Designation: E3006 – 15

Standard Practice for
Ultraviolet Conditioning of Photovoltaic Modules or Mini-Modules Using a Fluorescent Ultraviolet (UV) Lamp Apparatus[1]

This standard is issued under the fixed designation E3006; 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 practice covers specific procedures and test conditions for performing ultraviolet conditioning exposures on photovoltaic modules or mini-modules using fluorescent ultraviolet lamps in accordance with Practices G151 and G154. This practice covers test conditions that meet the requirements for UV preconditioning in initial qualification tests of photovoltaic modules or mini-modules as published in International Electrotechnical Commission (IEC) standards.

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

1.3 *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]

E772 Terminology of Solar Energy Conversion

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

G130 Test Method for Calibration of Narrow- and Broad-Band Ultraviolet Radiometers Using a Spectroradiometer

G151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

G154 Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials

G177 Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37° Tilted Surface

2.2 *IEC Standards:*[3]

IEC 61215 Crystalline silicon terrestrial photovoltaic (PV) modules – design qualification and type approval, Second Edition

IIEC 61345 UV test for photovoltaic (PV) modules, First Edition

IEC 61646 Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval, Edition 2.0

2.3 *ISO Standards:*

ISO 4892-3 Plastics – Method of exposure to laboratory light sources—Part 3: Fluorescent UV lamps

3. Terminology

3.1 The definitions given in Terminology G113 and Terminology E772 are applicable to this practice.

4. Summary of Practice

4.1 Specimens are exposed to fluorescent ultraviolet lamps of types UVA-340 and UVB-313 as needed to achieve specific dosages of ultraviolet radiation as required by IEC qualification standards for photovoltaic modules and materials or by agreement between contractual parties.

5. Significance and Use

5.1 Photovoltaic modules and components must be resistant to prolonged exposure to solar radiation, moisture and heat. Degradation of polymeric components, delamination at the encapsulant and other interfaces, and moisture ingress are among the degradation modes known to decrease the output of photovoltaic modules. IEC qualification standards for PV modules include tests intended to uncover whether solar ultraviolet radiation induced degradation may cause early-life failures. This practice provides general and specific guidance on performing tests that meet the requirements of the ultraviolet radiation conditioning exposures in the IEC qualification

[1] This practice 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 Feb. 1, 2015. Published April 2014. DOI: 10.1520/E3006-15

[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.

[3] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland, http://www.iec.ch.

standards.[4] Other protocols exist that may also conform to the IEC test requirements.

5.2 In the qualification test sequence, this UV preconditioning exposure is conducted prior to the thermal cycling and humidity freeze tests. These tests were included to replicate a delamination failure observed in modules.[5]

5.3 IEC exposure methods should not be considered as long term weathering tests. Exposure to moisture in the form of condensation or water spray is not a requirement of the UV exposure tests in IEC PV module qualification standards. Inclusion of moisture is typically a consideration in weathering tests.

5.4 Variation in test results may be expected when operating conditions are varied within the acceptable limits of this standard. In particular, reciprocity of degradation among varying irradiance levels should not be assumed. Consequently, no reference to this practice should be made without an accompanying report prepared in accordance with Section 9 that describes the specific operating conditions used.

5.5 Correlation between this practice and long term performance of PV modules in real-world installations has not been determined. Although experience has shown these methods are effective in screening for unstable materials and systems, it is unknown at this time if degradation due to prolonged solar ultraviolet exposure can be replicated by extending the time and energy dosage of the exposures described in this practice. The most effective use of this practice is as a comparative tool for evaluating materials and systems. Consequently, the use of controls or reference materials of known performance is recommended; refer to Practice G151, Section 6.2.4.

