use of natural sunshine as the source.

1.4 Calibrations of field radiometers may be performed at tilt as well as horizontal (at 0° from the horizontal to the earth). The essential requirement is that the reference radiometer shall have been calibrated at essentially the same tilt from horizontal as the tilt employed in the transfer of calibration.

1.5 The primary reference instrument shall not be used as a field instrument and its exposure to sunlight shall be limited to calibration or intercomparisons.

NOTE 1—At a laboratory where calibrations are performed regularly it is advisable to maintain a group of two or three reference radiometers that are included in every calibration. These serve as controls to detect any instability or irregularity in the standard reference instrument.

1.6 Reference standard instruments shall be stored in a manner as to not degrade their calibration.

1.7 The method of calibration specified for total solar pyranometers shall be traceable to the World Radiometric Reference (WRR) through the calibration methods of the reference standard instruments (Test Methods G167 and E816), and the method of calibration specified for narrow- and broad-band ultraviolet radiometers shall be traceable to the National Institute of Standards and Technology (NIST), or other internationally recognized national standards laboratories (Test Method G138).

[1] This test method is under the jurisdiction of ASTM Committee G03 on Durability of Nonmetallic Materials and is the direct responsibility of Subcommittee G3.09 on Solar and Ultraviolet Radiation Measurement Standards.

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1.8 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology Relating to Solar Energy Conversion

E816 Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers

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

G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance

G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer

2.2 *Other Standard:*

ISO 9847 Solar Energy—Calibration of Field Pyranometers by Comparison to a Reference Pyranometer[3]

3. Terminology

3.1 *Definitions:*

3.1.1 See Terminologies E772 and G113 for terminology relating to this test method.

4. Summary of Test Method

4.1 Mount the reference radiometer, or pyranometer, and the field (or test) radiometers, or pyranometers, on a common calibration table for horizontal calibration (Type *A*), on a tilted platform for calibration at tilt (Type *B*), or on an altazimuth or sun-pointing mount for normal-incidence calibration (Type *C*). Adjust the height of the photoreceptor, or radiation receptor, of all instruments to a common elevation.

4.2 Ensure that the pyranometer's, or radiometer's, azimuth reference marks point in a common direction.

NOTE 2—Current convention is to use the electrical connector as the azimuth reference and to point it towards the equator and downward. The reasons are (*1*) this convention diminishes the possibility of moisture intrusion into the connector, and (*2*) it ensures that instruments with disparities in the hemispherical domes, or with domes not properly centered over the receptor, are not operated in such a manner that they amplify deviations from the cosine law.

4.3 For a transfer of calibration to a field instrument that will be used in a tilted position the following conditions must be met: The reference instrument must have a calibration at the desired tilt angle; both instruments must be oriented at the tilt angle and facing the equator.

4.4 The analog voltage signal from each radiometer is measured, digitized, and stored using a calibrated data-acquisition instrument, or system. A minimum of fifteen 10-min measurement sequences are obtained, each sequence comprising a minimum of 21 instantaneous readings. It is preferable that a larger number of measurement sequences be performed over several days duration and that data be taken in early morning or late afternoon, as well as near solar noon.

NOTE 3—Transfer of calibration to both total and narrow-band ultraviolet radiometers may require a larger number of measurement sequences in order to account for spectral changes due to changing air mass both early and late in the day, and to the loss of north-sky ultraviolet when calibrating at tilts.

4.5 The data are mathematically ratioed, employing the instrument constant of the reference instrument to determine the instrument constant of the radiometer being calibrated. The mean value and the standard deviation are determined.

5. Significance and Use

5.1 The methods described represent the preferable means for calibration of field radiometers employing standard reference radiometers. Other methods involve the employment of an optical bench and essentially a point source of artificial light. While these methods are useful for cosine and azimuth correction analyses, they suffer from foreground view factor and directionality problems. Transfer of calibration indoors using artificial sources is not covered by this test method.

5.2 Traceability of calibration of global pyranometers is accomplished when employing the method using a reference global pyranometer that has been calibrated, and is traceable to the World Radiometric Reference (WRR). For the purposes of this test method, traceability shall have been established if a parent instrument in the calibration chain participated in an International Pyrheliometric Comparison (IPC) conducted at the World Radiation Center (WRC) in Davos, Switzerland. Traceability of calibration of narrow- and broad-band radiometers is accomplished when employing the method using a reference ultraviolet radiometer that has been calibrated and is traceable to the National Institute of Standards and Technology (NIST), or other national standards organizations. See Zerlaut[4] for a discussion of the WRR, the IPC's and their results.

5.2.1 The reference global pyranometer (for example, one measuring hemispherical solar radiation at all wavelengths) shall have been calibrated by the shading-disk or component summation method against one of the following instruments:

5.2.1.1 An absolute cavity pyrheliometer that participated in a WMO sanctioned IPC's (and therefore possesses a WRR reduction factor),

5.2.1.2 An absolute cavity radiometer that has been intercompared (in a local or regional comparison) with an absolute cavity pyrheliometer meeting the requirements given in 5.2.1.1.

5.2.1.3 A WMO First Class pyrheliometer that was calibrated by direct transfer from such an absolute cavity.

5.2.2 Alternatively, the reference pyranometer may have been calibrated by direct transfer from a World Meteorological Organization (WMO) First Class pyranometer that was calibrated by the shading-disk method against an absolute cavity pyrheliometer possessing a WRR reduction factor, or by direct

[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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[4] Zerlaut, G. A., "Solar Radiation Instrumentation," Chapter 5 in *Solar Resources*, The MIT Press, Cambridge, MA, 1989, pp. 173–308.

transfer from a WMO Standard Pyranometer (see WMO's Guide WMO—No. 8[5] for a discussion of the classification of solar radiometers).

