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14. ABSTRACT
This document describes procedures for conducting environmental and performance tests for fixed photovoltaic systems used in fixed and dismounted operations. These tests involve characterizing performance under various solar incidence conditions as well as under unique environmental abuse conditions.

15. SUBJECT TERMS
Renewable power systems, power quality, photovoltaic, solar simulator, irradiance, PV, IV curve

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 09-2-291 23 January 2020
DTIC AD No.

ENVIRONMENTAL AND PERFORMANCE TESTING OF PHOTOVOLTAIC SYSTEMS

Approved for public release; distribution unlimited.

1. SCOPE.

1.1 Overview.

a. This test series is for solar panels whose output is electrical energy, and applies to rigid, semi-rigid, and flexible types. A representative random sampling should be made. Solar panels/modules are to be subjected to electrical characterization, physical inspection, and testing assessing durability, environmental exposure, and safety. An overall sequence of test events outlined in this Test Operations Procedure (TOP) is shown in Figure 1.

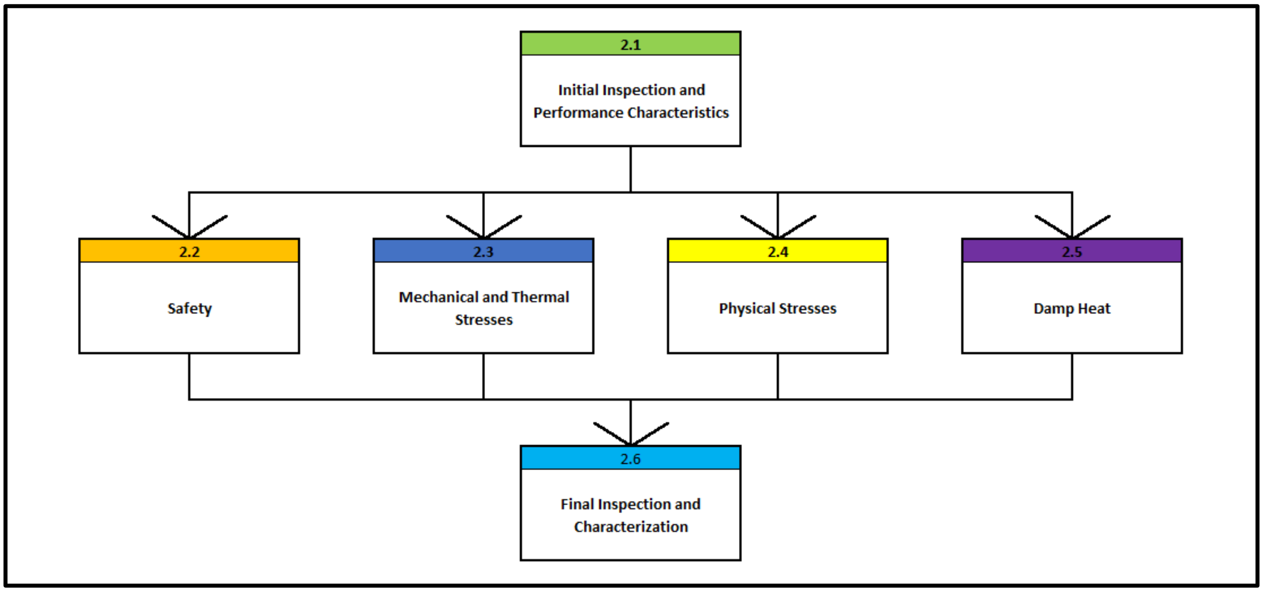


Figure 1. Test flow overview.

b. The overall Safety; Mechanical and Thermal Stresses; Physical Stresses (to the module packaging when deployed); and Damp Heat test flows shown in Figure 1 have been broken down into individual subtests with the specific test methods of each outlined in Section 2 of this TOP. The sequence of the individual subtests has been structured to minimize the overall test duration and optimize the assessment of each test module.

1.2 Sequence of Tests.

The test sequence is outlined in Figures 2 through 7. The individual block numbering on each figure is associated with the corresponding subtest paragraph numbers in Section 2 of this TOP.

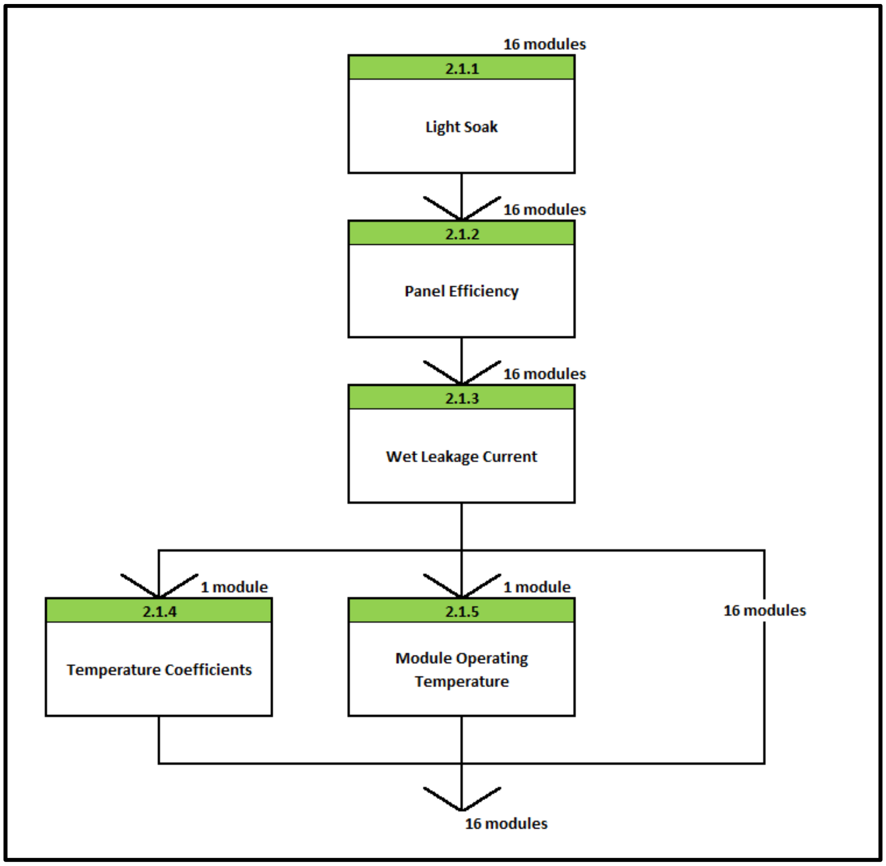


Figure 2. Test sequence number 2.1: Initial Inspection and Performance Characterization.

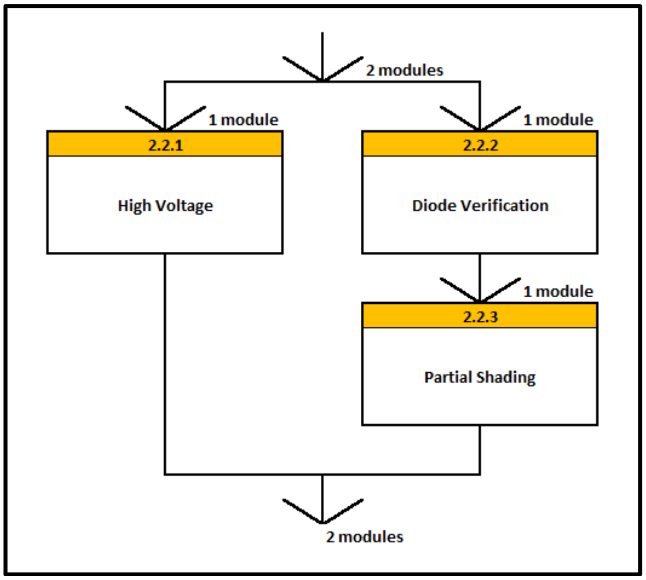


Figure 3. Test sequence number 2.2: Safety.

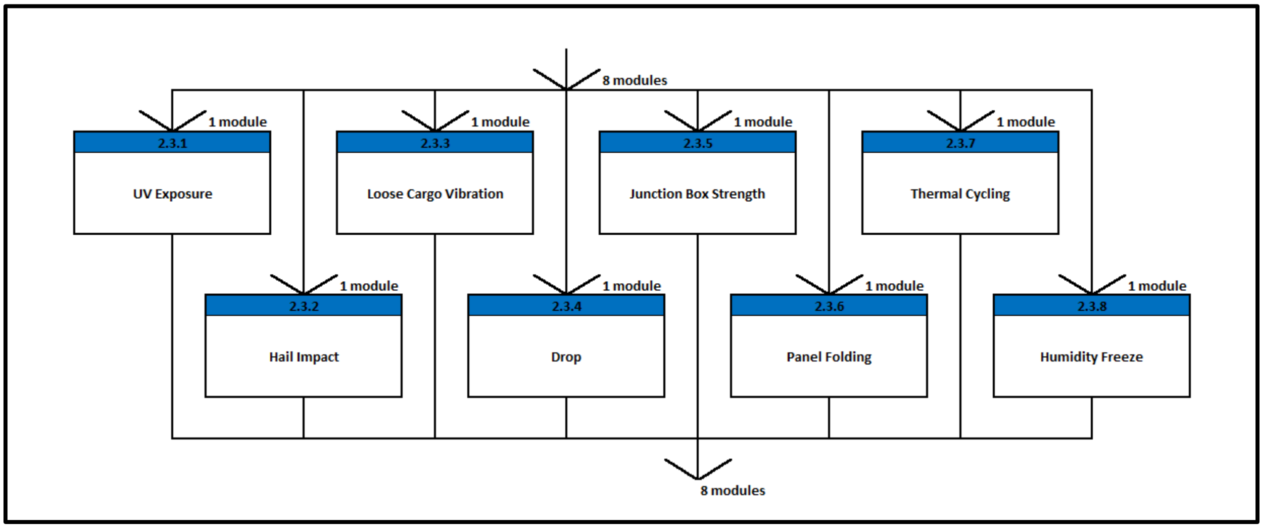


Figure 4. Test sequence number 2.3: Mechanical and Thermal Stresses.