6. Apparatus

6.1 Practice G154 and ISO 4892-3 describe essential features of the apparatus and equipment required for this practice.

6.2 *Laboratory Light Source*—The light source shall be fluorescent UV lamps as defined in Practice G154. Differences in lamp intensity or spectrum may cause significant differences in test results. A detailed description of the type(s) of lamp(s) used shall be stated in the test report. The particular qualification test requirement or application determines which lamp type(s) is used.[6]

6.2.1 Actual irradiance levels at the test specimen surface may vary due to the type or manufacturer of the lamp used, the age of the lamps, the power supply, the distance to the lamp array, the air temperature within the exposure chamber, reflectivity of interior chamber surfaces, and the ambient laboratory temperature. Consequently, the use of a radiometer to monitor the irradiance at the specimen plane is required. The radiometer shall comply with the requirements of Practice G151. Use of a feedback loop system to control the irradiance during the exposure is recommended.

6.2.2 Several factors can affect the spectral power distribution of fluorescent UV lamps, including type and uniformity of the phosphor coating, changes in transmission due to aging of the glass used in some types of lamps, accumulation of dirt or other residue on lamps, and thickness of the lamp glass.

6.2.3 *Common Lamp Types*—Two types of lamps used in the fluorescent UV lamp devices are defined in Practice G154 for photodegradation and weathering tests: UVB-313 and UVA-340, respectively. Lamp manufacturers shall follow Annex A1 of Practice G154 to demonstrate conformance to Table 1 and Table 2. If other lamp types are employed, their spectral irradiance must be included in the test report showing enough resolution to calculate UV exposure dosages. See Annex A1 for further information.

6.2.3.1 *Spectral Irradiance of UVA-340 Lamps*—The spectral power distribution of UVA-340 fluorescent lamps, which have a peak emission at 343 nm, shall comply with the

TABLE 1 Relative Ultraviolet Spectral Power Distribution Specification for Fluorescent UVA-340 Lamps

Spectral Bandpass Wavelength λ in nm	Minimum Percent	Benchmark AM1.5 Solar Radiation Percent	Benchmark AM1 Solar Radiation Percent	Maximum Percent[A]
λ <290				0.01
290 ≤ λ ≤ 320	5.9	3.5	5.8	9.3
320 < λ ≤ 360	60.9	38.0	40.0	65.5
360 < λ ≤ 400	26.5	58.5	54.2	32.8

[A] Visible light output from fluorescent UV lamps typically represents 10-20 % of total radiation, but this value is not specified in Practice G154.

[4] IEC photovoltaic module standards require a series of simulated solar ultraviolet radiation exposure tests to evaluate the performance of modules and components under the stresses simulating inherent in the in-service environment. Since few of these tests protocols, nor the equipment required for their execution, are clearly defined, ASTM Subcommittee E44.09, part of Committee E44 on Solar, Geothermal and Other Alternative Energy Sources has set out on a course of action to standardize defined test methods confroming to the IEC requirements.

[5] Osterwald, C. R., and McMahon, T. J., "History of Accelerated and Qualification Testing of Terrestrial Photovoltaic Modules: A Literature Review," *Prog. Photovolt: Res. Appl.*, 2009, 17, pp. 11–33.

[6] Mixing of different types of lamps in a single exposure is not recommended, as this may produce inconsistencies in the radiation falling on the samples, unless the apparatus has been specifically designed to ensure a uniform spectral distribution. Use of two different lamp types may be desirable or required to meet exposure requirements of certain methods. In devices not capable of providing uniform irradiance using multiple lamp types, it is recommended to divide the exposure period into distinct parts so that specimens are exposed to each lamp type consecutively rather than concurrently. See Section 7 and Appendix X2 for additional information.

