INTERNATIONAL

Designation: ~~E1125 – 10 (Reapproved 2015)~~ E1125 – 16

Standard Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum[1]

This standard is issued under the fixed designation E1125; 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 test method is intended ~~to be used~~ for calibration and characterization of primary terrestrial photovoltaic reference cells to a desired reference spectral irradiance distribution, such as Tables G173. The recommended physical requirements for these reference cells are described in Specification E1040. Reference cells are principally used in the determination of the electrical performance of photovoltaic devices.

1.2 Primary photovoltaic reference cells are calibrated in natural sunlight using the relative ~~spectral response~~quantum efficiency of the cell, the relative spectral distribution of the sunlight, and a tabulated reference spectral irradiance distribution. Selection of the reference spectral irradiance distribution is left to the user.

1.3 This test method requires the use of a pyrheliometer that is calibrated according to Test Method E816, which requires the use of a pyrheliometer that is traceable to the World Radiometric Reference (WRR). Therefore, reference cells calibrated according to this test method are traceable to the WRR.

1.4 This test method is ~~a technique that may be used instead of the procedures found in~~ used to calibrate primary reference cells; Test Method E1362~~. This test method offers convenience in its ability to characterize a reference cell under any spectrum for which tabulated data are available. The selection~~ may be used to calibrate secondary and non-primary reference cells (these terms are defined in Terminology E772~~of the specific reference spectrum is left to the user.~~).

1.5 This test method applies only to the calibration of a photovoltaic cell that shows a linear dependence of its short-circuit current on irradiance over its intended range of use, as defined in Test Method E1143.

1.6 This test method applies only to the calibration of a reference cell fabricated with a single photovoltaic junction.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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]

E490 Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables
E772 Terminology of Solar Energy Conversion
E816 Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers
E927 Specification for Solar Simulation for Photovoltaic Testing
E948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight
E973 Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell
E1021 Test Method for Spectral Responsivity Measurements of Photovoltaic Devices
E1040 Specification for Physical Characteristics of Nonconcentrator Terrestrial Photovoltaic Reference Cells

[1] This test method is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

Current edition approved ~~March 1, 2015~~July 1, 2016. Published ~~April 2015~~October 2016. Originally approved in 1986. Last previous edition approved in ~~2010~~2015 as ~~E1125 – 10.~~E1125 – 10 (2015). DOI: ~~10.1520/E1125-10R15.~~10.1520/E1125-16.

[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.

E1328E1143 Terminology Relating to Photovoltaic Solar Energy ConversionTest Method for Determining the Linearity of a Photovoltaic Device Parameter with Respect To a Test Parameter (Withdrawn 2012)
E1362 Test Methods for Calibration of Non-Concentrator Photovoltaic Non-Primary Reference Cells
E2554 Practice for Estimating and Monitoring the Uncertainty of Test Results of a Test Method Using Control Chart Techniques
G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance
G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface
G183 Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers
2.2 *WMO Document:*[3]
WMO-No. 8 Guide to Meteorological Instruments and Methods of Observation, Seventh ed., 2008.

3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminology E772 and Terminology E1328.

3.2 The following symbols and units are used in this test method:Symbols:
3.2.1 The following symbols and units are used in this test method:
λ—Wavelength, nm or µm,
I_{sc}—Short-circuit current, A,
E—Irradiance, Wm^{-2},
E_t—Total irradiance, Wm^{-2},
E(λ)—Spectral irradiance, $Wm^{-2}µm^{-1}$,
R(λ)—Spectral response, AW^{-1},
$R_r(λ)$—Reference cell spectral response, AW^{-1},
T—Temperature, °C,
α—Temperature coefficient of reference cell I_{sc}, $°C^{-1}$,
n—Total number of data points,
C—Calibration constant, Am^2W^{-1},
M—Spectral mismatch parameter,
F—Spectral correction factor, and
S—Standard deviation.

3.3 *Symbols:*

3.3.1 A_x—collimator aperture identifiers (non-numeric).

3.3.2 *C*—calibration value, reference cell (Am^2W^{-1}).

3.3.3 **C**—array of calibration values, reference cell (Am^2W^{-1}).

3.3.4 *D*—as a subscript, refers to the reference cell to be calibrated; as a variable, distance from collimator entrance aperture to reference cell top surface, or to spectroradiometer entrance optics (m).

3.3.5 *E*—total irradiance, measured with pyrheliometer (Wm^{-2}).

