Designation: E 1125 – 99

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

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## 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 E 891 or E 892. The recommended physical requirements for these reference cells are described in Specification E 1040. 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 of the cell, the relative spectral distribution of the sunlight, and a tabulated reference spectral irradiance distribution.

1.3 This test method requires the use of a pyranometer that is calibrated according to Test Method E 816, 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 Test Methods E 1039 and Test Method E 1362. This test method offers convenience in its ability to characterize a reference cell under any spectrum for which tabulated data are available. The selection 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 E 1143.

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

1.7 There is no similar or equivalent ISO 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:*

E 772 Terminology Relating to Solar Energy Conversion[2]

E 816 Method for Calibration of Secondary Reference Pyrheliometers and Pyrheliometers for Field Use[2]

E 891 Tables for Terrestrial Direct Normal Solar Spectral Irradiance for Air Mass 1.5[3]

E 892 Tables for Terrestrial Solar Spectral Irradiance at Air Mass 1.5 for a 37° Tilted Surface[3]

E 948 Test Methods for Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Cells Using Reference Cells[2]

E 973 Test Method for Determination of the Spectral Mismatch Between a Photovoltaic Device and a Photovoltaic Reference Cell[2]

E 1021 Test Methods for Measuring the Spectral Response of Photovoltaic Cells[2]

E 1039 Test Method for Calibration and Characterization of Non-Concentrator Terrestrial Photovoltaic Reference Cells Under Global Irradiation[2]

E 1040 Specification for Physical Characteristics of Non-Concentrator Terrestrial Photovoltaic Reference Cells[2]

E 1328 Terminology Relating to Photovoltaic Solar Energy Conversion[2]

E 1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells[2]

## 3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminology E 772 and Terminology E 1328.

3.2 *Symbols:*

3.2.1 The following symbols and units are used in this test method:

$\lambda$—Wavelength, nm or µm,

$I_{sc}$—Short-circuit current, A,

$E$—Irradiance, $Wm^{-2}$,

$E_t$—Total irradiance, $Wm^{-2}$,

$E(\lambda)$—Spectral irradiance, $Wm^{-2}\mu m^{-1}$,

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[2] *Annual Book of ASTM Standards*, Vol 12.02.

[3] *Annual Book of ASTM Standards*, Vol 14.04.

*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.

## 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 solar irradiance using a pyrheliometer. The ratio of the short-circuit current of the cell to the irradiance, divided by a correction factor similar to the spectral mismatch parameter defined in Test Method E 973, is the calibration constant 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.

4.1.1 The relative spectral irradiance of the sunlight is measured using a spectral irradiance measurement instrument as specified in Test Method E 973.

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 of the cell is determined in accordance with Test Methods E 1021.

4.2.2 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 7.2.2).

4.2.3 Linearity of short-circuit current versus irradiance is determined in accordance with Test Method E 1143.

4.2.4 The fill factor of the reference cell is determined using Test Method E 948. 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, it is necessary to account for the error in the short-circuit current that occurs if the relative spectral response of the reference cell is not identical to the spectral response 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 E 973), 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 E 891 or E 892. This test method allows calibration with respect to any tabular spectrum.

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 E 1040.

## 6. Apparatus

6.1 *Pyrheliometer*— A secondary reference pyrheliometer that is calibrated in accordance with Method E 816. An absolute cavity radiometer may also be used. Because secondary reference pyrheliometers are calibrated against an absolute cavity radiometer, the total uncertainty in the primary reference cell calibration constant will be reduced if an absolute cavity radiometer is used.

6.2 *Collimator*—A collimator fitted to the reference cell during calibration that has the same field-of-view as the pyrheliometer. An acceptable collimator design is described in Annex A1.

6.3 *Spectral Irradiance Measurement Equipment*, as required by Test Method E 973.

6.3.1 The spectral range of the spectral irradiance measurement shall be wide enough to include the spectral response of the cell to be calibrated.



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

6.3.3 If the spectral irradiance measurement is unable to measure the entire wavelength range required by 6.3.2, it is acceptable to use a reference spectrum, such as Table E 891, 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 model.

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 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.

6.5 *Temperature Measurement Equipment*—An instrument or instruments used to measure the temperature of the reference cell to be calibrated, that has a resolution of at least 0.1°C, and a total error of less than ±1°C of reading.

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 $I_{sc}$ of the cell to be calibrated and the