TABLE 2 Relative Ultraviolet Spectral Power Distribution Specification for Fluorescent UVB-313 Lamps

Spectral Bandpass Wavelength λ in nm	Minimum Percent	Benchmark AM1.5 Solar Radiation Percent	Benchmark AM1 Solar Radiation Percent	Maximum Percent[A]
$\lambda < 290$	1.3			5.4
$290 \le \lambda \le 320$	47.8	3.5	5.8	65.9
$320 < \lambda \le 360$	26.9	38.0	40.0	43.9
$360 < \lambda \le 400$	1.7	58.5	54.2	7.2

[A] Visible light output from fluorescent UV lamps typically represents 10-20 % of total radiation, but this value is not specified in Practice G154.

requirements specified in Table 1. Additional information is provided in Annex A1.

6.2.3.2 *Spectral Irradiance of UVB-313 Lamps*—The spectral power distribution of UVB-313 fluorescent lamps, which have a peak emission at 313 nm, shall comply with the requirements specified in Table 2. Additional information is provided in Annex A1.

6.3 *Test Chamber and Ultraviolet Radiation Uniformity*—The design of the test chamber may vary, but it should be constructed from corrosion resistant material. The fluorescent UV lamp(s) shall be located with respect to the specimens such that the uniformity of irradiance at the specimen face complies with the requirements in Practice G151.

6.4 *Thermometer*—The chamber shall have means of controlling temperature. An uninsulated black panel thermometer is recommended to measure and control test temperatures, but insulated black panels or white panels may also be used. Thermometers shall conform to the descriptions found in Practice G151. If the control temperature and the specimen temperature differ, then the relationship between the two shall be determined and the control temperature set so as to maintain the required specimen temperature during the exposure test. The correlation between control temperature and specimen temperature during irradiation can be obtained by placing a thermometer/thermocouple on the unirradiated side of the specimen and measuring the specimen temperature over a range of control temperatures.

7. Procedure

7.1 *Calibration and Maintenance*—Calibrate all sensors and maintain devices according to manufacturers' recommendations. Narrow or broad band radiometers may be calibrated according to Test Method G130.

7.2 *Mounting of Test Specimens*—Mount test specimens using non-corrosive holders or module clips specifically designed for the module tested in such a manner that they are not subject to physical stress. When test specimens do not completely fill the specimen racks or exposure area, fill all empty spaces with blank panels and seal any holes or gaps in specimens to maintain the test conditions within the chamber.

7.3 *Specimen Repositioning*—Unless specimen size makes repositioning impossible, follow the guidelines on repositioning in Practice G154.

7.4 *Measuring and Setting Irradiance*—These methods do not require any specific irradiance set point as long as the total ultraviolet irradiance integrated over the range 280-400 nm is less than 250 W/m^2, which is approximately equal to five times standard test condition (STC) irradiance. However, the UV irradiance must be measured in the same plane as test specimens in order to verify compliance with the maximum allowed irradiance and to accurately calculate radiant dosage, and the test apparatus must be maintained in order to account for the effects of lamp aging and power fluctuations. Annex A1 describes a method of measuring and setting the irradiance and test duration using a narrow band radiometer calibrated according to Test Method G130 for use with specific fluorescent UV lamps. Wide band radiometers designed to measure UVA and UVB energy may also be used.

7.4.1 Although not a requirement, systems with feedback loop irradiance control are preferred. When systems without irradiance control are used, the operator must take additional steps to measure the irradiance at regular intervals and make adjustments to lamp power or test duration to ensure proper radiant dosage has been delivered to specimens.

7.4.2 *Test Duration*—These methods specify exposure duration in terms of total radiant energy dosages (kWh/m^2) rather than time because a wide range of irradiance levels are allowed by the IEC. These radiant energy dosages are defined for specific spectral regions. Exposure durations are determined by these energy dosages and the spectral irradiance of the light source(s) in these regions. Dosages specified in 7.5[7] are described by the equation:

$$D_{A \rightarrow B} = \int_{\lambda A}^{\lambda B} I \times t \quad (1)$$

where:

$D_{A \rightarrow B}$ = radiant dosage of wavelength band between wavelengths A and B in kilowatt-hours per square metre
I = irradiance in watts per square meter
λ_A = wavelength at lower limit of spectral band specified
λ_B = wavelength at upper limit of spectral band specified
t = duration of exposure in hours

7.4.3 Irradiance in each of the required spectral bands can be measured directly or, in cases where the spectral power distribution of the fluorescent UV lamps is known to remain stable over time, by mathematically converting measurements taken at a 1 nm bandpass wavelength (narrow band) or in the entire UV spectral region (wide band). When converting measurements, see Annex A1 for specific guidance.