3.3.6 **E**—array of measured total irradiance values (Wm^{-2}).

3.3.7 *E(λ)*—spectral irradiance ($Wm^{-2}µm^{-1}$ or $Wm^{-2}nm^{-1}$).

3.3.8 $E_S(λ)$—measured solar spectral irradiance ($Wm^{-2}µm^{-1}$ or $WM^{-2}nm^{-1}$).

3.3.9 $E_0(λ)$—reference spectral irradiance distribution ($Wm^{-2}µm^{-1}$ or $WM^{-2}nm^{-1}$).

3.3.10 *F*—spectral correction factor (dimensionless).

3.3.11 *FOV*—field-of-view (°).

3.3.12 *I*—short-circuit current, reference cell (A).

3.3.13 **I**—array of measured short-circuit currents, reference cell (A).

3.3.14 *i* —as a subscript, refers to the *i*th current and irradiance data point (dimensionless).

3.3.15 *j* —as a subscript, refers to the *j*th calibration value data point (dimensionless).

3.3.16 *L*—collimator length (m).

3.3.17 *n*—number of current and irradiance data points measured during calibration time period (dimensionless).

3.3.18 *m*—number of calibration value data points (dimensionless).

3.3.19 *M*—spectral mismatch parameter (dimensionless).

3.3.20 $O_D(λ,T)$—quantum efficiency, reference cell (%).

[3] The last approved version of this historical standard is referenced on www.astm.org.Available from World Meteorological Organization (WMO), 7bis, avenue de la Paix, Case Postale No. 2300, CH-1211 Geneva 2, Switzerland, http://www.wmo.int.

3.3.21 r_x—collimator inner aperture radius (m).

3.3.22 *R*—collimator entrance aperture radius (m).

3.3.23 R_E—pyrheliometer to integrated spectral irradiance ratio (dimensionless).

3.3.24 *RNG*—as a subscript, refers to the minimum-to-maximum range of an array of values.

3.3.25 *s*—sample standard deviation, reference cell calibration value (Am^2W^{-1}).

3.3.26 *T*—temperature (°C).

3.3.27 T_0—calibration temperature, reference cell (25°C).

3.3.28 $Z_P(\lambda)$—pyrheliometer spectral transmittance function (dimensionless).

3.3.29 λ—wavelength (µm or nm).

3.3.30 θ_O—collimator opening angle (°).

3.3.31 θ_S—collimator slope angle (°).

3.3.32 $\Theta_D(\lambda)$—partial derivative of quantum efficiency with respect to temperature ($\%\cdot°C^{-1}$).

4. Summary of Test Method

4.1 The calibration of a primary photovoltaic reference cell consists of measuring the short-circuit current of the cell when illuminated with natural sunlight, along with the ~~total~~direct solar irradiance using a ~~pyrheliometer.~~ pyrheliometer (see Terminology E772). The ratio of the short-circuit current of the cell to the ~~irradiance,~~ irradiance is called the responsivity, which, when divided by a spectral correction factor similar to the spectral mismatch parameter defined in Test Method E973, is the calibration ~~constant~~value for the reference cell. ~~Also, if the temperature of the cell is not 25 ± 1°C, the short-circuit current must be corrected to 25°C.~~The spectral correction factor also corrects the calibration value to 25°C (see 4.2.2).

4.1.1 The relative spectral irradiance of the sunlight is measured using a ~~spectral irradiance measurement instrument~~ spectroradiometer as specified in Test Method G138 and Test Method E973.

4.1.2 A pyrheliometer measures direct solar irradiance by restricting the field-of-view (FOV) to a narrow conical solid angle, typically 5°, that includes the 0.5° cone subtended by the sun. This calibration method requires that the same irradiance measured by the pyrheliometer also illuminate the primary reference cell to be calibrated and the spectroradiometer simultaneously. Thus, both are required to have collimators (see 6.2).

4.1.3 Multiple calibration values determined from *I*,*E*, and $E(\lambda)$ measurements made on a minimum of three different days, are averaged to produce the final calibration result. Each data point corresponds to a single $E(\lambda)$ spectral irradiance.

4.2 The following is a list of measurements that are used to characterize reference cells and are reported with the calibration data:

4.2.1 The ~~spectral response~~ relative quantum efficiency of the cell is determined in accordance with Test Methods E1021.

