Designation: E 1596 – 99

Standard Test Methods for Solar Radiation Weathering of Photovoltaic Modules[1]

This standard is issued under the fixed designation E 1596; 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 The three radiant energy weathering procedures described in these test methods are intended to determine the effects of extended outdoor exposure-induced stress that may occur during service life of photovoltaic modules.

1.1.1 Because most accelerated weathering devices are not large enough to accept full-sized photovoltaic modules, the simulated weathering test procedures may be suitable only for smaller test modules. The construction of smaller test modules should be as close in design and function as possible to full-size modules.

1.2 The three solar weathering test methods are as follows:

1.2.1 *Procedure A*—Natural sunlight, real-time exposure testing,

1.2.2 *Procedure B*—Accelerated exposure testing concentrated natural sunlight, and

1.2.3 *Procedure C*—Accelerated exposure testing using simulated sunlight.

1.3 The test methods do not provide for weathering studies on individual components of photovoltaic modules.

1.4 There is no similar or equivalent ISO Standard.

1.5 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.6 *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 1036 Test Methods for Testing the Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells[2]

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

E 1462 Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules[2]

G 7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials[3]

G 26 Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[3]

G 90 Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight[3]

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *test specimen, n*—a full-size photovoltaic module, or a smaller size photovoltaic module fabricated with similar materials and processing as a full-size module, that will be subjected to the solar weathering tests.

3.2.2 *total UV dose, n*—see **UV below 385 nm.**

3.2.3 *UV below 385 nm, n*—the radiant exposure in W/m^2 of wavelengths shorter than 385 nm incident upon a test specimen.

4. Summary of Test Methods

4.1 Three solar weathering test methods are provided for determining the effects of extended outdoor exposure-induced stress that may occur during service life of photovoltaic modules.

4.2 The duration of each of the test methods is determined by the amount of time needed to accumulate a total ultraviolet (wavelengths shorter than 385 nm) exposure of 2000 MJ/m^2, which is roughly equivalent to 72 months exposure in southern U.S. latitudes. If no failure mechanisms are detected or measured after 2000 MJ/m^2 of UV radiant exposure, testing shall continue until the photovoltaic module failure mechanisms are characterized or until the UV radiant dose exceeds 6600 MJ/m^2.

4.3 The three test methods are:

[1] These test methods are under the jurisdiction of ASTM Committee E-44 on Solar, Geothermal, and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Systems.

Current edition approved Oct. 10, 1999. Published November 1999. Originally published as E 1596-94. Last previous edition E 1596-94.

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

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

4.3.1 *Procedure A*—Exposure in natural sunlight on a fixed-angle rack facing the equator or on a tracking rack.

4.3.2 *Procedure B*—Exposure in a Fresnel reflector panel rack that provides concentrated natural sunlight irradiation by following the sun and focusing the sunlight on the test modules by means of mirrors. The test modules may be wetted periodically by distilled or deionized water spray.

4.3.3 *Procedure C*— Exposure in an apparatus that provides high intensity simulated sunlight illumination of the photovoltaic modules from a filtered xenon arc light source. The test modules may be wetted periodically by distilled or deionized water spray.

4.4 The selection of one of these test methods is dependent on the time available for the exposure tests and the degree of reliability required for predictions of durability.

5. Significance and Use

5.1 One or more of these test methods are generally performed on a sample lot of photovoltaic modules or smaller test modules to determine the effects of extended outdoor exposure-induced stress that may occur during service life.

5.1.1 Potential effects include (but are not limited to) stress-induced deterioration of the structural, optical, and electrical performance characteristics of modules.

5.1.2 These test methods are intended to be used as time-to-failure tests (see 4.2 and 5.3). Annex A1 provides guidelines for using these test methods for shorter-term qualification testing.

5.2 Although natural, real-time exposure testing is the preferred method, the necessity of performing accelerated testing to make module design and construction decisions quickly is well recognized. This is particularly true when testing is in support of extended lifetime requirements. However, accelerated testing should be accompanied (preferably preceded) whenever possible by natural, real-time testing in order to validate accelerated weathering by providing correlation factors for the early exposure stages.

5.3 Modules subjected to the three test methods are exposed for equivalent UV radiant exposure of 72 months in southern U.S. latitudes. For purposes of these tests, this equivalent exposure is defined as 48 000 MJ/m^2 of sunlight. This exposure represents a total ultraviolet exposure of 2000 MJ/m^2 of energy below 385 nm wavelength (an average of 4 % of total annual sunlight). However, if no failure occurs after this exposure period, additional testing is required to ascertain the mechanism by which the photovoltaic module will eventually fail. Different accelerated weathering devices may record UV irradiance over different wavelengths than energy below 385 nm. These measurement methods are acceptable provided this data can be converted to UV below 385 nm.

5.4 The determination of relevant structural and performance measurements at intermediate exposure levels is necessitated if degradation-rate information is sought to establish a correlation between real-time and accelerated test procedures.