7.4.4 Test duration may be calculated by dividing the required dosage in kWh/m^2 in the defined spectral regions by the irradiance of that region. Wide band radiometers designed to measure accumulated dosage may also be used.

7.4.5 The spectral irradiance of common fluorescent ultraviolet lamps does not simultaneously meet the dosage requirements of all wavelength bands for some methods. Operators may need to expose specimens under two different types of lamps in consecutive exposures in order to avoid dosages in

[7] The methods in 7.5 include dosage requirements in the following spectral bands: 280 to 400 nm, 280 to 385 nm, 280 to 320 nm.

excess of the requirements. See Appendix X1 for guidance and specific examples using common lamp types.

7.4.6 Although the IEC standards allow a range of irradiance values, reciprocity between various cycles should not be assumed. Refer to Practice G151, Section 4 and Appendix X1.

7.5 *Test Methods:*

7.5.1 *Method A*—This method conforms to the requirements of IEC 61646: Design Qualification for Thin Film PV Modules—UV Preconditioning Under Resistive Load, Edition 2.0 and IEC 61215: Crystalline Silicon Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval–UV Preconditioning, Third Edition.[8]

7.5.1.1 *Lamp Type*—UVA-340 lamps as defined in Table 1.

7.5.1.2 *Test Temperature*—Control the chamber temperature such that the specimen temperature is 60°C (with allowable operational fluctuations of ±5°C) by means of correlation to an uninsulated black panel temperature or other method agreed upon by contractual parties.

7.5.1.3 When required by the specific module qualification standard, attach a resistive load to the module such that at STC the module will operate close to its maximum power point.

7.5.1.4 Mount the specimens in the test plane such that they are normal to the UV irradiance beam. In practical terms this means specimens will be parallel to the fluorescent UV lamps and at the same distance in which irradiance measurements are taken.

7.5.1.5 Operate the apparatus until the total radiant dosage is 15 kWh/m^2 in the wavelength range from 280 to 400 nm. When using UVA-340 lamps, the dosage at wavelengths between 280 and 320 nm will meet the requirement that is 3 to 10 % of the total. See Appendix X2 for specific test settings for certain test apparatus.

7.5.2 *Method B*—This method conforms to the requirements of IEC 61215: Design Qualification for Crystalline Silicon PV Modules—UV Preconditioning Under Open Circuit Conditions, Second Edition.

7.5.2.1 *Lamp Type*—For this method, consecutive exposures with UVA-340 lamps as defined in Table 1 and UVB-313 lamps as defined in Table 2 meet the requirement without excessive exposure to UV radiation in part of the spectrum.

7.5.2.2 *Test Temperature*—Control the chamber temperature such that the specimen temperature is 60°C (with allowable operational fluctuation of ±5°C) by means of an uninsulated black panel or other method agreed upon by contractual parties.

7.5.2.3 Modules shall be exposed under open-circuit conditions unless mutually agreed by contractual parties.

7.5.2.4 Mount the specimens in the test plane such that they are normal to the UV radiation beam. In practical terms this means specimens will be parallel to the fluorescent UV lamps and at the same distance in which irradiance measurements are taken.

7.5.2.5 Operate the apparatus until the total UV dosage is 15 kWh/m^2 in the wavelength range from 280 to 385 nm. In the wavelength range between 280 and 320 nm, the energy dosage must be a minimum of 5 kWh/m^2. When using lamp types described in this standard, the operator may choose to complete separate UVA-340 and UVB-313 exposures to avoid excessive UVB irradiation. See Appendix X2 for specific test settings for certain test apparatus.