4.2.2 ~~The~~ Temperature sensitivity of the cell's short-circuit current ~~temperature coefficient~~ is determined experimentally by measuring the ~~short-circuit current at various temperatures and computing the temperature coefficient (see~~partial derivative of quantum efficiency with respect to temperature, as specified ~~7.2.2).~~in Test Method E973.

4.2.3 Linearity of short-circuit current versus irradiance is determined in accordance with Test Method E1143.

4.2.4 The fill factor of the reference cell is determined using Test Method E948. Providing the fill factor with the calibration data allows the reference cell to be checked in the future for electrical degradation or damage.

5. Significance and Use

5.1 The electrical output of a photovoltaic device is dependent on the spectral content of the illumination source, its intensity, and the device temperature. To make standardized, accurate measurements of the performance of photovoltaic devices under a variety of light ~~sources,~~ sources when the intensity is measured with a calibrated reference cell, it is necessary to account for the error in the short-circuit current that occurs if the relative ~~spectral response~~quantum efficiency of the reference cell is not identical to the ~~spectral response~~quantum efficiency of the device to be tested. A similar error occurs if the spectral irradiance distribution of the test light source is not identical to the desired reference spectral irradiance distribution. These errors are accounted for by the spectral mismatch parameter (described in Test Method E973), which is a quantitative measure of the error in the short-circuit current measurement. It is the intent of this test method to provide a recognized procedure for calibrating, characterizing, and reporting the calibration data for primary photovoltaic reference cells using a tabular reference spectrum.

5.2 The calibration of a reference cell is specific to a particular spectral irradiance distribution. It is the responsibility of the user to specify the applicable irradiance distribution, for example Tables G173. This test method allows calibration with respect to any tabular spectrum.

5.2.1 Tables G173 do not provide spectral irradiance data for wavelengths longer than 4 µm, yet pyrheliometers (see 6.1) typically have response in the 4–10 µm region. To mitigate this discrepancy, the Tables G173 spectra must be extended with the data provided in Annex A2.

5.3 A reference cell should be recalibrated at yearly intervals, or every six months if the cell is in continuous use outdoors.

5.4 Recommended physical characteristics of reference cells can be found in Specification E1040.

5.5 ~~Because silicon solar cells made on p-type substrates are susceptible to a loss of~~ High-quality silicon primary I_{sc} ~~upon initial exposure to light, it is required that newly manufactured reference cells be light soaked at an irradiance level greater than 850 W/m~~reference cells are expected to be stable devices by nature, and as such can be considered[2] ~~for 2 h prior to initial characterization in Section~~control samples. Thus, the calibration value data points (see ~~7~~9.3~~.~~) can be monitored with control chart techniques according to Practice E2554, and the test result uncertainty estimated. The control charts can also be extended with data points from previous calibrations to detect changes to the reference cell or the calibration procedures.

6. Apparatus

6.1 *Pyrheliometer*— A secondary reference pyrheliometer that is calibrated in accordance with Test Method E816~~. An absolute cavity radiometer may also be used. Because secondary reference pyrheliometers are calibrated against~~ , or an absolute cavity ~~radiometer,~~ radiometer. See also World Radiometric Reference in Terminology E772~~the total uncertainty in~~ and the World Meteorological Organization (WMO) guide WMO-No.8, Chapter 7. Practice G183~~the primary reference cell calibration constant will be reduced if an absolute cavity radiometer is used.~~ provides guidance to the use of pyrheliometers for direct solar irradiance measurements.

6.1.1 Because secondary reference pyrheliometers are calibrated against an absolute cavity radiometer, the total uncertainty in the primary reference cell calibration value will be reduced if an absolute cavity radiometer is used.

6.1.2 The spectral transmittance function of the pyrheliometer must be considered. For an absolute cavity radiometer without a window, $Z_P(\lambda)$ can be assumed to be one over a very wide wavelength range. Secondary reference pyrheliometers typically have a window at the entrance aperture, so $Z_P(\lambda)$ can be assumed to be the spectral transmittance of the window material.

6.1.2.1 Test Method E816 requires absolute cavity radiometers to be "nonselective over the range from 0.3 to 10 µm", and secondary reference pyrheliometers to be "nonselective over the range from 0.3 to 4 µm."