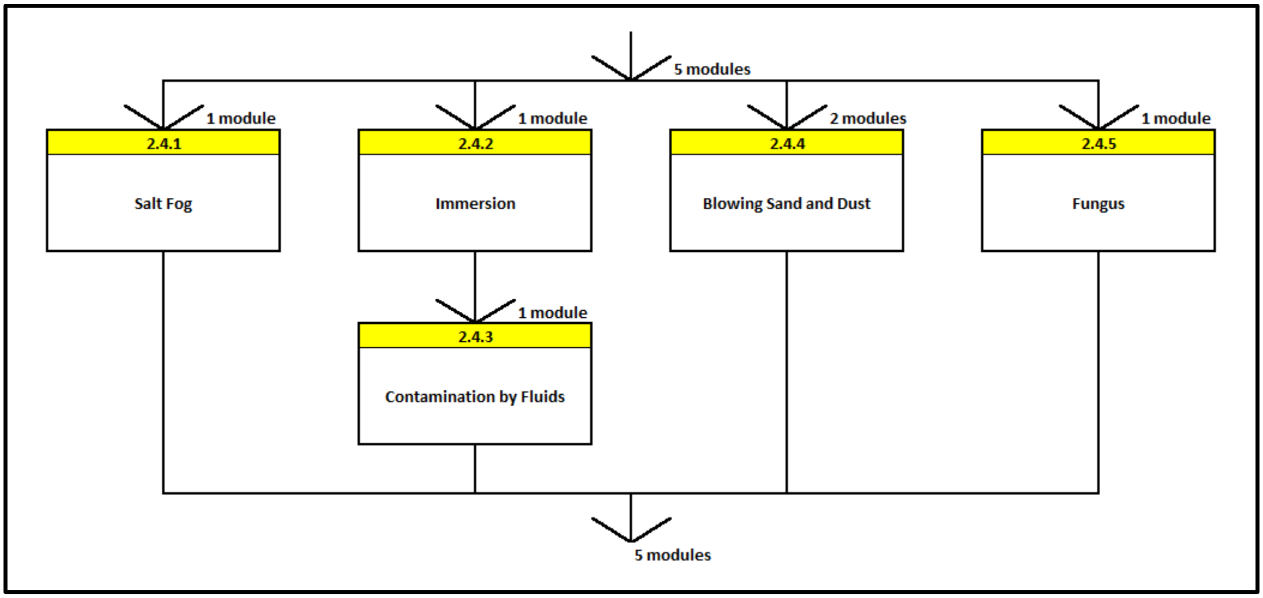


Figure 5. Test sequence number 2.4: Physical Stresses (to the module packaging when deployed).

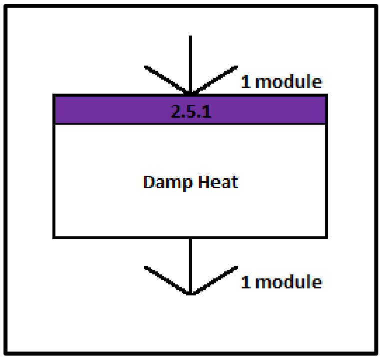


Figure 6. Test sequence number 2.5: Damp Heat.

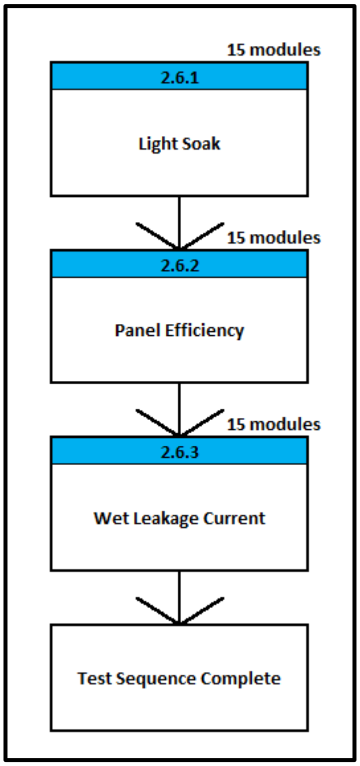


Figure 7. Test sequence number 2.6: Final Inspection and Performance Characterization.

2. TEST METHODS.

2.1 Initial Inspection and Performance Characterization.

2.1.1 Light Soak.

This test is organized into two parts. Method 1: "Light Soaking" describes how to stabilize a module via light soaking and how the test levels differ for different cell technologies. Method 2:

"Light Soaking Check" describes how to check the performance of a single module before and after light soaking, to see whether or not all products in that group need to be stabilized.

2.1.1.1 Light Soak - Instrumentation.

Both light soaking and the light soaking check require the following instrumentation:

a. A continuous light source for light soaking that operates within the intensity range of 200 to 1,200 watts per meter squared (W/m^2). Outdoor illumination (natural sunlight) may be utilized. The light source must not exhibit non-uniformity larger than ±10 percent over the test module area.

b. A sensor to monitor the irradiance of the continuous light source. The sensor must be mounted in the plane of the test module.

c. Electronics to log the sensor output.

d. If performing a light soaking check, instrumentation for performing a current-voltage (IV) measurement, as described in paragraph 2.1.2, is also required. The current-voltage measurement system may utilize a different light source than that required for light soaking in paragraph 2.1.1.1.a of this list.

2.1.1.2 Light Soak - Required Test Conditions.

a. Light soaking is performed:

(1) With continuous illumination, either outdoors or utilizing a continuous simulator.

(2) To an insolation level determined by the cell technology used in the test module, as specified in Table 1.

TABLE 1. LIGHT SOAKING REQUIREMENTS FOR COMMERCIAL PRODUCTS BASED ON VARIOUS CELL TECHNOLOGIES

Cell Technology	Minimum Initial Exposure ($kW\text{-}hr/m^2$)	Continuous Exposure at $\geq$200W/m^2 Just Before Measurement ($kW\text{-}hr/m^2$)	Longest Time Between Light Soaking and Current-Voltage (minutes)	Minimum Exposure After Stress Tests ($kW\text{-}hr/m^2$)
x-Si	10	No requirement	No requirement	Not required
CIGS	20	1	60	20
CdTe	40	1	60	40
a-Si	86	1	30	86
GaAs	Not required	No requirement	No requirement	Not required

NOTE: $kW\text{-}hr/m^2$ = kilowatt - hour per meter squared

b. The light soaking check adds a current-voltage measurement to the test procedure. Test conditions for the current-voltage procedure are found in paragraph 2.1.2.

2.1.1.3 Light Soak - Test Procedure.

a. Method 1: Light Soaking.

(1) Check the exposure requirements using Table 1. Requirements differ depending on the cell technology used in the test module, and whether the light soaking is being utilized as part of an initial stabilization (i.e., first measurement of the product, before stress is applied) or a final stabilization (i.e., after stress has been applied).

(2) If Table 1 indicates that stabilization is not required, record “not required” in the appropriate fields of the test report, and do not perform any of the remaining steps.

(3) Mount the test module in front of the continuous light source, with the output open-circuited. If the module is exposed to humidity, cover the connectors so that they do not corrode due to the light soak. Such corrosion could lead to increased resistance and an incorrect subsequent power measurement.

(4) Log the irradiance (kW/m^2) normal to the module surface, tracking the insolation ($kW\text{-}hr/m^2$) in real time.

(5) Continue this procedure until the exposure equals or exceeds the amount listed in column “Minimum Initial Exposure” of Table 1. The requirements differ based on the cell technology utilized in the test module.

(6) For cell types that are prone to metastability (i.e., reversible changes with light soaking), the conditions just prior to measurement are important. These cell types show a requirement in columns “Continuous Exposure at $\geq 200W/m^2$ Just Before Measurement” and “Longest Time Between Light Soaking and Current-Voltage” of Table 1. For cell types showing a requirement in column “Continuous Exposure at $\geq 200W/m^2$ Just Before Measurement”, there must be some continuous illumination at irradiance $>200W/m^2$ just before current-voltage measurement. In other words, one cannot light soak the module; let it sit overnight in the dark, then measure it first thing in the morning. Before moving the test module to current-voltage measurement, the irradiance on the module must be continuously higher than $200W/m^2$ for the exposure specified in column “Continuous Exposure at $\geq 200W/m^2$ Just Before Measurement”.

(7) Once the module is removed from the light soak, the current-voltage curve must be measured within the time period specified in column “Longest Time Between Light Soaking and Current-Voltage” of Table 1.

b. Method 2: Light Soaking Check.

(1) Perform a current-voltage measurement according to paragraph 2.1.2, with no light soaking of the test module.

(2) Record the power output as $P_{initial}$.

(3) Perform light soaking as specified in paragraphs 2.1.1.3.a(1) through 2.1.1.3.a(7).

(4) Perform a current-voltage measurement according to paragraph 2.1.2, adhering to any timing requirements in Method 1 for limiting time between light soaking and IV curve measurement.

(5) Record the power output as P_{final}.

(6) Calculate the percent change in power using Equation 1.

$$\Delta P = 100\ x\ \frac{(P_{final} - P_{initial})}{P_{initial}} \qquad (Equation\ 1)$$

(7) If $|\Delta P| = >5$, then all modules of this product type that are being tested as a part of this TOP must undergo light soaking (per Method 1) before any IV measurement.

2.1.1.4 Light Soak - Procurement Document Requirements.

This test does not depend on specifications from the procurement document. Light soaking is performed according to the requirements associated with the cell technology utilized in the test module.

2.1.1.5 Light Soak - Data Required and/or Sample Data.

The following items shall be recorded in the test report each time this procedure is performed:

a. Type of light soaking (“initial stabilization”, “final stabilization”, or “light soaking check”).

b. Cell technology, as in Table 1, column “Cell Technology”.

c. Total exposure (kW-hr/m^2, or “not required”).

d. If performing a light soaking check, also record the following:

(1) $P_{initial}$.

(2) P_{final}.

(3) ΔP in percent.

2.1.2 Panel Efficiency.

a. This section describes IV measurement of test articles. Current voltage measurements are very important as they determine the power output of the module. The change in power output from before to after stress is used in many cases to determine whether the test article meets requirements. Current voltage measurements are also used to compare the actual power out of the module to that claimed on the label, and to determine open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), voltage at maximum power (V_{mp}), current at maximum power (I_{mp}), and fill factor (ff). The IV measurements described in this section are measured at standard test conditions (STC), i.e., 25 °Celsius (°C) (77 °Fahrenheit (°F))and 1000 W/m^2 irradiance.

b. Standard procedures exist for measuring IV curves of photovoltaic (PV) modules with very high accuracy (±1%), as in International Electrotechnical Commission (IEC) 61215-2[1]** and related documents. However, the IEC procedures may require expensive equipment (e.g., a flash simulator producing uniform irradiance or an extensive set of calibrated reference modules). This test procedure is aimed at determining whether a test article undergoes ~20% change in performance after stress. Thus, a total uncertainty of approximately ±5% is acceptable for these power output determinations, and requirements are modified accordingly to make this test accessible to a number of laboratories. Any laboratory performing this test must have completed the “Test Lab Self-Documentation for Current-Voltage Measurement,” which is a required component of the reporting for this test.