7.5.3 *Method C*—UV test for photovoltaic modules (IEC 61345).

7.5.3.1 *Lamp Type*—For this method, consecutive exposures to UVA-340-lamps as defined in Table 1 and UVB-313 lamps as defined in Table 2 are required to meet the requirement without excessive exposure to UV irradiation in part of the spectrum.

7.5.3.2 *Test Temperature*—Control the chamber temperature such that the specimen temperature is 60°C (with allowable chamber operational fluctuation of ±5°C) by means of an uninsulated black panel or other method agreed upon by contractual parties.

7.5.3.3 Modules may be exposed under open-circuit conditions or after attaching a resistive load to the module such that at STC the module will operate close to its maximum power point. The test report must specify which condition is used.

7.5.3.4 Mount the specimens in the test plane such that they are normal to the UV irradiance beam. In practical terms this means specimens will be parallel to the fluorescent UV lamps and at the same distance in which irradiance measurements are taken.

7.5.3.5 Operate the apparatus until the total UV dosage is a minimum of 15 kWh/m^2 in the wavelength range from 280 to 400 nm. In the wavelength range between 280 and 320 nm, the energy dosage must be a minimum of 7.5 kWh/m^2. When using lamp types described in this standard, the operator may choose to complete separate UVA-340 and UVB-313 exposures to avoid excessive UVB irradiation. See Appendix X2 for specific test settings for certain test apparatus.

7.5.3.6 At the end of the initial exposure, reorient the module(s) so that the back side is facing the lamps and expose for an additional 10 % of the time of the initial exposure under the same conditions.

7.5.4 *Other Cycles*—Varying test conditions by altering the irradiance, temperature is allowed as agreed upon by contractual parties.

8. Precision and Bias

8.1 *Precision*—The repeatability and reproducibility of results obtained in exposures conducted in accordance with this practice will vary with the materials being tested, the material property being measured, and the specific test conditions and cycles that are used. It is essential to determine reproducibility of the exposure/property measurement process when using the results from exposures conducted in accordance with this practice in product specifications.

8.2 *Bias*—Bias cannot be determined because no acceptable standard weathering reference materials are available.

9. Report

9.1 Report the following information:

[8] The third edition of IEC 61215 will supersede the second edition of both 61215 and 61646 upon publication.

9.1.1 Type and model of exposure device or a technical description of the device if not a commercially available apparatus.

9.1.2 Type and age of fluorescent UV lamps used at the start of the exposure, and whether any lamps were changed during the period of exposure.

9.1.3 If using an irradiance controlled apparatus, record the irradiance set point in W/m^2 at the control wavelength(s). If converting a narrow band irradiance to a value over a spectral range, record the conversion factor used and the source of the factor.

9.1.4 If using an apparatus without irradiance control, record the irradiance measured at the specimen plane at regular intervals and whenever lamps are changed or rotated.

9.1.5 Elapsed exposure time.

9.1.6 Results of property tests as required by the relevant qualification or other standard.

10. Keywords

10.1 degradation; fluorescent UV; photovoltaic; ultraviolet; UV conditioning; weathering

ANNEX

(Mandatory Information)

A1. CALCULATING ULTRAVIOLET RADIANT DOSAGE USING CONVERSION FACTORS FOR NARROW BAND MEASUREMENTS

A1.1 Purpose—In order to comply with the energy dosage requirements of the UV conditioning tests contained within the PV qualification standards, it is necessary to measure the irradiance within prescribed wavelength bands. It may be cost prohibitive for many laboratories to purchase and maintain the necessary equipment to conduct direct irradiance measurement in these bands. An indirect measurement method exists that may be used when using UVA-313 and UVB-340 lamp types. This method is valid in cases where lamps experience insignificant spectral shift as a result of aging.[9]

A1.2 Procedure Overview—Some Fluorescent UV lamp apparatus measure and control the irradiance at a single wavelength using a narrow band UV sensor. UVA-340 lamps are measured and controlled at 340 nm, while UVB-313 lamps are measured and controlled at 310 nm. By measuring the spectral power distribution of the lamp[10], a conversion factor can be calculated such that multiplying it by the narrow band irradiance provides the broad band irradiance over any desired wavelength band. Once the broad band irradiance is known, it can be divided into the prescribed energy dosage to determine the exposure duration.