6.1.2.2 Commercially available secondary pyrheliometers use a variety of different window materials, and many do not meet the 0.3 to 4 µm requirement of Test Method E816. The transmittance of fused silica (SiO_2), for example, has significant variations in the 2 to 4 µm region that depend on the grade of the material (ultraviolet or infrared grade). Sapphire (Al_2O_3) transmits beyond 4 µm, but its transmittance is not entirely flat over 0.4 to 4 µm. Crystalline quartz (SiO_2) is very flat over 0.25 to 2.5 µm, but the transmittance falls to zero by 4 µm. The pyrheliometer manufacturer should be consulted to obtain the window transmittance data.

6.1.2.3 The calibration procedure in Test Method E816 places restrictions on allowable atmospheric conditions and does not adjust calibration results with spectral information: all pyrheliometers are calibrated with the same procedure regardless of the window material.

6.2 ~~*Collimator*—~~*Collimators*—~~A collimator~~ Tubes with internal baffles, intended for pointing toward the sun, that restrict the FOV and are fitted to the reference cell ~~during calibration that has the same field-of-view~~to be calibrated and the spectroradiometer (see 6.3~~as the pyrheliometer. An~~); an acceptable collimator design is ~~described~~provided in Annex A1. The collimators must match the FOV of the pyrheliometer (see A1.4.1).

6.2.1 Eliminate or minimize any stray light entering the collimators at the bottoms of the tubes.

6.2.2 The receiving aperture of the reference cell collimator shall be sized such that the entire optical surface of the primary reference cell to be calibrated is completely illuminated, including the window (see Specification E1040). Thus, for a reference cell with a 50 mm square window, the collimator would require a receiving aperture radius equal to:

$$\sqrt{50^2+50^2}/2 = 35.4 \text{ mm}$$

6.3 ~~*Spectral Irradiance Measurement Equipment,*~~ *Spectroradiometer,* as required by Test ~~Method~~Methods G138 and E973~~.~~ for direct normal solar spectral irradiance measurements.

6.3.1 The ~~spectral~~wavelength range of the spectral irradiance measurement shall be wide enough to ~~include~~span the ~~spectral response~~wavelength range of the quantum efficiency of the cell to be ~~calibrated.~~ calibrated (see 6.7.3) and the spectral sensitivity function of the pyrheliometer (see 6.1.2).

~~6.3.2 The spectral range of the spectral irradiance measurement shall include 98 % of the total irradiance to which the pyrheliometer is sensitive.~~

6.3.2 If the spectral irradiance measurement is unable to measure the entire wavelength range required by 6.3.1 and 6.3.2, it is acceptable to use a reference spectrum, such as Tables G173, to supply the missing wavelengths. The reference spectrum is scaled to match the measured spectral irradiance data over a convenient wavelength interval within the wavelength range of the spectral irradiance measurement equipment. It is also acceptable to calculate the missing spectral irradiance data using a numerical spectral irradiance model.

6.3.2.1 Note that the reference spectrum is also required to include the wavelengths specified by 6.3.1: see 5.2.1.

~~6.3.4 The spectral irradiance measurement equipment shall have the same field-of-view as the pyrheliometer and the reference cell collimator.~~

6.4 *Normal Incidence Tracking Platforms*—~~Tracking platforms used to follow the sun during the calibration and to~~ A platform or platforms that hold the reference cell to be calibrated, the ~~pyrheliometer, the collimator, and spectral irradiance measurement equipment. The pyrheliometer and the collimator must be parallel within ±0.25°. The platforms shall be able to track the sun~~

~~within ±0.5° during the calibration procedure.~~pyrheliometer, and the spectroradiometer during the calibration procedure. Using two orthogonal axes, such as azimuth and elevation (that is, altazimuthal mount), the platforms must follow the apparent motion of the sun such that the angle between the sun vector and the normal vector is less than 0.1° (that is, the tracking error). The collimators (including that of the pyrheliometer) define the normal vector and shall be parallel to each other within ±0.25°.

6.4.1 The tracking error tolerance is dependent on the FOV and slope angle of the pyrheliometer and the collimators (see A1.4.1); WMO-No. 8 states that 0.1° is acceptable for the recommended FOV of 5° and slope angle of 1°.

6.5 *Temperature Measurement Equipment*—~~An~~The instrument or instruments used to measure the temperature of the reference cell to be ~~calibrated, that has~~calibrated must have a resolution of at least 0.1°C, and a total ~~error~~uncertainty of less than ±1°C of ~~reading.~~reading when such uncertainty is combined with the uncertainty of the sensors themselves.