2.1.2.1 Panel Efficiency - Instrumentation.

a. Light source with the characteristics specified in the Test Lab Self-Documentation for Current-Voltage Measurement (Appendix A), (hereafter referred to as “Self-Documentation Procedure” or “SDP”).

b. Means for determining module temperature meeting requirements described in the SDP.

c. Reference module meeting the requirements described in the SDP.

d. Electronics for performing a current-voltage sweep, meeting the requirements described in the SDP.

e. Means for light soaking (paragraph 2.1.1.3), if the light soaking check has indicated that all modules of this product type need stabilization.

2.1.2.2 Panel Efficiency - Required Test Conditions.

a. Test conditions are:

(1) Temperature of 25 °C (77 °F).

** Superscript numbers correspond to Appendix C, References.

(2) Irradiance of 1000 W/m^2.

(3) Air Mass (AM) 1.5 spectrum.

(4) Voltages applied from 0 to V_{oc} (open circuit).

b. Small deviations in temperature, irradiance, and spectrum may be addressed by calculated corrections, if these corrections are performed in accordance with Appendix A, Test Lab Self-Documentation for Current-Voltage Measurement.

2.1.2.3 Panel Efficiency - Test Procedures.

a. If the light soaking check (paragraph 2.1.1.3.b) on one module of this product type has indicated that stabilization is needed, perform light soaking (paragraph 2.1.1.3.a). All steps below are to be performed only according to the methods that were used to achieve acceptable uncertainty, as detailed in the laboratory's self-documentation. Any modifications to the test laboratory's procedures (e.g., new light source) requires a new self-documentation.

b. Prepare the light source. This preparation may include warming up the simulator, setting simulator irradiance using a reference module, selecting times of suitable weather for outdoor measurement, and measuring the irradiance for systems where it is not set to 1000 W/m^2.

c. Position the module for exposure to irradiance from the light source.

d. Sweep voltage between 0 and open circuit.

e. Make any post-measurement corrections for temperature or irradiance.

f. Record a graph of current versus voltage, and the parameters maximum power (P_{mp}), V_{oc}, I_{sc}, I_{mp}, V_{mp}, and ff.

2.1.2.4 Panel Efficiency - Procurement Document Requirements.

Current-voltage measurements are to be performed at standard test conditions, and do not require further specifications from the procurement document.

2.1.2.5 Panel Efficiency - Data Required and Sample Data.

The test report shall include a graph of current vs. voltage, as well as the values of P_{mp}, V_{oc}, I_{sc}, I_{mp}, V_{mp}, and ff.

2.1.3 Wet Leakage Current.

The Wet Leakage Current test is designed to determine whether the module can withstand wet environments without any degradation of the module insulation and to ensure the moisture does not penetrate the module electrical components, resulting in module failure. Testing shall be conducted in accordance with IEC 61215-2, Module Quality Test (MQT)-15 unless otherwise described within this section.

2.1.3.1 Wet Leakage Current - Instrumentation.

The instrumentation and apparatus outlined in IEC 61215-2, MQT-15 are sufficient for this test. No modifications or adaptations to the instrumentation/apparatus stated in IEC 61215-2, MQT 15 are required.

2.1.3.2 Wet Leakage Current - Required Test Conditions.

Prior to the start of the Wet Leakage Current test, the module surface temperature shall be stabilized at standard ambient test conditions as described in Military Standard (MIL-STD)-810H[2] and provided below:

a. Temperature: 25°C ± 10 °C (77 °F ± 18 °F).

b. Relative humidity: 20 to 80 percent.

c. Atmospheric pressure: site pressure.

2.1.3.3 Wet Leakage Current - Test Procedures.

Testing shall be conducted in accordance with IEC 61215-2, MQT-15. No modifications to the test procedures outlined in IEC 61215-2, MQT-15 are required as part of this TOP.

2.1.3.4 Wet Leakage Current - Procurement Document Requirements.

The following items must be specified in the individual procurement document:

a. Minimum allowable insulation resistance.

b. If no minimum allowable insulation resistance is provided by the procurement agency, the limits outlined in IEC 61215-2, MQT-15, shall be used.

2.1.3.5 Wet Leakage Current - Data Required and Sample Data.

The test report shall contain a comparison to the collected insulation resistance with respect to module size in regard to the minimum allowable insulation resistance (either provided by the procurement agency or that outlined in IEC 61215-2, MQT-15) and a comparison to all other wet-leakage current tests conducted on the same module throughout the test sequence.

2.1.4 Temperature Coefficients.

a. Temperature coefficients describe how short-circuit current, open-circuit voltage, and peak power vary with module temperature. Thus, they are key to energy generation prediction during outdoor operation.

b. This test uses the method of IEC 60891:2009[3] clause 4, either indoors (clause 44) or outdoors (clause 43). The module may be assumed to be linear (as defined in IEC 60904-10[4]), and thus the test method applicable, for irradiances greater than 500 W/m^2.

2.1.4.1 Temperature Coefficients - Instrumentation.

The instrumentation and apparatus outlined in IEC 60891:2009, clause 4.2, are sufficient for this test.

2.1.4.2 Temperature Coefficients - Required Test Conditions.

For either the indoor or outdoor test method, irradiance shall be greater than 500 W/m^2, and temperature over the module under test shall vary by at least 30 °C (54 °F).

2.1.4.3 Temperature Coefficients - Test Procedures.

Testing will be performed in accordance with IEC 60891:2009, clause 4.4 (indoor test method), or clause 4.3 (outdoor test method).

2.1.4.4 Temperature Coefficients - Procurement Document Requirements.

Temperature coefficients are measured for energy generation predictions. Procurement agencies may desire to specify maximum values for temperature coefficients (i.e., maximum decrease in output with increasing temperature), but such specifications are not required.

2.1.4.5 Temperature Coefficients - Data Required and Sample Data.

Graphs of P_{mp} vs. T, I_{sc} vs. T, and V_{oc} vs. T shall be included in the test report. The linear fit used to extract temperature coefficient from these plots shall also be included in the graph. The extracted values for temperature coefficients of P_{mp}, I_{sc}, and V_{oc} shall be reported. Example data are shown in Figures 8 and 9. The data in Figures 8 and 9 were taken from T. J. Silverman, M. G. Deceglie, B. Marion, S. Cowley, B. Kayes, and S. Kurtz, “Outdoor performance of a thin-film gallium-arsenide photovoltaic module,” in 2013 Institute of Electrical and Electronics Engineers (IEEE) 39th Photovoltaic Specialists Conference (PVSC), June 2013, pp. 0103 - 0108.

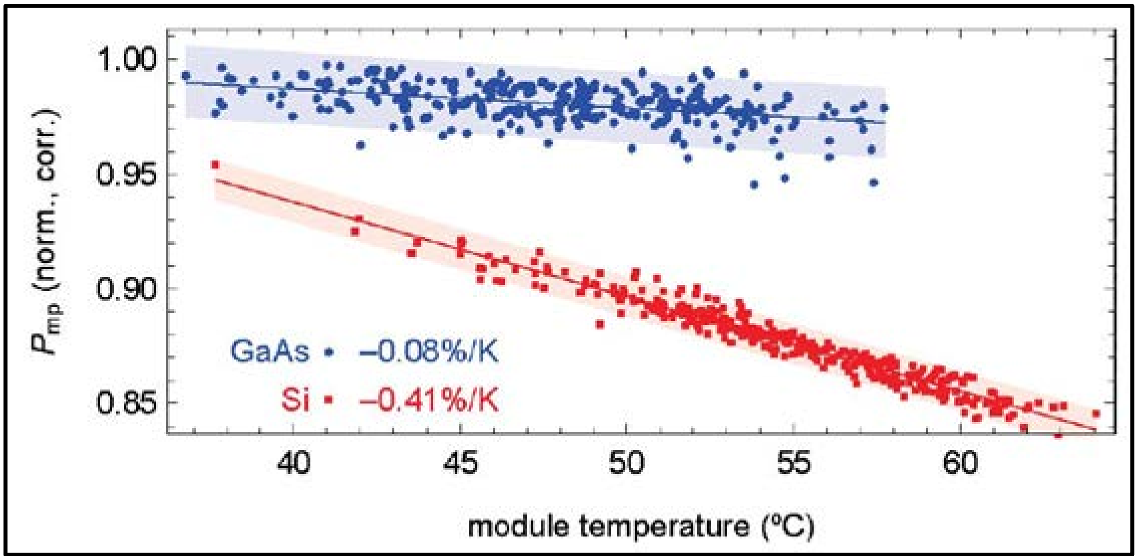


Figure 8. P_{mp} as a function of module temperature measured outdoors for two different modules (red and blue). Linear fits used to extract temperature coefficients of P_{mp} are also shown.

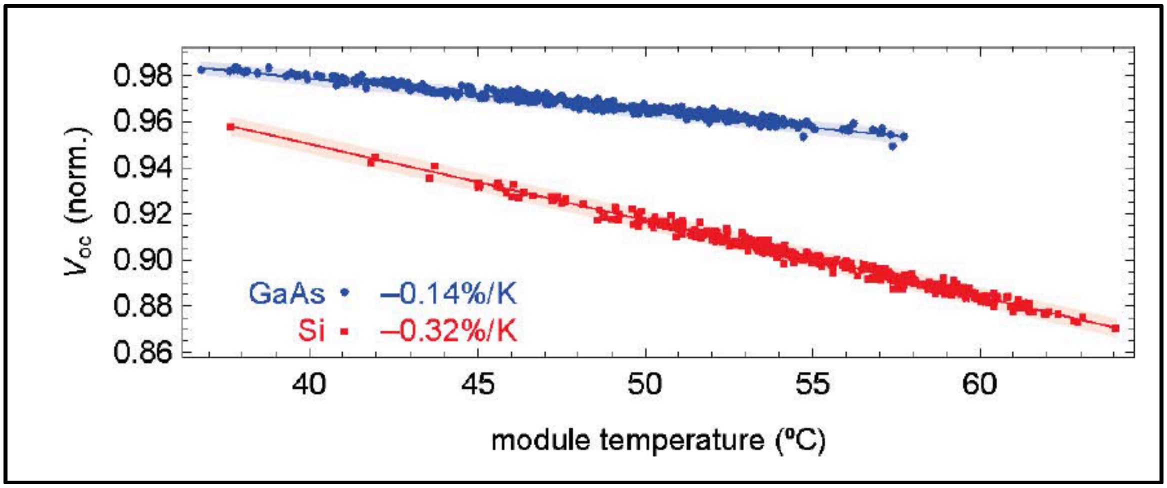


Figure 9. V_{oc} as a function of module temperature measured outdoors for two different modules (red and blue). Linear fits used to extract temperature coefficients of V_{oc} are also shown.