A1.2.1 This method can be used even if the apparatus does not have controlled irradiance. Use of a narrow band radiometer calibrated according to Test Method G130 for use with specific fluorescent UV lamp types is the key element of this approach.

A1.3 Procedure:

A1.3.1 Measure the spectral power distribution of the fluorescent UV lamp in W/(m^2·nm) from 250 to 400 nm in increments of 1 nm.

A1.3.2 Calculate a conversion factor from the narrow band irradiance to a broad band irradiance using the following formula:

$$k_{A\rightarrow B} = \sum_{\lambda i = A}^{\lambda i = b} E_{\lambda i} \div E_{Nb} \quad \text{(A1.1)}$$

where:

E = irradiance at wavelength λ_I
A = lower limit of wavelength bandpass
B = upper limit of wavelength bandpass
λ_I = wavelength at which irradiance was measured
$k_{A\rightarrow B}$ = multiplier to convert narrow band irradiance to broad band irradiance between wavelengths A and B
E_{Nb} = narrow band irradiance measured by fluorescent UV lamp apparatus that has been calibrated according to Test Method G130.

A1.3.3 *Calculating Exposure Duration*—Exposure duration is calculated by dividing the prescribed dosage by the product of the narrow band to broad band multiplier and the narrow band irradiance.[11] This is described by the following equation:

$$t = \frac{D_{A\rightarrow B}}{E_{Nb\times k_{A\rightarrow B}}} \quad \text{(A1.2)}$$

$D_{A\rightarrow B}$ = radiant dosage of wavelength band between wavelengths A and B

[9] Determining long term spectral stability is a requirement of lamp suppliers.

[10] Spectral power distributions may be obtained by lamp manufacturers.

[11] To calculate the radiant dosage, first multiply the narrow band irradiance by the appropriate conversion factor in Table X1.1, then mulitply by time in hours. Example: The narrow band irradiance of an exposure using UVA-340 lamps is 0.89 W/(m^2·nm). The radiant dosage from 321 to 400 nm for a 168 h exposure is calculated as follows: 0.89 W/(m^2·nm) × 50.2 × 168 h = 7506 Wh/m^2.

APPENDIXES

(Nonmandatory Information)

X1. CONVERSION FACTORS FOR CALCULATING UVA AND UVB BROAD BAND IRRADIANCE FROM NARROW BAND IRRADIANCE MEASUREMENTS ON COMMON UVA-340 AND UVB-313 FLUORESCENT UV LAMPS

X1.1 Although a variety of fluorescent UV lamps may be used in this practice, the lamps shown in this section are representative of two common types used in UV fluorescent weathering test methods.

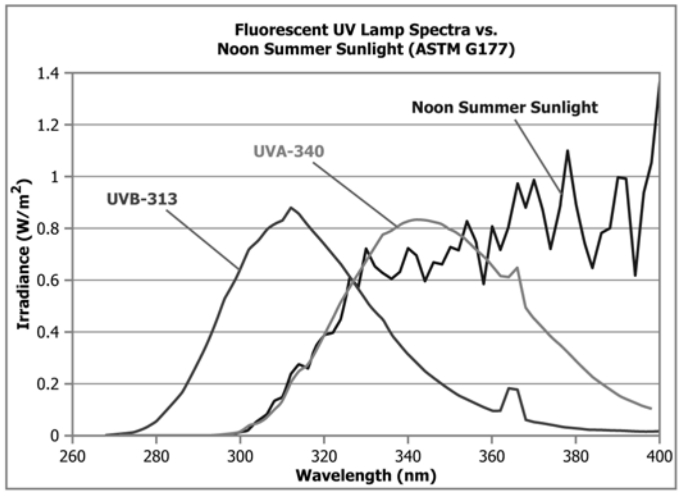

FIG. X1.1 Spectra of Common Fluorescent Ultraviolet Lamps Versus Noon Summer Sunlight (G177)