6.5.1 Sensors such as thermocouples or thermistors used for the temperature measurements must be located in a position that minimizes any temperature gradients between the sensor and the photovoltaic device junction.

6.6 *Electrical Measurement Equipment*—Voltmeters, ammeters, or other suitable electrical measurement instruments, used to measure the short-circuit current, I_{sc} of the cell to be calibrated and the pyrheliometer output, ~~*that*~~*E,* must have a resolution of at least 0.02 % of the maximum current or voltage encountered, and a total ~~error~~uncertainty of less than 0.1 % of the maximum current or voltage encountered.

6.6.1 The electrical measurement equipment should be able to record a minimum of 50 to 100 data points during the calibration time period (see 8.1).

6.7 ~~*Spectral Response*~~*Quantum Efficiency Measurement Equipment,* as required by Test Method E1021~~.~~ for spectral responsivity measurements and the following additional requirements:

6.7.1 The wavelength interval between ~~spectral response~~ successive quantum efficiency data points shall be ~~a maximum of 50 nm.~~10 nm or less.

6.7.2 For reference cells made with direct bandgap semiconductors such as GaAs, it is recommended that the wavelength interval be no greater than 5 nm.

6.7.3 The low- and high-wavelength endpoints of the quantum efficiency measurement shall span all wavelengths for which the measured quantum efficiency are greater than 1 % of the maximum quantum efficiency.

6.7.4 The full-width-at-half maximum bandwidth fo the monochromatic light source shall be 10 nm or less.

6.8 *Temperature Control Block (Optional)*—A device to maintain the temperature of the reference cell at 25 ± 1°C for the duration of the calibration.

7. Characterization

7.1 ~~Prior to the characterization measurements, illuminate the reference cell to be calibrated at 1000 Wm~~Because some silicon solar cells are susceptible to a loss of short-circuit current upon initial exposure to light, newly manufactured reference cells~~$^{-2}$ for 2 h. This is necessary to stabilize any light-induced degradation of the cell prior to calibration.~~shall be light soaked prior to initial characterization, as follows:

7.1.1 Measure the short-circuit current and the cell area of the reference cell to be calibrated according to Test Method E948, with respect to standard reporting conditions corresponding to the reference spectral irradiance distribution (see 5.2 and Table 1 of Test Method E948).

7.1.2 Connect the reference cell to the electrical measurement equipment (see 6.6) and prepare to record short-circuit current versus time.

7.1.3 Illuminate the reference cell with either natural sunlight or a solar simulator (see Specification E927); the spectral irradiance is not critical, nor is the cell temperature.

7.1.4 Record the short-circuit current of the reference cell when the current is greater than 85 % of the current measured in 7.1.1.

7.1.5 Integrate the short-circuit currents recorded in 7.1.4 with time to calculate the total charge generated.

7.1.6 Discontinue the illumination when 22 MCm^{-2} have been generated. For an Si solar cell with a short-circuit current density of 300 Am^{-2} at 1000 Wm^{-2}, this amount of charge requires approximately 20 h of illumination.

7.2 Characterize the reference cell ~~being~~ to be calibrated by the following methods:

7.2.1 ~~*Spectral Response*—~~*Quantum Efficiency*—Determine the relative ~~spectral response,~~quantum efficiency ~~R(λ),~~(optionally the absolute ~~spectral response)~~quantum efficiency) of the reference cell to be calibrated at 25°C in accordance with Test Methods E1021 and the requirements of 6.7.

7.2.1.1 Repetition of 7.2.1 is optional if the quantum efficiency has been previously measured in accordance with 7.2.1.

7.2.2 ~~*Temperature Coefficient*—~~*Partial Derivative of Quantum Efficiency with Respect to Temperature*—Determine the working temperature ~~coefficient,~~range ~~α,~~of the reference cell to be calibrated ~~as follows:~~and measure its $\Theta_D(\lambda)$ according to Annex A1 of Test Methods E973.

~~7.2.2.1 Using the electrical measurement equipment, measure I_{sc} at four or more temperatures over at least a 50°C temperature range centered around 35°C. The irradiance shall be at least 750 Wm^{-2} and less than 1100 Wm^{-2}, as measured with a second reference cell. Measure the temperature of the being calibrated at the same time.~~

NOTE 1—Test Method E973 requires all quantum efficiency measurements needed for $Q_D(\lambda,T_0)$ and $\Theta_D(\lambda)$ be measured with the same multiplicative calibration or scaling factors.