2.1.5 Module Operating Temperature.

a. Module operating temperature is an important factor in predicting energy yield since power decreases as temperature increases. This test measures the module operating condition when the module is mounted as it is intended to be used. The test measures the module operating temperature as a function of irradiance, ambient temperature, and wind speed so that these data for specific locations can be used for accurate energy yield prediction. The method is based on the model in Equation 2:

$$T_{module} = T_{ambient} + \frac{G}{(U_0 + U_{1v})} \qquad \textit{(Equation 2)}$$

where:

T_{module}= the module temperature in °C.
$T_{ambient}$ = the ambient air temperature in °C.
G = global irradiance in the module plane of incidence (W/m^2).
U_0 = coefficient relating irradiance and module temperature (W/ °C-m^2).
U_{1v} = coefficient relating wind speed and module temperature (W/ °C-m^2).

b. This model was developed by Faiman[5] and has been the subject of several experimental studies[6,7]. It differs from the IEC “normal module operating temperature (NMOT)” procedure in that different mounting configurations can be applied, less data filtering are utilized, and the test period is fixed and of relatively short duration. Also, two mounting configurations are considered - mounted as the product is designed, and a mounting representing worst-case misuse.

2.1.5.1 Module Operating Temperature - Instrumentation.

2.1.5.1.1 Worst-Case Mounting Instructions.

Worst-case mounting is used to examine potential damage to the product if it is used in a manner for which it is not designed, such as being draped over a vehicle. The worst-case mounting is illustrated in Figure 10. The module is attached to a 3.2 millimeter (mm) (1/8-inch) thick aluminum plate. The front of the aluminum plate is covered with flat black paint. The aluminum plate is sized such that it extends 304.8 ± 25.4 mm (12 ± 1 inch) beyond the edge of the module in all directions. The 304.8 mm (12 inch) are measured perpendicular to the module edges, as shown by the red arrows in Figure 10. The aluminum plate may be one continuous piece, or it may be formed from multiple pieces. If multiple pieces are used, the pieces shall be held via rear brackets with edges flush and in positive pressure with one another, to maximize lateral heat conduction. R30 insulation shall be adhered to the back of the plate. The aluminum plate shall be mounted at 37 ± 5 degrees relative to horizontal.

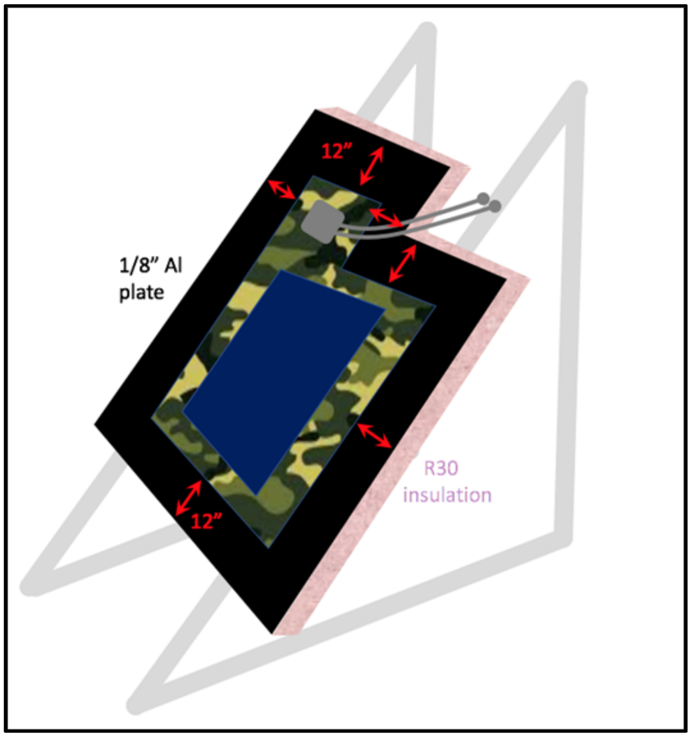


Figure 10. Schematic illustration of test fixture for simulated worst-case mounting.

2.1.5.1.2 Instrumentation Required.

The following instrumentation is required:

a. A means to mount the module in the manner specified by the procurement document.

b. A means to mount the module in the worst-case manner (paragraph 2.1.5.1.1).

c. A resistive load sized such that the modules will operate near their maximum power point at STC, or an electronic Maximum Power Point Tracker (MPPT).

d. A means to measure irradiance (such as a pyranometer or calibrated photovoltaic device) shall be mounted in the plane of the module. It shall be located within 1 meter (m) of the module and shall be accurate to within ±5 percent.

e. An anemometer that functions in the range of at least 0.25 - 10 meters per second (m/s). It shall be installed approximately 1 m above the top of the module and mounted as close to the module as possible without shading the module.

f. An ambient temperature sensor, with a time constant less than 5 minutes, installed in a shaded enclosure with good ventilation near the wind sensor.

g. A thermal imaging device capable of surveying the surface of the module with a numerical readout to qualitatively locate any abnormally hot cells.

h. A thermocouple attached to the back side of each module. The thermocouple shall be placed as close to the module center as possible while being located directly behind a solar cell. The thermocouple shall not be placed directly behind electrically inactive areas, such as the space between solar cells. The thermocouple shall also not be placed behind a hot cell, as described in paragraph 2.1.5.3.

i. A data acquisition system to record irradiance, ambient temperature, module temperatures, and wind speed with an interval of no more than 5 seconds.

2.1.5.2 Module Operating Temperature - Required Test Conditions.

The module shall be exposed to outdoor conditions mounted in the manner specified by the procurement document, with instrumentation described in the previous section, for 28 days.

2.1.5.3 Module Operating Temperature - Test Procedures.

a. Select the thermocouple location on the module via infrared image. Subject the module to illumination of at least 400 W/m^2, either in natural sunlight or a class BBB (or better) steady-state solar simulator. Short-circuit the module by either directly connecting the output wires together or by fabricating a jumper wire to connect the positive and negative terminals. After the module has reached steady-state temperature (less than 2 °C (3.6 °F) change after 10 minutes), use the thermal imager to survey the entire front surface of the module. Using the color scale and the center focus temperature readout, identify and record the location of any cells that are more than 10 °C hotter than other cells on the module.

b. Apply the thermocouple to the back of module. If the cell closest to the module center was *not* identified as a hot cell in the previous step, center the thermocouple behind this cell and attach it to the module. If the cell closest to the module center *is* a hot cell, choose the next closest cell that is not hot, and center the thermocouple behind this next-closest cell.

c. Mount the module in the manner specified by the procurement document and connect the resistive or MPPT load as described in the instrumentation section.

d. Utilizing a second module, repeat the steps in paragraphs 2.1.5.3.a through 2.1.5.3.c, this time utilizing the worst-case mounting configuration described in paragraph 2.1.5.1.1.

e. Activate the data acquisition system described in paragraph 2.1.5.1.2.i.

f. Continue the exposure for a total of 28 days. Clean the modules weekly, during times when irradiance is below 400 W/m^2 (low-irradiance data are not used in the calculation).

g. Filter the data as follows:

(1) Reject all data taken when irradiance was below 400 W/m^2.

(2) Reject all data taken when wind speed was greater than 10 m/s or less than 0.25 m/s.

h. From the remaining data, for each module, create 5-minute running averages for wind speed, module temperature, ambient temperature, and irradiance. The 5-minute running averages must not contain any missing data points. Thus, every rejected data point from step 2.1.5.3.g. creates at least a 5-minute window where there are no running average data points.

i. Use the 5-minute running averages to create an x-y scatter plot for each module where $x = v$ and $y = G/(T_{module}–T_{ambient})$. Variables are defined in Equation 2 (paragraph 2.1.5).

j. For each module, use linear regression analysis to determine the slope (U_{1v}) and intercept (U_0) of the model.

k. These two sets of coefficients are then used for predictions of temperature and the resulting energy yield for the product mounted in this manner in specific locations.

2.1.5.4 Module Operating Temperature - Procurement Document Requirements.

The procurement agency shall be responsible for defining all aspects of the end-use mounting configuration. Parameters to be specified include the following:

a. The type of mounting or support structure for the module. If the back of the module will be in contact with the mounting structure or some material other than air, as much information as possible shall be specified to describe the material behind the module. Some examples of acceptable descriptions include *"open-air rack-mounted," "attached to vinyl-coated polyester temper-tent surface," "supported by nylon backpack," and "supported by natural earth surface such as sand or dirt".*

b. The expected tilt of the module relative to horizontal when deployed. Some examples of acceptable descriptions include *"racking is angled approximately to 35 degrees," "tent roof slopes at 30 degrees relative to horizontal," "pack is expected to be slanted such that module will be perpendicular to irradiance at solar noon", and "earthen surface is horizontal".*

c. Any further information that may affect temperature in deployment conditions. For example, if the module is applied to a heated tent, the minimum and maximum tent skin temperature should be specified.

2.1.5.5 Module Operating Temperature - Data Required and Sample Data.

The test report shall contain the following data, at a minimum:

a. The load type (resistive or MPPT). If a resistive load is used, record the resistance in ohms.

b. The location of any hot cells in the modules.

c. The location of the thermocouple on the back of each module. Include images if necessary.

d. The start and end dates and times of the outdoor exposure.

e. The highest and lowest average wind speeds used to make the scatter plot.

f. The highest and lowest average irradiances used to make the scatter plot.

g. A description of any equipment malfunctions that occurred during the test period and how the malfunction was rectified.

h. The derived coefficients U_0 and U_{1V} for each mounting configuration.

i. A description of any visible defects in the modules that developed during the outdoor exposure.

2.2 Safety.

2.2.1 High Voltage.

The high voltage test is intended to verify that the panel has proper electrical material and component selection and design for the intended system design voltage. Testing shall be conducted in accordance with IEC 61215-2 (MQT 03 (Insulation Test)), unless otherwise described within this section.

2.2.1.1 High Voltage - Instrumentation and Equipment.

The instrumentation and equipment outlined in IEC 61215-2 (MQT 03) are sufficient for this test. A calibrated, current-limited insulation resistance tester with the following capability is required:

a. Array voltage < 50 Volts direct current (VDC): 500 VDC maximum.

b. Array voltage > 50 VDC: 1000 VDC plus twice the maximum voltage of the array.

