Designation: G213 – 17 (Reapproved 2023)

Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers[1]

This standard is issued under the fixed designation G213; 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 guide provides guidance and recommended practices for evaluating uncertainties when calibrating and performing outdoor measurements with pyranometers and pyrheliometers used to measure total hemispherical- and direct solar irradiance. The approach follows the ISO procedure for evaluating uncertainty, the Guide to the Expression of Uncertainty in Measurement (GUM) JCGM 100:2008 and that of the joint ISO/ASTM standard ISO/ASTM 51707 Standard Guide for Estimating Uncertainties in Dosimetry for Radiation Processing, but provides explicit examples of calculations. It is up to the user to modify the guide described here to their specific application, based on measurement equation and known sources of uncertainties. Further, the commonly used concepts of precision and bias are not used in this document. This guide quantifies the uncertainty in measuring the total (all angles of incidence), broadband (all 52 wavelengths of light) irradiance experienced either indoors or outdoors.

1.2 An interactive Excel spreadsheet is provided as adjunct, ADJG021317. The intent is to provide users real world examples and to illustrate the implementation of the GUM method.

1.3 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]

E772 Terminology of Solar Energy Conversion

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

G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer

Guide for Estimating Uncertainties in Dosimetry for Radiation Processing

2.2 *ASTM Adjunct:*[2]

ADJG021317 CD Excel spreadsheet- Radiometric Data Uncertainty Estimate Using GUM Method

2.3 *ISO Standards*[3]

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

ISO/IEC Guide 98-3 Uncertainty of Measurement—Part 3: Guide to the Expression of Uncertainty in Measurement (GUM:1995)

ISO/IEC JCGM 100:2008 GUM 1995, with Minor Corrections, Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement

3. Terminology

3.1 Standard terminology related to solar radiometry in the fields of solar energy conversion and weather and durability testing are addressed in ASTM Terminologies E772 and G113, respectively. Some of the definitions of terms used in this guide may also be found in ISO/ASTM 51707.

3.2 *Definitions of Terms Specific to This Standard:*

[1] This test method 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, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

3.2.1 *aging (non-stability), n*—a percent change of the responsivity per year; it is a measure of long-term non-stability.

3.2.2 *azimuth response error, n*—a measure of deviation due to responsivity change versus solar azimuth angle.

NOTE 1—Often cosine and azimuth response are combined as "Directional response error," which is a percent deviation of the radiometer's responsivity due to both zenith and azimuth responses.

3.2.3 *broadband irradiance, n*—the solar radiation arriving at the surface of the earth from all wavelengths of light (typically wavelength range of radiometers 300 nm to 3000 nm).

3.2.4 *calibration error, n*—the difference between values indicated by the radiometer during calibration and "true value."

3.2.5 *cosine response error, n*—a measure of deviation due to responsivity change versus solar zenith angle. See Note 1.

3.2.6 *coverage factor, n*—numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty.

3.2.7 *data logger accuracy error, n*—a deviation of the voltage or current measurement of the data logger due to resolution, precision, and accuracy.

3.2.8 *effective degrees of freedom, n*—v_{eff}, for multiple (N) sources of uncertainty, each with different individual degrees of freedom, v_i that generate a combined uncertainty u_c, the Welch-Satterthwaite formula is used to compute:

$$v_{eff} = \frac{u_c^4}{\Sigma_{i=1}^{N} \frac{u_4^i}{v_i}} \tag{1}$$

3.2.9 *expanded uncertainty, n*—quantity defining the interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand.

3.2.9.1 *Discussion*—Expanded uncertainty is also referred to as "overall uncertainty" (BIPM Guide to the Expression of Uncertainty in Measurement).[4] To associate a specific level of confidence with the interval defined by the expanded uncertainty requires explicit or implicit assumptions regarding the probability distribution characterized by the measurement result and its combined standard uncertainty. The level of confidence that may be attributed to this interval can be known only to the extent to which such assumptions may be justified.

3.2.10 *leveling error, n*—a measure of deviation or asymmetry in the radiometer reading due to imprecise leveling from the intended level plane.

3.2.11 *non-linearity, n*—a measure of deviation due to responsivity change versus irradiance level.

3.2.12 *primary standard radiometer, n*—radiometer of the highest metrological quality established and maintained as an irradiance standard by a national (such as National Institute of Standards and Technology (NIST)) or international standards organization (such as the World Radiation Center (WRC) of the World Meteorological Organization (WMO)).

3.2.13 *reference radiometer, n*—radiometer of high metrological quality, used as a standard to provide measurements traceable to measurements made using primary standard radiometer.

3.2.14 *response function, n*—mathematical or tabular representation of the relationship between radiometer response and primary standard reference irradiance for a given radiometer system with respect to some influence quantity. For example, temperature response of a pyrheliometer, or incidence angle response of a pyranometer.

3.2.15 *routine (field) radiometer, n*—instrument calibrated against a primary-, reference-, or transfer-standard radiometer and used for routine solar irradiance measurement.

3.2.16 *sensitivity coefficient (function), n*—describes how sensitive the result is to a particular influence or input quantity.

3.2.16.1 *Discussion*—Mathematically, it is partial derivative of the measurement equation with respect to each of the independent variables in the form:

$$y(x_i) = c_i = \frac{\delta y}{\delta x_i} \tag{2}$$

where $y(x_1, x_2, \ldots x_i)$ is the measurement equation in independent variables, x_i.

3.2.17 *soiling effect, n*—a percent change in measurement due to the amount of soiling on the radiometer's optics.

3.2.18 *spectral mismatch error, radiometer, n*—a deviation introduced by the change in the spectral distribution of the incident solar radiation and the difference between the spectral response of the radiometer to a radiometer with completely homogeneous spectral response in the wavelength range of interest.

3.2.19 *temperature response error, n*—a measure of deviation due to responsivity change versus ambient temperature.

3.2.20 *tilt response error, n*—a measure of deviation due to responsivity change versus instrument tilt angle.

3.2.21 *transfer standard radiometer, n*—radiometer, often a reference standard radiometer, suitable for transport between different locations, used to compare routine (field) solar radiometer measurements with solar radiation measurements by the transfer standard radiometer.

3.2.22 *Type A standard uncertainty, adj*—method of evaluation of a standard uncertainty by the statistical analysis of a series of observations, resulting in statistical results such as sample variance and standard deviation.

3.2.23 *Type B standard uncertainty, adj*—method of evaluation of a standard uncertainty by means other than the statistical analysis of a series of observations, such as published specifications of a radiometer, manufacturers' specifications, calibration, or previous experience, or combinations thereof.

3.2.24 *zero offset A, n*—a deviation in measurement output (W/m^2) due to thermal radiation between the pyranometer and the sky, resulting in a temperature imbalance in the pyranometer.

[4] International Bureau of Weights and Measures (BIPM) Working Group 1 of the Joint Committee for Guides in Metrology (JCGM/WG 1).2008. "Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement (GUM)." JCGM 100:2008 GUM 1995 with minor corrections.