TABLE X1.1 Multipliers to Convert Single Wavelength Irradiance Measurements into Broad Band Measurements

NOTE 1—These are unitless values. These values may not be valid for all commercially available lamps. Check with the lamp manufacturer.

Wavelength in Range	UVA-340 (340 nm)	UVB-313 (310 nm)
280 – 400 nm	54.5	46.3
280 – 320 nm	4.3	27.2
321 – 400 nm	50.2	19.2
280 – 385 nm	52.0	46.0

X2. EXAMPLE TEST CONDITIONS FOR MEETING IEC QUALIFICATION TEST REQUIREMENTS FOR UV PRE-CONDITIONING OF PHOTOVOLTAIC MODULES

X2.1 Method A: Design Qualification for Thin Film PV Modules—UV Preconditioning Under Resistive Load (IEC 61646, First Edition) and Design Qualification for Crystalline Silicon PV Modules—UV Preconditioning Under Open Circuit Conditions (IEC 61215, Third Edition)

X2.1.1 *CYCLE A1:*

X2.1.1.1 Continuous UV with UVA-340 lamps, irradiance 1.15 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C.
Duration: 240 h.

X2.1.2 *CYCLE A2:*

TABLE X2.1 Summary of Example Exposures to Meet IEC Requirements

Cycle	Lamp Type	Irradiance (W/(m^2 · nm)	Duration (hours)	UV Dosage Achieved (kWh/m^2)
Method A: IEC 61215 Ed 3 IEC 61646 Ed 1				
A1	UVA-340	1.15 @ 340 nm	240	280-400 nm: 15.1 280-320 nm: 1.2
A2	UVA-340	1.50 @ 340 nm	184	280-400 nm: 15.1 280-320 nm: 1.2
A3	UVA-340	0.68 @340 nm	405	280-400 nm: 15.1 280-320 nm: 1.2
Method B: IEC 61215 Ed 2				
B1	UVA-340	0.87 @ 340 nm	168	280-385 nm: 7.6 280-320 nm: 0.6
	UVB-313	0/96 @ 310 nm	168	280-385 nm: 7.4 280-320 nm: 4.4
		Totals:	336	280-385 nm: 15.0 280-320 nm: 5.0
B2	UVA-340	0.89 @ 340 nm	165	280-385 nm: 7.6 280-320 nm: 0.6
	UVB-313	0.71 @ 310 nm	230	280-385 nm: 7.5 280-320 nm: 4.4
		Totals:	395	280-385 nm: 15.1 280-320 nm: 5.1
B3	UVA-340	1.55 @ 340 nm	94	280-385 nm: 7.6 280-320 nm: 0.6
	UVB-313	1.23 @ 310 nm	132	280-385 nm: 7.5 280-320 nm: 4.4
		Totals:		280-385 nm: 15.1 280-320 nm: 5.1
Method C: IEC 61345 Ed 1				
C1 – Front Side	UVA-340	0.86 @ 340 nm	240	280-320 nm: 0.9 320-400 nm: 10.4
	UVB-313	1.02 @ 310 nm	240	280-320 nm: 6.6 320-400 nm: 4.7
		Totals:	480	280-320 nm: 7.5 320-400 nm: 15.2
C1 – Back Side	UVA-340	0.86 @ 340 nm	24	280-320 nm: 0.09 320-400 nm: 1.04
	UVB-313	1.02 @ 310 nm	24	280-320 nm: 0.66 320-400 nm: 0.47
		Totals:	48	280-320 nm: 0.75 320-400 nm: 1.51
C2 – Front Side	UVA-340	1.55 @ 340 nm	135	280-320 nm: 0.9 320-400 nm: 10.5
	UVB-313	1.23 @ 310 nm	200	280-320 nm: 6.7 320-400 nm: 4.7
		Totals:	335	280-320 nm: 7.6 320-400 nm: 15.2
C2 – Back Side	UVA-340	1.55 @ 340 nm	13.5	280-320 nm: 0.09 320-400 nm: 1.05
	UVA-313	1.23 @ 310 nm	20	280-320 nm: 0.67 320-400 nm: 0.47
		Totals:	33.5	280-320 nm: 0.76 320-400 nm: 1.52