2.2.1.2 High Voltage - Required Test Conditions.

Perform high voltage testing at ambient conditions within the ranges provided below:

a. Temperature: 25°C ± 10 °C (77 °F ± 18 °F).

b. Relative humidity: less than 75 percent.

c. Atmospheric pressure: site pressure.

2.2.1.3 High Voltage - Test Procedures.

The procedures described in IEC 61215-2 (MQT 03) shall be followed for modules to be fielded singly or in parallel. For arrays connecting multiple modules in series, the system voltage used in this test shall be defined as the maximum voltage of the series array.

2.2.1.4 High Voltage - Procurement Document Requirements.

No specific requirements need to be defined in the procurement document; IEC 61215-2 (MQT 03) specifies the required voltages and durations and the following pass criteria, which may be used by the program office to specify panel high voltage tolerance:

a. For modules with an area of less than 0.1 m^2, the insulation resistance shall not be less than 400 MΩ.

b. For modules with an area larger than 0.1 m^2, the measured insulation resistance times the area of the module shall not be less than 40 $M\Omega/m^2$.

2.2.1.5 High Voltage - Data Required and Sample Data.

Any dielectric breakdown (diminishing of the electrical resistance during testing) will be noted. Visible physical damage, such as surface tracking, incurred during testing should be documented with photographs.

2.2.2 Diode Verification.

a. This test records bypass and blocking diode functionality before and after stress. Stress levels are similar to those applied in IEC 61215-2 MQT 18.2; however, tests are modified so that special modules with extra leads to access diodes that may be potted or embedded in laminate are not required. It is assumed that such special samples may be difficult to obtain for new lightweight products, and thus requiring the special samples would cause unacceptable delays in the test cycle.

b. The difference between bypass and blocking diodes is illustrated in Figure 11. Bypass diodes are placed in parallel with a solar cell(s), so that power is not dissipated in a shaded solar cell when solar cells in series with that cell are illuminated and continue to produce current. The current-producing cells may be either within the same module, or in another module connected in series with the partially-shaded module. A blocking diode prevents power dissipation in a shaded string of cells when another string in parallel with the shaded string still produces voltage. The voltage-producing string may be either within the same module, or in another module connected in parallel with the partially-shaded module.

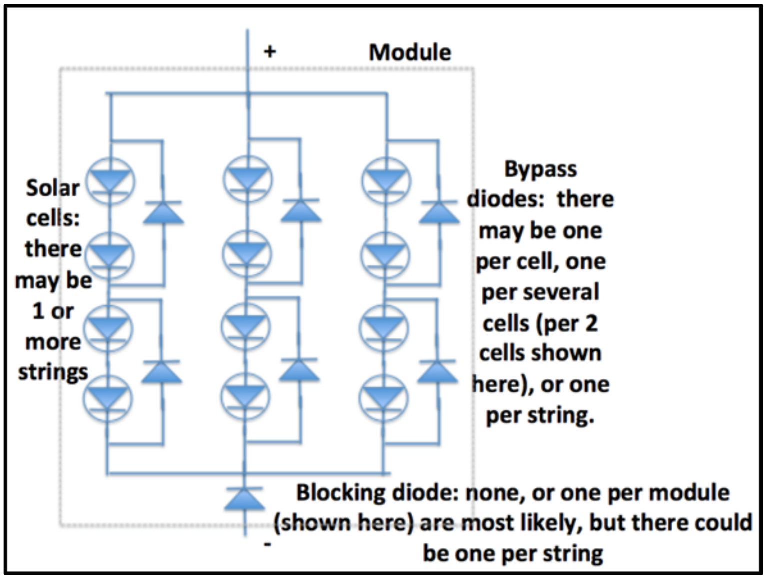


Figure 11. Schematic illustration of placement and polarity of bypass and blocking diodes in a module.

2.2.2.1 Diode Verification - Instrumentation and Equipment.

The following instrumentation is required:

a. Means for heating the module to a temperature of 75 ± 5 °C (167 ± 9 °F).

b. Means for monitoring the temperature of the module to an accuracy of ± 2.0 °C (3.6 °F) and repeatability of ± 0.5 °C (0.9 °F).

c. Means for applying a current equal to 1.25 times the STC short-circuit current of the module, throughout the test.

d. Infrared camera with sufficient spatial resolution to identify individual bypass diodes and temperature resolution of 5 °C or better.

2.2.2.2 Diode Verification - Required Test Conditions.

This is a multi-step test. As described in the next section, test conditions involve, sequentially:

a. 25 °C (77 °F) and AM1.5 IV characterization.

b. Application of I_{sc} during thermography.

c. Application of V_{oc}.

d. Application of 1.25 x I_{sc} at 75 °C (167 °F).

e. Application of I_{sc} during thermography.

f. Application of V_{oc}.

g. 25 °C and AM1.5 IV characterization.

2.2.2.3 Diode Verification - Test Procedures.

a. Pre-stress power assessment. Measure the module pre-stress power output as per paragraph 2.1.2. If a power measurement was performed on this module at the conclusion of the preceding test, that measurement may be used as the pre-stress power.

b. Pre-stress thermography.

(1) With the module in the dark and at 25 ± 10 °C (77 ± 18 °F), apply I_{sc} to the module (to make I_{sc} flow through the bypass diodes, the positive voltage of the power supply will be connected to the negative module terminal).

(2) Record the voltage necessary to cause I_{sc} to flow.

(3) Set the temperature scale on the infrared (IR) camera such that readings from all parts of the module are valid (no area is off-scale low or high, but otherwise as narrow as possible). Leave the scale set this way for the remainder of the test.

(4) Record a thermal image over each bypass or blocking diode in the module. Record the scale with the image. If possible, count how many diodes are warm, i.e., operational. If diodes are all in a potted junction box, their thermal images may not be distinct.

c. Pre-stress blocking diode test.

(1) If the module does not contain blocking diodes, and procurement requirements do not mandate parallel connection of modules in deployment, skip step c, and record “not applicable” for the forward current.

(2) If the module does contain blocking diodes, or procurement requirements indicate that there will be parallel connection of modules during deployment, apply the module’s open circuit voltage at STC to the module terminals while the module is in the dark (positive terminal of power supply to positive terminal on module). Allow the current to stabilize for 10 minutes. Record this forward current flow while the voltage is applied. If the current is < 100 milliamp (mA), record “< 100 mA”. Caution: If the module does not contain blocking diodes, or they are not working properly, this may be a destructive test.

d. Stress. Heat the module to 75 ± 5 °C (167 ± 9 °F). Apply a current to the module equal to 1.25 times the short circuit current (i.e., 1.25 x I_{sc}) ± 2 percent of the module as measured at STC while maintaining the module temperature at 75 ± 5 °C (the positive voltage of the power supply will be connected to the negative module terminal). Maintain the current flow for 1 hour.

e. Post-stress thermography.

(1) With the module in the dark and at 25 ± 10 °C (77 ± 18 °F), apply I_{sc} to the module (to make I_{sc} flow through the bypass diodes, the positive voltage of the power supply will be connected to the negative module terminal).

(2) Record the voltage necessary to cause I_{sc} to flow.

(3) With the temperature scale still set as determined in step 2.2.2.3.b(3), record a thermal image over each bypass or blocking diode in the module. Record the scale with the image. If possible, count how many diodes are warm, i.e., operational. If diodes are all in a potted junction box, their thermal images may not be distinct.

(4) Note any of the following changes, which are indicative of a diodes failing in the open condition, between the pre- and post-stress images:

(a) A diode has disappeared from the thermal image.

(b) A cell is warmer.

(c) A junction box containing diode(s) is cooler.

(d) More voltage is required to create the current of I_{sc}.

f. Post-stress blocking diode test.

(1) If the module does not contain blocking diodes and procurement requirements do not require parallel connection of modules in deployment, skip step f, and record “not applicable” for the forward current.

(2) If the module does contain blocking diodes, or procurement requirements indicate parallel connection of modules in deployment, apply the module’s open circuit voltage at STC to the module terminals while the module is in the dark. (Positive terminal of power supply to positive terminal on module.) Allow the current to stabilize for 10 minutes. Record this forward current flow while the voltage is applied. If the current is < 100 mA, record “< 100 mA”. Caution: If the module does not contain blocking diodes, or they are not working properly, this may be a destructive test.

(3) A significant increase in measurable current flow indicates a change in the blocking diode characteristics.

g. Post-stress power loss.

(1) Measure the post-stress module power output as per paragraph 2.1.2. Calculate the module power loss using Equation 3.

$$\%\, power\ loss = \frac{100\ x\ (P_{pre-stress} - P_{post-stress})}{P_{pre-stress}} \qquad (Equation\ 3)$$

(2) Record post-stress power and the percent power loss. Significant power loss may be an indicator of bypass diodes failed in the closed position.

h. Post-stress visual inspection. The module should be inspected for any visual defects, and the results recorded in the test report.

i. Post-stress wet leakage current. The wet leakage current test (paragraph 2.1.3) should be repeated, and data recorded in this section of the test report.

2.2.2.4 Diode Verification - Procurement Document Requirements.

The following items must be specified in the individual procurement document:

a. Whether modules will be deployed with multiple modules connected in parallel.

b. Whether blocking diodes are required.

c. Whether any failure of blocking diodes is allowed.

d. Maximum power loss from shorted bypass diodes.

e. Whether any signs of bypass diode failure in the open state are allowed.

2.2.2.5 Diode Verification - Data Required and Sample Data.

Diode verification data shall be reported as shown in Table 2. An example of data that might complete the table are shown in blue.

TABLE 2. REQUIRED DATA FOR DIODE VERIFICATION

PARAMETER	MEASURED OR OBSERVED VALUE
Does this module contain blocking diodes?	No
Forward current before stress, A	Not applicable
Forward current after stress, A	Not applicable
Is there evidence of blocking diode failure via significant forward current increase?	Not applicable
Pre-stress module STC power, W	50
Post-stress module STC power, W	49
Percent power loss (may be associated with shorted bypass diodes)	2%
Number of bypass diodes in module, obtained either from manufacturer information or inspection	18
Number of bypass diodes functioning pre-stress	18
Number of bypass diodes functioning post-stress	17
Pre-stress voltage required for I_{sc} in reverse current, V	9
Post-stress voltage required for I_{sc} in reverse current, V	19
Pre-stress thermal images	Include pre-stress images and all supporting metadata
Post-stress thermal images	Include post-stress images and all supporting metadata
Are there signs of bypass failure in open state? Circle all that apply. [✓ Diodes have disappeard from thermal image.] Some cells are warmer Jbox containing diodes is cooler [✓ Voltage required to flow I_{sc} during thermal image has increased.]	Yes
Visual inspection results	No visual defects observed
Post stress wet leakage current	2 microAmps
Panel resistance x area	1 m^2 x500V/ (2 x 10^{-6}A) = 250 Mohm-m^2

2.2.3 Partial Shading.

a. The partial shading test determines the effects of shading or partially shading a single cell to screen for excessive heating that may damage the module and to determine the power loss due to shading. The test is accomplished in three steps:

(1) The two highest and two lowest temperature cells are selected using an IR image. This step is described in paragraph 2.2.3.3.1, Cell Selection Procedure.