5.5 Modules may be exposed in the open-circuit, short-circuit, or loaded conditions. It is the responsibility of the user of these test methods to specify the load conditions of the test specimens during the exposure testing.

NOTE 1—Since Procedure A and Procedure B weathering are conducted at significantly higher irradiance levels than 1000 W/m^2, care must be exercised if exposing the modules in the short circuit or loaded configuration. Also, differences in the module loading conditions between Procedures A, B, and C may significantly affect the ability to correlate the test results between the three procedures.

5.6 Since the natural environment varies with respect to time, geography, and topography, it may be expected that the effects of natural exposure will vary accordingly. Further, all materials are not affected equally by increased irradiance and temperature. Therefore, the quantitative correlation between exposures conducted in accordance with these test methods and those carried out under specified natural exposure conditions will vary with the type and composition of the material.

6. Apparatus

6.1 *Total Ultraviolet Radiometer*—A properly calibrated total ultraviolet radiometer, filtered to exclude all wavelengths greater than 385 nm, used to measure the ultraviolet dosage of test specimens subjected to Procedure A. It shall be mounted either coplanar with, or at the same tilt angle as the test specimens. These instruments shall be calibrated at least yearly.

6.2 *Direct Normal Ultraviolet Radiometer*—A properly calibrated direct normal ultraviolet radiometer as specified by Practice G 90 shall be used to measure the ultraviolet dosage of test specimens subjected to Procedure B. These instruments shall be calibrated yearly.

6.3 *Exposure Racks*—Adjustable exposure test racks as described in Practice G 7 or tracking racks for mounting test specimens subjected to Procedure A.

6.3.1 Exposure racks shall be located in accordance with Practice G 7. The type of ground cover shall be indicated in the report (see 8.1.4).

6.4 *Natural Sunlight Concentrator*—Fresnel-reflecting concentrator test equipment as described in Practice G 90. This equipment shall provide uniform illumination to ±5 % across the test specimens, cooling to control test specimen temperature from 0°C to 15°C above the expected in-service temperature under loaded conditions based on 45°C ambient temperature, and periodic distilled or deionized water spray on the test specimens in accordance with Practice G 90 spray cycle No. 3.

6.5 *Simulated Sunlight Exposure Chamber*—A chamber in which test specimens are mounted while subjected to concentrated xenon-arc illumination as specified by Practice G 26 and also controls irradiance levels, temperature and humidity and is capable of spray cycles is appropriate. The ultraviolet dosage shall be measured with UV radiometers properly calibrated at least monthly.

7. Procedure

7.1 *Test Lot Selection*—Select a minimum of four test specimens considered to be representative of the type to be tested. Reserve one of the four specimens as a control sample.

7.2 *Cleaning*—Clean the test specimens with deionized or distilled water and mild soap and then rinsing, followed by towel or free air drying. Rubbing shall be avoided. Compressed air, heated air, or other methods of drying the test specimens is not permitted.

7.3 *Visual Inspection*:

7.3.1 Visually inspect each test specimen to determine the presence or absence of defects or anomalies. Such anomalies or defects may include delaminations or voids, discolorations, corrosion, or cracks in any part of the assembly. Consider defects to be any obvious deviations from acceptable appearance, as defined by the user of the test methods.

7.3.2 Record the results of the visual examination using photographs or a diagram of the specimen, or both, showing the location and type of defect.

7.4 *Electrical Tests*— Perform the following electrical tests on all samples, including the control, prior to the exposure tests:

7.4.1 *Electrical Performance*—Measure and record the electrical performance of each test specimen. An acceptable method for non-concentrator modules is Test Methods E 1036.

7.4.2 *Insulation Resistance Test*—Measure the insulation resistance of each test specimen using 7.2 of Test Method E 1462.

7.4.3 *Insulation Current Leakage Test*—Measure the insulation current leakage of each test specimen using 7.1 of Test Method E 1462.

NOTE 2—Additional tests may be used to determine the failure mechanisms of the test specimen.

7.5 *Procedure A*:

7.5.1 Mount the four test specimens that will be subjected to the weathering test in the exposure racks in a position equivalent to the intended end use. Retain the control test specimen in a safe location.

7.5.2 Attach the test specimens to an electrical load as specified by the user of the test methods (see 5.5).

7.5.3 Expose the mounted specimens to sunlight for a period of time sufficient to accumulate the appropriate total ultraviolet dose (see 4.2).

7.5.4 At intermediate exposure levels, the test specimens may be removed from the exposure racks and the cleaning (7.2), visual inspection (7.3), and electrical tests (7.4) repeated.

7.5.5 Remove the three test specimens from the exposure racks.

7.6 *Procedure B*:

7.6.1 Mount the three test specimens that will be subjected to the weathering test in the natural sunlight concentrator. Retain the control test specimen in a safe location.