X2.1.2.1 Continuous UV with UVA-340 lamps, irradiance 1.50 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 184 h.

X2.1.3 *CYCLE A3:*

X2.1.3.1 Continuous UV with UVA-340 lamps, irradiance 0.68 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 405 h.

X2.2 Method B: Design Qualification for Crystalline Silicon PV Modules—UV Preconditioning Under Open Circuit Conditions (IEC 61215, Second Edition)

X2.2.1 *CYCLE B1:*

X2.2.1.1 *Step 1:* Continuous UV with UVA-340 lamps, irradiance 0.87 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 168 h.

X2.2.1.2 *Step 2:* Continuous UV with UVB-313 lamps, irradiance 0.96 W/(m^2·nm) at 310 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 168 h.

X2.2.2 *CYCLE B2:*

X2.2.2.1 *Step 1:* Continuous UV with UVA-340 lamps, irradiance 0.89 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 165 h.

X2.2.2.2 *Step 2:* Continuous UV with UVA-313 lamps, irradiance 0.71 W/(m^2·nm) at 310 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 230 h.

X2.2.3 *CYCLE B3:*

X2.2.3.1 *Step 1:* Continuous UV with UVA-340 lamps, irradiance 1.55 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 94 h.

X2.2.3.2 *Step 2:* Continuous UV with UVA-313 lamps, irradiance 1.23 W/(m^2·nm) at 310 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 132 h.

X2.3 Method C: UV Test for Photovoltaic Modules—(IEC 61345, First Edition)

X2.3.1 *CYCLE C1:*

X2.3.1.1 *Step 1:* Continuous UV with UVA-340 lamps, irradiance 0.86 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 240 h.

X2.3.1.2 *Step 2:* Continuous UV with UVB-313 lamps, irradiance 1.02 W/(m^2·nm) at 310 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 240 h.

X2.3.1.3 *Step 3 (back side of module facing lamps): Step 1:* Continuous UV with UVA-340 lamps, irradiance 0.86 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 24 h.

X2.3.1.4 *Step 4 (back side of module facing lamps):* Continuous UV with UVB-313 lamps, irradiance 1.02 W/(m^2·nm) at 310 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 24 h.

X2.3.2 *CYCLE C2:*

X2.3.2.1 *Step 1:* Continuous UV with UVA-340 lamps, irradiance 1.55 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 135 h.

X2.3.2.2 *Step 2:* Continuous UV with UVB-313 lamps, irradiance 1.23 W/(m^2·nm) at 310 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 200 h.

X2.3.2.3 *Step 3 (back side of module facing lamps):* Continuous UV with UVA-340 lamps, irradiance 1.55 W/(m^2·nm) at 340 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 13.5 h.

X2.3.2.4 *Step 4 (back side of module facing lamps):* Continuous UV with UVB-313 lamps, irradiance 1.23 W/(m^2·nm) at 310 nm, uninsulated black panel temperature controlled at 60°C with allowable operational fluctuation of ±5°C
Duration: 20 h.