(2) For each selected cell, the percent shading that causes I_{mp} to flow through the illuminated, short-circuited, module is identified. This step is described in paragraph 2.2.3.3.2, Shade Determination Procedure.

(3) For each selected cell, the identified percent shading is applied for an extended time at elevated temperature. This step is described in paragraph 2.2.3.3.3, Extended Exposure Procedure.

b. The partial shading test is related to IEC 61215-2, MQT 09 “Hot-spot endurance test”, but with several important differences. First, cell selection is accomplished via examination of an IR image rather than the time-consuming process of taking an IV curve with each cell in the module successively shaded. Second, a performance check is performed after the shading in this test flow. Third, there is no dry insulation test (IEC 61215-2 MQT 03) at the end of the shading stress. Fourth, this test is performed identically for any type of internal wiring (series, parallel, etc.), with only one option for how to select worst-case shading.

2.2.3.1 Partial Shading - Instrumentation and Equipment.

a. Thermal imaging device capable of surveying the surface of the module with a numerical readout to quantitatively identify the hottest cells.

b. Light source with an irradiance that can be maintained at 1,000 ±100 W/m^2. Natural sunlight or a class BBB (or better) steady-state solar simulator may be used.

c. Equipment to monitor the module current.

d. A means to shade a single cell in the module in increments of no more than 10 percent, such as opaque covers that shade between 10 and 100 percent of a single cell for the module design under test.

e. Equipment to measure the module temperature and maintain it in the range of 50 ± 10 °C (122 ± 18 °F).

f. Equipment to measure module irradiance level during the test.

2.2.3.2 Partial Shading - Required Test Conditions.

The worst-case shading conditions shall be applied for 1 hour for each of the selected cells, with the average module temperature maintained at 50 ± 10 °C (122 ± 18 °F), and the illumination maintained at 1,000 ± 100 W/m^2.

2.2.3.3 Partial Shading - Test Procedures.

2.2.3.3.1 Cell Selection Procedure.

Subject the module to the required test conditions, and place the module under a short circuit condition by either directly connecting the output wires together or by fabricating a jumper wire to connect the positive and negative terminals. After the module has reached steady-state temperature (less than 2 °C (3.6 °F) change after 10 minutes), use the thermal imager to survey the entire front surface of the module. Using the color scale and the center focus temperature readout, identify and record the two highest and two lowest temperature cells on the module; these cells will be used in the remainder of the test.

2.2.3.3.2 Shade Determination Procedure.

a. To stress the sample as much as possible, it is desirable to dissipate the largest possible amount of power in the partially-shaded cell. There is not one universal “most damaging” partial shading percentage. The shading conditions that produce exactly the largest possible power dissipation are a function of the number of cells and bypass diodes in a module and the IV characteristics of the cells and bypass diodes.

b. Achieving maximum power dissipation requires maximizing the product of the current and the (reverse) voltage in the partially-shaded cell. Shading too much of the cell can cause current (and thus dissipated power) to be very small, whereas shading too little of the cell causes the reverse voltage (and thus the dissipated power) to be small. For typical cell characteristics, maximum power dissipation occurs when cell shading decreases the current through the short-circuited string slightly, commonly from I_{sc} to I_{mp}. A precise determination of the current at which maximum power dissipation is achieved would require a detailed knowledge of the cell and bypass diode forward and reverse characteristics. Thus, reducing the current through the string from I_{sc} to I_{mp} is used in this test method as an approximation of the worst possible shading condition when individual cells are not electrically accessible.

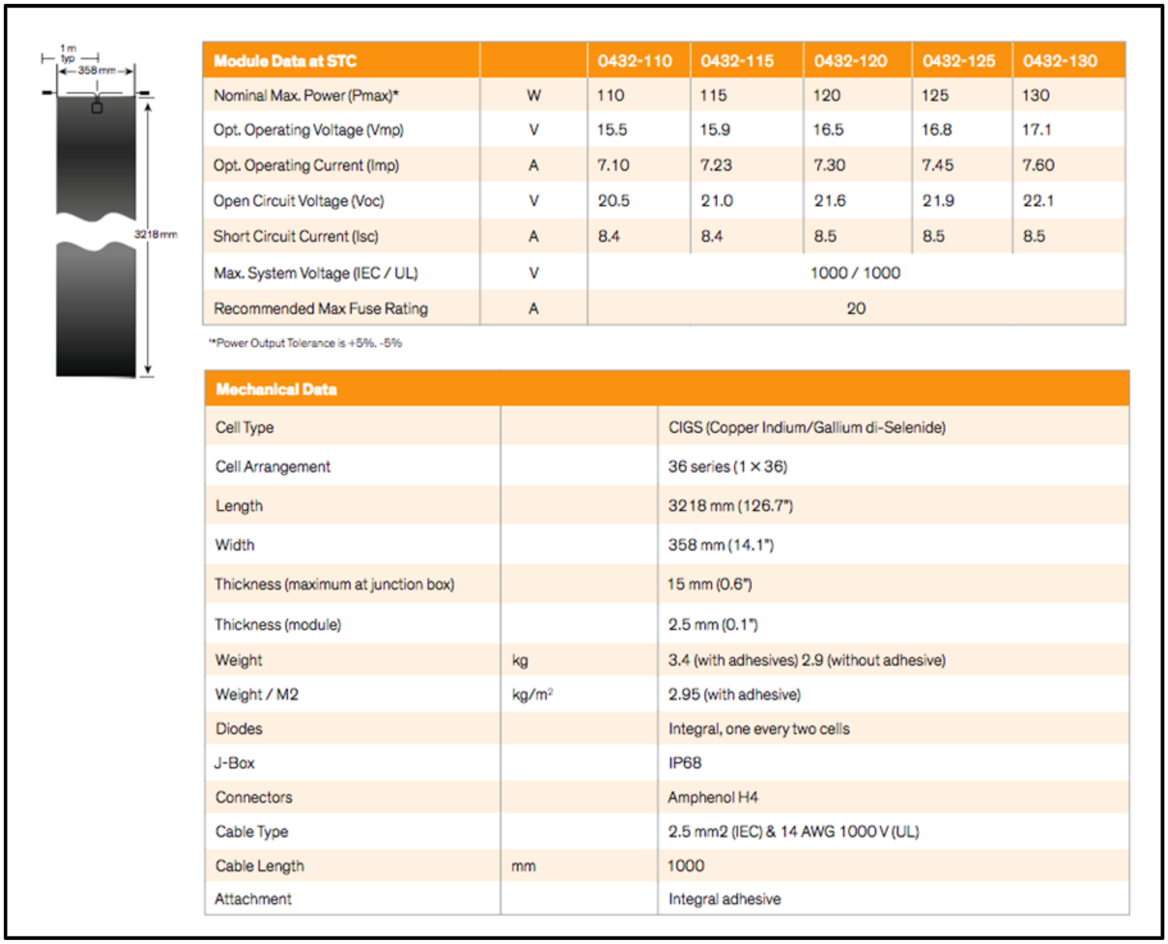
c. The impact of multiple parallel strings of cells on the current must be taken into account so that applied stress is consistent across module types. For an illustration of parallel strings, see Figure 11 in the diode verification test, which shows a module with three parallel strings. When one cell in a string is shaded, the other strings will still generate current normally, so that reducing the current in the partially-shaded string to the worst condition relates to the module I_{sc} and I_{mp} as follows in Equation 4:

$$I_{module}@worst\ shading = I_{sc} - \frac{(I_{sc}-I_{mp})}{n}$$ (Equation 4)

where:

n = the number of parallel strings

d. The number of parallel strings in a module can be determined either from manufacturer information or from a comparison of cell size and number with module current and voltage. An example of these two methods for determining n is shown in Figure 12. In Figure 12, a manufacturer data sheet specifies a single string of 36 cells in a flexible copper indium/gallium di-selenide (CIGS) module. In Table 3, measured current and voltages on a different product are used to deduce that the product contains two parallel strings of 36 cells each. If all cell interconnects (wires, ribbons, or scribes) are visible, it may also be possible to determine the number of strings in the module by visual inspection.



Module Data at STC		0432-110	0432-115	0432-120	0432-125	0432-130
Nominal Max. Power (Pmax)*	W	110	115	120	125	130
Opt. Operating Voltage (Vmp)	V	15.5	15.9	16.5	16.8	17.1
Opt. Operating Current (Imp)	A	7.10	7.23	7.30	7.45	7.60
Open Circuit Voltage (Voc)	V	20.5	21.0	21.6	21.9	22.1
Short Circuit Current (Isc)	A	8.4	8.4	8.5	8.5	8.5
Max. System Voltage (IEC / UL)	V	1000 / 1000				
Recommended Max Fuse Rating	A	20				

**Power Output Tolerance is +5%, -5%

Mechanical Data		
Cell Type		CIGS (Copper Indium/Gallium di-Selenide)
Cell Arrangement		36 series (1 × 36)
Length		3218 mm (126.7")
Width		358 mm (14.1")
Thickness (maximum at junction box)		15 mm (0.6")
Thickness (module)		2.5 mm (0.1")
Weight	kg	3.4 (with adhesives) 2.9 (without adhesive)
Weight / M2	kg/m²	2.95 (with adhesive)
Diodes		Integral, one every two cells
J-Box		IP68
Connectors		Amphenol H4
Cable Type		2.5 mm2 (IEC) & 14 AWG 1000 V (UL)
Cable Length	mm	1000
Attachment		Integral adhesive

Figure 12. Determining the value of n from vendor datasheet.