7.2.2.1 Divide each value Repetition of 7.2.2 is optional if $I\Theta_{sc-D}$ by the normalized instantaneous irradiance level at(λ) has been previously measured in accordance with 7.2.2the time of each measurement..

NOTE 1—The normalized instantaneous irradiance can be determined by dividing the second reference cell's I_{sc} by its calibration constant.

7.2.2.3 Determine the temperature coefficient by performing a least-squares fit of the I_{sc} versus T data to a straight line. The slope of the line divided by the value of the current from the least-squares fit at 25°C is the temperature coefficient, α.

7.2.3 *Linearity*—Determine the short-circuit current versus irradiance linearity of the cell being calibrated in accordance with Test Method E1143 for the irradiance range 750 to 1100 Wm^{-2}.

7.2.3.1 For reference cells that use single-crystal silicon solar cells, or for reference cells that have been previously characterized, the short-circuit current versus irradiance linearity determination is optional.

7.2.4 *Fill Factor*— Determine the fill factor of the cell to be calibrated from the I-V curve of the device, as measured in accordance with Test Methods E948.

8. Procedure

8.1 Select the time period for a single calibration data point. Two factors must be considered: *(1)* the response time of the pyrheliometer, and *(2)* the time required for the spectroradiometer to measure a single spectral irradiance.

8.1.1 Pyrheliometers have response times (defined as the time required for the instrument to indicate 95 % of a step change of input irradiance) on the order of 1 to 30 s. It is recommended that the calibration time period span the manufacturer's specified response time by a factor of at least five.

8.1.1.1 Absolute cavity radiometers are self-calibrating instruments that rely on periodically blocking all light with shutters; the blocked periods must be considered when selecting the calibration time period.

8.1.2 Spectroradiometers that use mechanically rotated diffraction gratings can require as much as 60 s to scan a single spectral irradiance, while those that employ photodiode arrays can reduce the measurement time to tens of milliseconds.

8.1.3 Use the larger of either 8.1.1 or 8.1.2 as the calibration time period.

8.2 Mount the reference cell to be calibrated, the collimator, the pyrheliometer, and the spectral irradiance measurement equipment spectroradiometer on the tracking platforms.platforms, and orient the collimating tubes parallel to the sun vector within the tracking limits of the platforms (see 6.4).

8.3 Measure the relative spectral irradiance of the sun,Collect data for a single calibration data point E(λ),during using the spectral irradiance measurement instrument (see the calibration time period as follows:6.6) and the procedure of Test Method E973. During the spectral irradiance measurement, perform the following:

8.3.1 Measure the pyrheliometer output,an array of Ereference cell$_t$, short-circuit current values, where n and verify that the total irradiance is between is the number of current values:

$$\mathbf{I} = [I_1\, I_2\, \ldots\, I_n] \tag{1}$$

750 Wm^{-2} and 1100 Wm^{-2}.

8.3.2 Measure the short-circuit current an array of the reference cell, pyrheliometer output values, where In_{sc}. is the number of irradiance values:

$$\mathbf{E} = [E_1\, E_2\, \ldots\, E_n] \tag{2}$$

8.3.3 Measure the reference cell temperature,Depending on the speed of the T.electrical measurement equipment (see 6.6), the numbers of current and irradiance values obtained in 8.3.1 and 8.3.2 might not be identical, and they are not required to be identical. However, the time periods over which the values are obtained must be identical.

8.3.4 RepeatMeasure 8.2.1 and 8.2.2 at least four times. These repetitions must be distributed in time during the spectral irradiance measurement. To assure temporal stability, the short-circuit current of the reference cell shall not vary by more than ±0.2 % during the repetitions.for the calibration time period using the spectroradiometer.

8.3.4.1 If the spectroradiometer measurement time is less than the calibration time period, collect multiple spectra and average them to obtain a single spectral irradiance.

8.3.5 Average the short-circuit current and total irradiance values from Measure the reference cell temperature, 8.2.4 to obtain the IT_{sc-D}. and E$_t$ that corresponds to the spectral irradiance measurement.

8.4 Perform a minimum of fivesix replications of 8.28.3. on at least three separate days; more repetitions are recommended.

8.3.1 The five replications must be performed on at least three separate days. Therefore, five replications all performed on the same day would not be an acceptable data set for the calibration.

8.3.2 In order to reduce precision errors through averaging, it is recommended that at least 30 replications of 8.2 be performed.