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Standard Specification for
Solar Simulation for Photovoltaic Testing[1]

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1. Scope

1.1 This specification provides means for classifying solar simulators intended for indoor testing of photovoltaic devices (solar cells or modules), according to their spectral match to a reference spectral irradiance, non-uniformity of spatial irradiance, and temporal instability of irradiance.

1.2 Testing of photovoltaic devices may require the use of solar simulators. Test Methods that require specific classification of simulators as defined in this specification include Test Methods E948, E1036, and E1362.

1.3 This standard is applicable to both pulsed and steady state simulators and includes recommended test requirements used for classifying such simulators.

1.4 A solar simulator usually consists of three major components: *(1)* light source(s) and associated power supply; *(2)* any optics and filters required to modify the output beam to meet the classification requirements in Section 4; and *(3)* the necessary controls to operate the simulator, adjust irradiance, etc.

1.5 A light source that does not meet all of the defined requirements for classification presented in this document may not be referred to as a solar simulator.

1.6 Spectral irradiance classifications are provided for Air Mass 1.5 direct and global (as defined in Tables G173), or Air Mass 0 (AM0, as defined in Standard E490).

1.7 The classification of a solar simulator is based on the size of the test plane; simulators with smaller test plane areas have tighter specifications for non-uniformity of spatial irradiance.

1.8 The data acquisition system may affect the ability to synchronize electrical measurements with variations in irradiance and therefore may be included in this specification. In all cases, the manufacturer must specify with the temporal instability classification: *(1)* how the classification was determined; and *(2)* the conditions under which the classification was determined.

1.9 The classification of a solar simulator does not provide any information about electrical measurement errors that are related to photovoltaic performance measurements obtained with a classified solar simulator. Such errors are dependent on the actual instrumentation and procedures used.

1.10 The following precautionary caveat pertains only to the hazards portion, Section 6, of this specification. *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 requirements 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 Relating to Solar Energy Conversion

E948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight

E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

E1328 Terminology Relating to Photovoltaic Solar Energy Conversion

E1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells

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

2.2 *IEC Standard:*

IEC 60904-9 Photovoltaic Devices—Part 9: Solar Simulator Performance Requirements

3. Terminology

3.1 *Definitions*—Definitions of terms used in this specification may be found in Terminologies E772 and E1328.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *solar simulator*—equipment used to simulate solar radiation. Solar simulators shall be labeled by their mode of operation during a test cycle (steady state, single pulse or

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[1] This specification 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.

multi-pulse) and by the size of the test plane area. A solar simulator must fall into at least the C classification.

3.2.2 *simulator classification*—a solar simulator may be one of three classes (A, B, or C) for each of three categories: spectral match, spatial non-uniformity, and temporal instability. The simulator is rated with three letters in order of spectral match, spatial non-uniformity and temporal instability (for example: Class ABA). Large area and small area simulators are classified according to the appropriate table. The simulator classification may be abbreviated by a single letter characterization. A simulator characterized by a single letter is indicative of a simulator with all three classes being the same (for example: a Class A simulator is the same as a Class AAA simulator).

3.2.3 *test plane area, A*—the area of the plane intended to contain the device under test.

3.2.4 *small area solar simulator*—a simulator whose test plane is equal to or less than 30 cm by 30 cm or a diameter of less than 30 cm if the test area is circular.

3.2.5 *large area solar simulator*—a simulator whose test plane is greater than 30 cm by 30 cm or a diameter of greater than 30 cm if the test area is circular.

3.2.6 *steady-state simulator*—a simulator whose irradiance output at the test plane area does not vary more than 5 % for time periods of greater than 100 ms.

3.2.7 *single-pulse simulator*—a simulator whose irradiance output at the test plane area consists of a short duration light pulse of 100 ms or less.

3.2.8 *multi-pulse simulator*—a simulator whose irradiance output at the test plane area consists of a series of short duration, periodic light pulses. Note that the light pulses do not necessarily have to go to zero irradiance between pulses; a steady-state simulator that fails the 5 % requirement in 3.2.6 can be classified as a multi-pulse simulator if the irradiance variations are periodic.

3.2.9 *time of data acquisition*—the time required to obtain one data point (irradiance, current, and voltage) if there is a simultaneous measurement of irradiance at each current-voltage data point. If no simultaneous measurement of the irradiance is made during the test, the time of data acquisition is the time to obtain the entire current-voltage (I-V) curve.

3.2.10 *solar spectrum*—the spectral distribution of sunlight at Air Mass 1.5 Direct (as defined in Tables G173), Air Mass 1.5 Global (as defined in Tables G173), or Air Mass 0 (as defined in Standard E490).

3.2.11 *spectral match*—ratio of the actual percentage of total irradiance to the required percentage specified in Table 3 for each wavelength interval.

3.2.12 *spatial non-uniformity of irradiance (in percent)*:

$$S_{NE} = 100 \% \times \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}} \quad (1)$$

where $E_{\max}$ and $E_{\min}$ are measured with the detector(s) over the test plane area.

3.2.13 *temporal instability of irradiance (in percent)*:

$$T_{IE} = 100 \% \times \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}} \quad (2)$$

where $E_{\max}$ and $E_{\min}$ are measured with the detector at any particular point on the test plane during the time of data acquisition.

3.2.14 *field of view*—the maximum angle between any two incident irradiance rays from the simulator at an arbitrary point in the test plane.

4. Significance and Use

4.1 In any photovoltaic measurement, the choice of simulator Class should be based on the needs of that particular measurement. For example, the spectral distribution requirements need not be stringent if devices of identical spectral response from an assembly line are being sorted according to current at maximum power, which is not a strong function of spectral distribution.

4.2 Classifications of simulators are based on the size of the test area and the probable size of the device being measured. It has been shown that when measuring modules or other larger devices the spatial non-uniformity is less important, and up to 3 % non-uniformity may not introduce unacceptable error for some calibration procedures.[3] Accurate measurements of smaller area devices, such as cells, may require a tighter specification on non-uniformity or characterization of the non-uniformity by the user. When measuring product it is recommended that the irradiance be measured with a reference device similar to the devices that will be tested on the simulator to minimize spatial non-uniformity errors.

4.3 It is the intent of this specification to provide guidance on the required data to be taken, and the required locations for this data to be taken. It is not the intent to define the possible methods to measure the simulator spectrum or the irradiance at every location on the test plane.

4.4 Note that the letter classification scheme (see 3.2.2) does not include a number of important properties, especially the test plane size, the field of view, nor the steady state or the pulsed classifications (see 3.2.3 through 3.2.8, and 3.2.14). These additional properties are included in the reporting requirements (see Section 9). It is also recommended that they be included in product specification sheets or advertising.

4.5 Because of the transient nature of pulsed solar simulators, considerations must be given to possible problems such as the response time of the device under test versus the time of data acquisition and the rise time of the pulsed irradiance. If a pulsed solar simulator includes a data acquisition system, the

TABLE 1 Classification of Small Area Simulator Performance

Classification	Characteristics		
	Spectral Match to all Intervals	Spatial Non-uniformity of Irradiance	Temporal Instability of Irradiance
Class A	0.75 to 1.25	2 %	2 %
Class B	0.6 to 1.4	5 %	5 %
Class C	0.4 to 2.0	10 %	10 %

[3] Herrman, W., and Wiesner, W., "Modelling of PV Modules—The Effects of Non-Uniform Irradiance on Performance Measurements with Solar Simulators," *Proc. 16th European Photovoltaic Solar Energy Conf.*, European Commission, Glasgow, UK, 2000.

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