TABLE 3. EXAMPLE OF CALCULATIONS USED TO DEDUCE THE VALUE OF N

Product	99-W flexible charger, CIGS
Measured I_{sc}	5.7 A
Measured V_{oc}	24.6 V
Measured cell area	20.5 cm x 4 cm = 82 cm^2
Measured number of cells	72
Typical V_{oc} for a CIGS device	0.65 V
Typical J_{sc} for a CIGS device	35 mA/cm^2
Implied I_{sc} for a CIGS device of this area	35 mA/cm^2 * 82 cm^2 = 2.9 A
Measured V_{oc} requires approximately how many devices in series?	24.6 V / ~0.65 V per cell = ~37.8 cells
Measured I_{sc} requires approximately how many devices in parallel?	5.7 A / ~ 2.9 A/cell = 1.97 cells
➔ This module is most likely configured as 2 parallel strings of 36 cells each	

e. Shading may be performed using discrete masks (for any cell) or a single mask that extends beyond the cell edge (only for edge cells). Masks shall be the same width as the cell and be placed such that increasing shading proceeds upward from the lower edge of the cell. Shading using discrete masks is illustrated in Figures 13a and b. Shading of a monolithically-integrated cell that extends to the module edge, using a mask that is larger than the cell, is illustrated in Figures 13c and d. The orientation of the module with respect to some feature (e.g., junction box, rear label, front label, etc.) shall be noted.

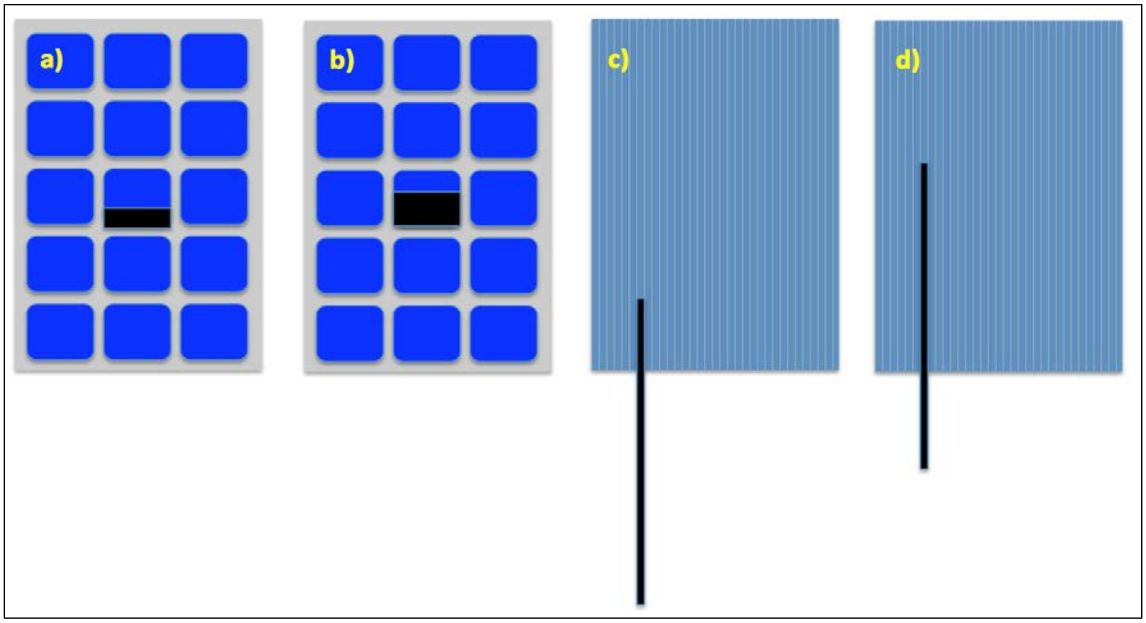


Figure 13. Cell shading for discrete cells at a. 20-percent shading, and b. 60-percent shading, and for monolithically-integrated cells at c. 20-percent shading, and d. 60-percent shading.

f. The following steps shall be used to determine the worst-case percent shading:

(1) Determine n, the number of parallel strings in the module, using any of the methods presented in the preceding paragraphs.

(2) Calculate the worst-case shading current (I_{module} @ worst shading) for this module according to Equation 4.

(3) For each of the four cells selected in the previous section, perform steps (a) through (e) below:

(a) Expose the module to steady-state known irradiance in the range of 1000 ± 100 W/m^2.

(b) Short-circuit the module, and monitor its current throughout this test. If intensity is not equal to 1000 W/m^2, correct the measured current for the intensity difference.

(c) Apply approximately 10-percent shading to the selected cell and note the current through the module.

(d) Continue to increase shading by increments of no more than 10 percent until reaching the first condition for which measured (intensity-corrected) current is less than I_{module} @ worst shading.

(e) Revert to the shading that is one size smaller than the final mask from step f (i.e., the largest mask for which the intensity-corrected module current is greater than or equal to I_{module} @ worst shading). This mask shall be used for the extended exposure. If the smallest mask (e.g., 10-percent shading) already decreases the current to less than I_{module} @ worst shading, use this smallest mask for extended exposure.

2.2.3.3.3 Extended Exposure Procedure.

a. Short circuit the module.

b. Expose the module to 1000 ± 100 W/m^2.

c. Allow the module temperature to equilibrate within the range of 50 ± 10 °C (122 ± 18 °F).

d. Apply the worst case shading condition, as determined in paragraph 2.2.3.3.2, to the first cell.

e. Maintain this condition for 1 hour.

f. Remove the shading mask.

g. Repeat steps d, e, and f for the second, third, and fourth selected cells.

2.2.3.4 Partial Shading - Procurement Document Requirements.

The procurement agency shall be responsible for defining the following parameters:

a. The maximum allowable permanent electrical power degradation, in percent.

b. Whether visible permanent damage such as laminate melting or cell cracking is acceptable.

2.2.3.5 Partial Shading - Data Required and Sample Data.

The following data shall be included in the test report:

a. The infrared images used to select the hottest and coolest cells, with the location of the selected cells marked.

b. The orientation of the module during the infrared testing and extended shading with respect to some module feature such as junction box, rear label, front label, etc.

c. The percent shade applied to each of the selected cells during the 1-hour exposure period.

d. Any damage that occurred during the test shall be noted, with photos if applicable.

e. The maximum permanent electrical power degradation, in percent.

f. The maximum temporary electrical power loss during shading of any one cell, in percent.

2.3 Mechanical and Thermal Stresses.

2.3.1 Ultraviolet (UV) Exposure.

a. UV exposure is included to detect short-term discoloration or embrittlement of polymers. Embrittlement may not be visually apparent but is likely to affect test results after subsequent thermal cycling or mechanical stress. While overall UV dosage is roughly consistent with IEC 61215-2 (MQT 10), the test in this document can be performed outdoors and thus without temperature and intensity control. Alternatively, exposure can be performed indoors using MQT 10.

b. If indoor exposure is available, this method is recommended rather than the outdoor method. Because of the elevated and controlled temperature utilized during indoor exposure, it has both more reproducibility and higher-stress than the outdoor exposure.

2.3.1.1 UV Exposure - Instrumentation and Equipment.

2.3.1.1.1 Outdoor Method.

a. Means to mount the test module so that it is oriented close to the optimum for the local latitude.

b. A solar irradiation monitor accurate to ± 5 percent, mounted in the plane of the module within 1 m of the test module.

c. A resistive load sized such that the module will operate near its maximum power point or an electronic MPPT.

d. Insulating material (such as foam) that can be applied to the entire back of the module.

2.3.1.1.2 Indoor Method.

Refer to IEC 61215-2, Section 4.10.2.

2.3.1.2 UV Exposure - Required Test Conditions.

Exposure shall be 15 – 20 kWh/m^2 total UV irradiation in the wavelength range from 280 nanometers (nm) to 400 nm. If indoor exposure is utilized, the light source shall provide between 3 and 10 percent of the UV irradiance in the wavelength range from 280 nm to 320 nm.

2.3.1.3 UV Exposure - Test Procedures.

2.3.1.3.1 Outdoor Exposure Method.

a. Mount the test module outdoors in an area that is free of shading. The tilt (angle with horizontal) and azimuth (angle with north. should be chosen to maximize irradiance and thus minimize the exposure test time.

b. Note the angles of tilt and azimuth in the test report.

c. Apply an insulating material (such as foam) to the entire back of the module, in order to increase the module temperature during test.

d. Attach the resistive load or electronic maximum power point tracker to the module.

e. Subject the module to an irradiation totaling between 352 and 469 kWh/m^2, as measured by the monitor. This total irradiation corresponds to a UV dose between 15 and 20 kWh/m^2.

2.3.1.3.2 Indoor Exposure Method.

Requirements are detailed in IEC 61215-2, Section 4.10.3.

2.3.1.3.3 Post Test.

a. Inspect the module for any visual defects, and record the results in the test report.

b. Repeat wet leakage current test (paragraph 2.1.3) and record data in this section of the test report.

2.3.1.4 UV Exposure - Procurement Document Requirements.

a. The following items must be specified in the individual procurement document:

(1) Minimum allowable resistance after test.

(2) Whether visible defects after test are allowed.

b. If the item is intended for cumulative outdoor exposure >1 year, it is recommended that the procurement document specify no visual defects and a resistance $\geq$ 40 MΩ/m^2.

2.3.1.5 UV Exposure - Data Required and Sample Data.

After the UV exposure test, the data shown in Table 4 shall be recorded. An example of data that might complete the table is shown in blue.

TABLE 4. REQUIRED DATA FOR UV EXPOSURE

Method of UV exposure (indoor or outdoor)	Outdoor
If outdoors, module tilt angle	45
If outdoors, module azimuth angle	180 (south)
If outdoors, material used to insulate module back and method of attachment	3 inch multi-purpose flexible foam attached to module with spray adhesive
Exposure start date and time	6/20/17 10:02 AM
Exposure end date and time	8/30/17 11:05 AM
Cumulative exposure (kWh/m^2)	355
Visual inspection results	No visual defects observed
Post stress wet leakage current	2 microAmps
Panel Resistance x area	1 m^2 x 500 V/ (2 x 10^{-6} A) = 250 Mohm-m^2

2.3.2 Hail Impact.

The intent of the hail test is to determine whether PV modules are capable of withstanding the impact of 1-inch hail without incurring any physical damage, permanent deformation, or degradation in performance. The test procedures in this TOP were derived from IEC 61215-2 (MQT 17), and American Society for Testing and Materials (ASTM) E1038-10[8].

2.3.2.1 Hail Impact - Instrumentation and Equipment.

a. Launcher. A launcher capable of propelling a selected ice ball at the specified speed within ± 5 percent will be used (Figure 14). The aiming accuracy of the launcher will be verified to ensure it is sufficient for the ice ball to strike the specified impact area; otherwise, the surrounding area will be masked for protection from inadvertent impacts.