NOTE 4—Any of the absolute radiometers participating in the above intercomparisons and being within ±0.5 % of the mean of all similar instruments compared in any of those intercomparisons, shall be considered suitable as the primary reference instrument.

5.2.3 The reference ultraviolet radiometer, regardless of whether it measures total ultraviolet solar radiation, or narrow-band UV-A or UV-B radiation, or a defined narrow band segment of ultraviolet radiation, shall have been calibrated by one of the following:

5.2.3.1 By comparison to a standard source of spectral irradiance that is traceable to NIST or to the appropriate national standards organizations of other countries (using appropriate filter correction factors),[6]

5.2.3.2 By comparison to the integrated spectral irradiance in the appropriate wavelength band of a spectroradiometer that has itself been calibrated against such a standard source of spectral irradiance, and

5.2.3.3 By comparison to a spectroradiometer that has participated in a regional or national Intercomparison of Spectroradiometers, the results of which are of reference quality.

NOTE 5—The calibration of reference ultraviolet radiometers using a spectroradiometer, or by direct calibration against standard sources of spectral irradiance (for example, deuterium or 1000 W tungsten-halogen lamps) is the subject of Test Method G138.

5.3 The calibration method employed assumes that the accuracy of the values obtained are independent of time of year within the constraints imposed by the test instrument's temperature compensation (neglecting cosine errors). The method permits the determination of possible tilt effects on the sensitivity of the test instrument's light receptor.

5.4 The principal advantage of outdoor calibration of radiometers is that all types of radiometers are related to a single reference under realistic irradiance conditions.

5.5 The principal disadvantages of the outdoor calibration method are the time required and the fact that the natural environment is not subject to control (but the calibrations therefore include all of the instrumental characteristics of both the reference and test radiometers that are influenced simultaneously by the environment). Environmental circumstances such as ground reflectance or shading, or both, must be minimized and affect both instruments similarly.

5.6 The reference radiometer must be of the same type as the test radiometer, since any difference in spectral sensitivity between instruments will result in erroneous calibrations. The reader is referred to ISO TR 9673[7] and ISO TR 9901[8] for discussions of the types of instruments available and their use.

6. Interferences

6.1 In order to minimize systematic errors the reference and test radiometers must be as nearly alike in all respects as possible.

6.1.1 The spectral response of both the reference and test radiometers must be as nearly identical as possible.

6.2 *Sky Conditions*—The measurements selected in determining the instrument constant shall be for periods of essentially uniform rates of change of radiation (either cloudless or overcast conditions). Periods selected shall be for 10 to 20-min segments. Measurements selected under varying cloudy conditions may result in erroneous calibrations if the reference and test radiometers possess significantly different response times (see also 5.6).

7. Apparatus

7.1 *Data Acquisition Instrument*—A digital voltmeter or data logger capable of repeatability to 0.1 % of average reading, and an uncertainty of ±0.2 % with an input impedance of at least 1 MΩ may be employed. Data loggers having printout must be capable of a measurement frequency of at least two per minute. A data logger having three-channel capacity may be useful.

7.2 *Fixed-Angle Calibration Table*—A precision calibration table required for all horizontal and fixed angle tilt tests that is level at 0° horizontal and that is adjustable in tilt over a suitable range of angles from the horizontal.

7.3 *Tracking Calibration Table*—A precision calibration table required for normal incident calibrations and capable of tracking the sun to within ±0.5°.

8. Procedure

8.1 Mount reference and test radiometers on a common calibration table in sunlight. Adjust both instruments to a common elevation facing south for which a calibration value is available. Ensure that the azimuth reference marks point in a common direction: For tilted or tracking calibrations, also ensure that the electrical connector is pointed down (to preclude moisture intrusion), and that it is pointing to the equator (that is, south-facing in the northern hemisphere) if used as the azimuth reference.

8.2 Connect both the reference and test instruments to their respective, or common, data acquisition instrument, using low capacitance, shielded cable of at least 20 gauge and of identical length for each instrument. Check the instruments for electrical continuity, sign of the signal, and the nominal signal strength and stability. Clean the radiometer's outermost photoreceptive surface (glass dome, filter, window, diffuser, etc.) in accordance with the manufacturer's instructions. Check that the radiant fluxes of the foreground on both instruments are equal at the relevant tilt angle by transposing the positions of at least two of the most widely separated radiometers.

8.3 Take particular care to measure for zero off-sets. Check the off-set signals of both the reference and field radiometers at

[5] WMO—No. 8, "Guide to Meteorological Instruments and Methods of Observation," Fifth Ed., World Meteorological Organization, Geneva, Switzerland, 1983.

[6] Angstrom, A. K., and Drummond, A. J. "Fundamental Principles and Methods for the Calibration of Radiometers for Photometric Use," *Applied Optics*, Vol 1, No. 4 , July 1962, pp. 455-464.

[7] ISO Technical Report TR 9673, "Solar Radiation and Its Measurement for Determining Outdoor Weathering Exposure Levels," *International Standards Organization*, Geneva, Switzerland (in publication).

[8] ISO/TR 9901:1990, "Solar Energy—Field Pyranometers—Recommended Practice for Use."