



Standard Test Methods for Calibration of Non-Concentrator Photovoltaic Non-Primary Reference Cells¹

This standard is issued under the fixed designation E1362; 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 These test methods cover calibration and characterization of non-primary terrestrial photovoltaic reference cells to a desired reference spectral irradiance distribution. 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 a photovoltaic device.

1.2 Non-primary reference cells are calibrated indoors using simulated sunlight or outdoors in natural sunlight by reference to a previously calibrated reference cell, which is referred to as the calibration source device.

1.2.1 The non-primary calibration will be with respect to the same reference spectral irradiance distribution as that of the calibration source device.

1.2.2 The calibration source device may be a primary reference cell calibrated in accordance with Test Method [E1125](#), or a non-primary reference cell calibrated in accordance with these test methods.

1.2.3 For the special case in which the calibration source device is a primary reference cell, the resulting non-primary reference cell is also referred to as a secondary reference cell.

1.3 Non-primary reference cells calibrated according to these test methods will have the same radiometric traceability as that of the calibration source device. Therefore, if the calibration source device is traceable to the World Radiometric Reference (WRR, see Test Method [E816](#)), the resulting secondary reference cell will also be traceable to the WRR.

1.4 These test methods apply only to the calibration of a photovoltaic cell that demonstrates a linear short-circuit current versus irradiance characteristic over its intended range of use, as defined in Test Method [E1143](#).

1.5 These test methods apply only to the calibration of a photovoltaic cell that has been fabricated using a single photovoltaic junction.

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

1.7 *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.*

1.8 *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

- [E490](#) Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables
- [E691](#) Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
- [E772](#) Terminology of Solar Energy Conversion
- [E816](#) Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers
- [E927](#) Classification for Solar Simulators for Electrical Performance Testing of Photovoltaic Devices
- [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.

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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.

E1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum

E1143 Test Method for Determining the Linearity of a Photovoltaic Device Parameter with Respect To a Test Parameter

G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

3. Terminology

3.1 *Definitions*—Definitions of terms used in these test methods may be found in Terminology **E772**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration source device, photovoltaic, n*—the reference cell used to measure the incident irradiance during the calibration.

3.2.2 *monitor solar cell, n*—a solar cell used to measure the irradiance of the solar simulator during the calibration; prior to the calibration procedure, the monitor solar cell is compared against the calibration source device using a transfer-of-calibration procedure.

3.2.3 *non-primary reference cell, photovoltaic, n*—a photovoltaic reference cell calibrated against another reference cell in accordance with Test Method **E1362**. **E772**

3.2.4 *primary reference cell, photovoltaic, n*—a photovoltaic reference cell calibrated in sunlight in accordance with Test Method **E1125**. **E772**

3.2.5 *secondary reference cell, photovoltaic, n*—a photovoltaic reference cell calibrated against a primary reference cell in accordance with Test Method **E1362**. **E772**

3.2.6 *test light source, n*—a source of radiant energy used for the secondary reference cell calibration, either natural sunlight or a solar simulator.

3.3 *Symbols:*

3.3.1 The following symbols and units are used in these test methods:

A —active area, reference cell (m^2),

C —calibration constant, Am^2W^{-1} ,

C_T —transfer calibration ratio (dimensionless),

D —as a subscript, refers to the reference cell to be calibrated,

E —irradiance, (Wm^{-2}),

E_0 —total irradiance, reference spectral irradiance distribution (Wm^{-2}),

$E_0(\lambda)$ —reference spectral irradiance distribution ($\text{Wm}^{-2}\mu\text{m}^{-1}$ or $\text{Wm}^{-2}\text{nm}^{-1}$),

i —as a subscript, refers to the i th calibration data point,

I or I_{SC} —short-circuit current, (A),

I_M —short-circuit current, monitor solar cell (A),

M —spectral mismatch parameter (dimensionless),

n —total number of calibration data points,

$Q(\lambda, T)$ —quantum efficiency (electrons/photon or %),

R —as a subscript, refers to the calibration source device,

$R_A(\lambda)$ —absolute spectral response (AW^{-1}),

s —standard deviation,

T —temperature, ($^{\circ}\text{C}$),

T_0 —calibration temperature, ($^{\circ}\text{C}$),

ΔT —temperature difference, ($^{\circ}\text{C}$),

λ —wavelength (nm or μm), and

$\Theta(\lambda)$ —partial derivative of quantum efficiency with respect to temperature (electrons per photon $\cdot^{\circ}\text{C}^{-1}$ or $\%\cdot^{\circ}\text{C}^{-1}$).

4. Summary of Test Method

4.1 The calibration constant, C , of a photovoltaic reference cell is defined as the ratio of its short-circuit current to the total irradiance when illuminated with a reference spectral irradiance distribution (such as Standard **E490** or Tables **G173**). In integral form, the calibration constant is:

$$C = \frac{I_{SC}}{E_0} = \frac{A \int R_A(\lambda) E_0(\lambda) d\lambda}{\int E_0(\lambda) d\lambda} \quad (1)$$

4.2 A reference cell is used to measure irradiance through Eq 2:

$$E = I_{SC}/C \quad (2)$$

4.3 Errors and difficulties associated with measuring A and $R_A(\lambda)$ in Eq 1 can be avoided by comparing the short-circuit current of a reference cell to be calibrated (I_D) against that of a previously calibrated reference cell (that is, the calibration source device, I_R), while both cells are illuminated with a test light source. The calibration constant of the calibration source device transforms short-circuit current to total irradiance so that Eq 1 becomes:

$$C_D = \frac{I_D}{I_R/C_R} \quad (3)$$

4.4 For calibrations in natural sunlight, the calibration source device and the cell to be calibrated are placed on a normal incidence tracking platform, and the short-circuit currents of both devices are measured simultaneously.

4.5 For calibrations in simulated sunlight, the calibration source device is first placed in the test plane, and a transfer-of-calibration procedure is performed to a monitor solar cell. The calibration source device is then replaced with the cell to be calibrated in the same location, and the non-primary calibration is then performed.

4.6 *Calibration Temperature*—These procedures assume the calibration temperatures, T_0 , of both the calibration source device and the cell to be calibrated are 25°C ; other calibration temperatures may be substituted if desired.

4.7 *Calibration Data Collection*—Raw calibration constant data are corrected for spectral and temperature differences using the spectral mismatch parameter, M (see 5.2 and Test Method **E973**).

4.8 *Light Soaking*—Newly manufactured reference cells must be light soaked at an irradiance level greater than 850 W/m^2 for 20 h prior to initial characterization.

4.9 *Characterization*—Prior to calibration, the non-primary cell is characterized using the following procedures:

4.9.1 Quantum efficiency at the calibration temperature, $Q(\lambda, T_0)$, determined in accordance with Test Methods **E1021**.

4.9.2 Partial derivative of quantum efficiency with respect to temperature $\Theta_D(\lambda) = \partial Q_D / \partial T(\lambda)$, determined in accordance with Annex A1 of Test Methods **E973**.



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