7.6.2 Attach the test specimens to an electrical load as specified by the user of the test methods (see 5.5).

7.6.3 Expose the mounted test specimens to concentrated sunlight for a period of time sufficient to accumulate the appropriate total ultraviolet dose (see 4.2).

7.6.4 At intermediate exposure levels, the test specimens may be removed from the concentrator and the cleaning (7.2), visual inspection (7.3), and electrical tests (7.4) repeated.

7.6.5 *Water Spray*—Subject the test specimens to Practice G 90 water spray cycle No. 3 using distilled or deionized water that has less than 1.0 ppm total dissolved solids and less than 0.1 ppm silica.

7.6.6 Remove the three test specimens from the concentrator.

7.7 *Procedure C*:

7.7.1 Mount the three test specimens that will be subjected to the weathering test in the simulated sunlight exposure chamber. Retain the control test specimen in a safe location.

7.7.2 Attach the test specimens to an electrical load as specified by the user of the test methods (see 5.5).

7.7.3 Operate the exposure chamber such that the test specimen temperature is within 0° to 15°C above the expected in-service loaded conditions based on a 45°C ambient temperature.

7.7.4 Expose the mounted test specimens to simulated sunlight for a period of time sufficient to accumulate the appropriate total ultraviolet dose (see 4.2). The ultraviolet irradiance shall not exceed 200 W/m^2 below 385 nm. The optical filter system for each type of xenon devices shall approximate direct sunlight.

7.7.5 At intermediate exposure levels, the test specimens may be removed from the exposure chamber and the cleaning (7.2), visual inspection (7.3), and electrical tests (7.4) repeated.

7.7.6 *Water Spray*—Subject the test specimens to water spray cycles using distilled or deionized water that has less than 1.0 ppm total dissolved solids and less than 0.1 ppm silica.

7.7.7 Remove the three test specimens from the exposure chamber.

7.8 Clean all four test specimens using 7.2.

7.9 Visually inspect all four test specimens using 7.3.

7.10 Perform the electrical tests (7.4) on all four test specimens.

8. Report

8.1 The solar weathering test report shall include the following information as a minimum:

8.1.1 Test specimen manufacturer and identification,

8.1.2 Description of module construction,

8.1.3 Test method used (Procedure A, B, or C) and brief description of test apparatus and measurement instrumentation,

8.1.4 All relevant environmental conditions including cumulative UV radiant exposure. For Procedure C also report UV irradiance during light cycles, chamber air temperature, black panel or black standard temperature,

8.1.5 A line drawing or photograph of the test specimens showing orientation during testing,

8.1.6 Description of electrical measurement equipment, and measurement conditions or parameters,

8.1.7 Description of any apparent visual changes due to testing, with sketches or photographs,

8.1.8 Results of changes between pre- and post-testing electrical tests, if any, including comparison to control sample test results, and

8.1.9 Any deviations from the standard test procedures, such as interruptions.

9. Precision and Bias

9.1 The solar weathering procedures described by these test methods do not produce numeric results which would be subject to ASTM procedures for evaluating the precision and bias of these test methods. However, the precision and bias of the electrical performance measurements, when performed in accordance with Test Methods E 1036, are subject to the provisions of that document.

10. Keywords

10.1 exposure testing; Fresnel-reflecting concentrator; natural weathering; photovoltaic modules; simulated weathering; solar radiation; ultraviolet radiation; weathering; xenon arc

ANNEX

(Mandatory Information)

A1. RECOMMENDED USE OF TEST METHODS IN MODULE QUALIFICATION TESTING

A1.1 Because these test methods are time-to-failure tests, it may require many months or years of exposure before a failure occurs. Therefore, it is appropriate and practical to recommend guidelines for using these test methods as part of a module qualification test, that is, one that can be completed in a shorter time period and yet may still be able to discover many, if not all, field failures due to solar weathering. The purpose of this annex is to provide test procedures for such a shorter-term qualification test.

A1.2 The scope of this qualification test will be to simulate approximately two years (24 months) of exposure at southern U.S. latitudes. This exposure is equivalent to a total ultraviolet dose (for wavelengths shorter than 385 nm) of 700 MJ/m^2. Because the accelerated procedures use concentrated illumination, these procedures will not require a full two-year period for qualification. For example, with an acceleration factor of six, the 24 month equivalent exposure would require about four months.

A1.3 Any of the three exposure procedures are acceptable for this test: *Procedure A*—natural sunlight, real-time exposure; *Procedure B*—accelerated exposure using concentrated natural sunlight; or *Procedure C*—accelerated exposure using simulated sunlight. If Procedure C is used, the apparatus must provide high intensity simulated sunlight from a filtered xenon-arc light source (see 6.5).

A1.4 The apparatus, procedures, and reporting requirements of the qualification test should be identical to the time-to-failure test with the exception of the shorter duration of the exposure.