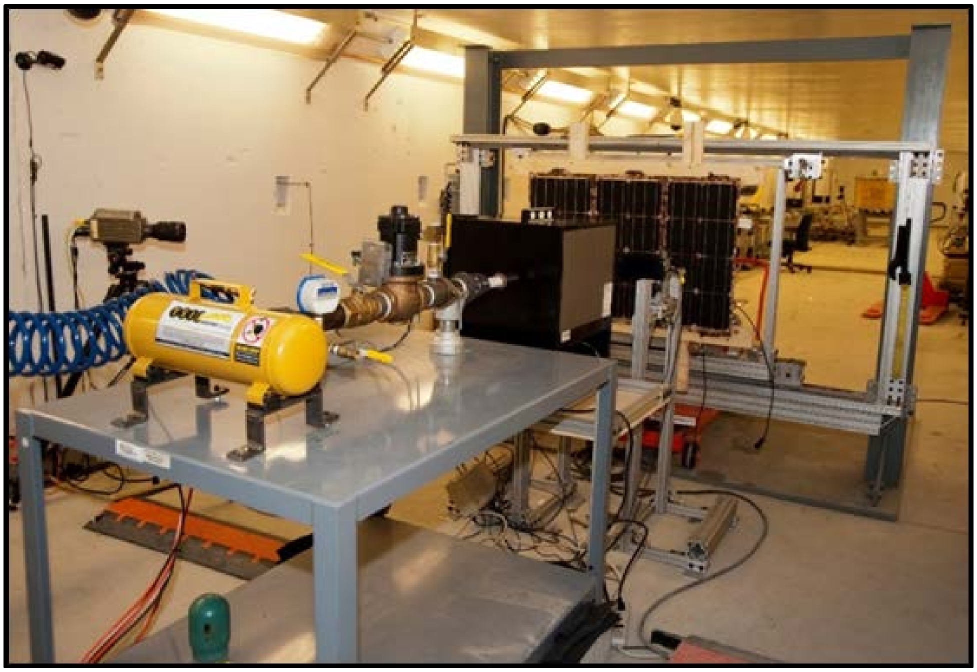


Figure 14. Representative ice ball launcher apparatus.

b. Speed Meter. A speed sensor capable of measuring ice ball speed to within ± 2 percent will be used (Figure 15).

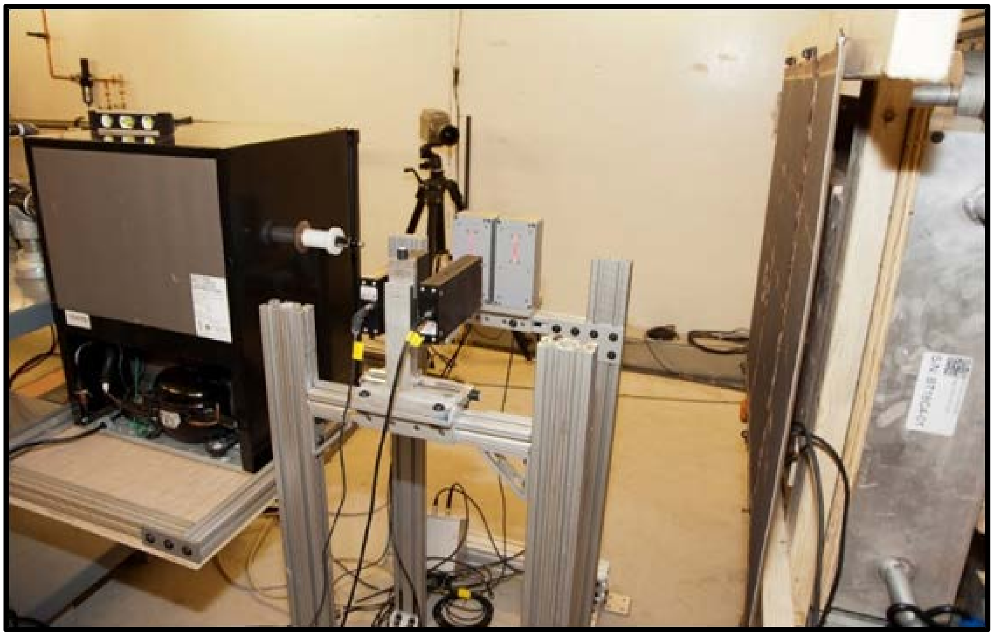


Figure 15. Representative laser intervalometer used to measure the ice ball speed.

c. Molds. Molds made from silicone rubber or expanded polystyrene will be used for casting ice balls of appropriate diameter (Figure 16).

Figure 16. Representative ice ball mold, clamped during ice making.

d. Freezer. A test environmental chamber capable of making ice balls in the molds at a controlled temperature of -10 ± 5 °C (14 ± 9 °F) shall be used.

e. Storage Container. A freezer or ice chest capable of maintaining ice balls at -4 ± 2 °C (25 ±3.6 °F) at the test facility shall be used.

f. Weight and Dimensions. A scale will be used to determine the ice ball mass to within ± 1 percent, and a caliper will be used to determine the ice ball size.

g. High-speed video. High speed video capable of recording the impact of ice balls on the panel will be used. The video shall be able to be played back by the test team in near real-time in order to verify the location of impact.

2.3.2.2 Hail Impact - Required Test Conditions.

a. Prior to the start of the hail test, the module surface temperature shall be stabilized at controlled ambient temperature and relative humidity conditions as described in MIL-STD-810H and provided below:

(1) Temperature: 23°C ± 2 °C (73 °F ± 3.6 °F).

(2) Relative humidity: 50 ± 5 percent.

(3) Atmospheric pressure: site pressure.

b. Ice Ball Preparation. In deviation from the IEC standard, the following procedures shall be used to determine acceptable ice balls:

(1) The molds shall be used to make a quantity of 50 ice balls. After making the ice balls, the molds shall be separated, and any ice balls that are visually deformed or cracked should be discarded.

(2) The weight and diameter of the remaining spherical ice balls shall be measured, and the measurements shall be compared with the allowable weight and diameter ranges for a 1-inch ice ball from ASTM E1038, outlined in Table 5. These data shall be used to determine whether the ice balls are within the allowable range through statistical analysis with a 90-percent confidence level.

TABLE 5. ALLOWABLE ASTM E1038 RANGE, 1-INCH ICE BALL

ALLOWABLE RANGE	MINIMUM	MAXIMUM
Weight, grams	7.125	7.785
Diameter, mm	23.750	26.250

c. After verifying the method used to make the ice balls is sufficient, ice balls to be used for the test shall be made, removed from their molds, and any visually deformed or cracked ice should be discarded. All remaining ice balls shall be placed in the storage container and removed just prior to placing into the launcher to limit ice melting and/or unwanted cracking of the ice prior to the test shot.

2.3.2.3 Hail Impact - Test Procedures.

Testing shall be conducted in accordance with IEC 61215-2 (MQT 17), with the following modifications:

a. Each ice ball does not need to be measured before testing as long as the procedures used to make the balls is proven to produce ice balls within the allowable range outlined in Table 5. At the time of test, and prior to loading into the launcher, test personnel shall verify that the ice balls contain no cracks visible to the unaided eye.

b. Cooling of the launcher apparatus that makes contact with the ice ball shall be allowed if test facility safety regulations require more than 60 seconds to elapse between the removal of the ice ball from the container, ice ball launch, and the impact of the ice ball with the module.

c. High-speed video shall be used to assist in the verification of the location of impact.

2.3.2.4 Hail Impact - Procurement Document Requirements.

a. Any deviation in IEC 61215-2 not already outlined in this section of the TOP.

b. Impact locations other than those outlined in Table 4 and Figure 14 of IEC 61215-2.

2.3.2.5 Hail Impact - Data Required and Sample Data.

The following data shall be collected and presented as part of the hail test.

a. Photograph of solar panel with all impact sites marked.

b. Description of visual effects of ice ball impacts, if any.

c. Size, mass, and speed of ice balls used.

d. Temperature of solar panel during testing.

e. Description of launcher and speed measurement apparatus used.

f. Pre- and post- module performance data.

2.3.3 Loose Cargo Vibration.

The loose cargo vibration test is designed to determine the effects of the transportation life cycle on the module. More specifically, the test is designed to determine whether the module can withstand the effects of transportation in trucks, trailers, or tracked vehicles, while not secured to the carrying vehicle, without damage or degradation of performance.

2.3.3.1 Loose Cargo Vibration - Instrumentation and Equipment.

The instrumentation and apparatus outlined in MIL-STD-810H, Test Method 514.8, paragraphs 4.2.3 and 4.1.2 are sufficient for this test. No modifications or adaptations to the instrumentation/apparatus outlined in MIL-STD-810H, Test Method 514.8 are required.

2.3.3.2 Loose Cargo Vibration - Required Test Conditions.

Unless otherwise specified in the procurement document, loose cargo vibration testing should be performed at standard ambient conditions as described in MIL-STD-810H, Part One, paragraph 5.1 and provided below:

a. Temperature: 25°C ± 10 °C (77 °F ± 18 °F).

b. Relative humidity: 20 to 80 percent.

c. Atmospheric pressure: site pressure.

2.3.3.3 Loose Cargo Vibration - Test Procedures.

The procedures outlined in MIL-STD-810H, Test Method 514.8, paragraph 4.5, Procedure II (paragraph 4.5.3) should be followed. The module should be packaged as it normally would be for transportation. The required fencing, module orientations, and module positioning will be dependent on the specific module under test. See MIL-STD-810H, Test Method 514.8, Annex C, paragraph 2.2, for further information. Exposure levels are not tailorable and should be performed as described in MIL-STD-810H, Test Method 514.8.

2.3.3.4 Loose Cargo Vibration - Procurement Document Requirements.

The procurement document must specify exposure duration. An exposure duration of 20 minutes per orientation equates to 240 kilometers (km) (150 miles) of loose cargo transportation. The expected material transportation life cycle should be used to define the total exposure duration. See MIL-STD-810H, Test Method 514.8, Annex C, paragraph 2.2.f for further information. The procurement document need not specify exposure levels. Exposure levels are not tailorable and should be performed as described in MIL-STD-810H, Test Method 514.8. If no duration is specified by the procurement agency, a minimum of 20 minutes shall be utilized.

2.3.3.5 Loose Cargo Vibration - Data Required and Sample Data.

The following data shall be included in the test report:

a. Photograph of solar panels (and transit cases if applicable) before and after loose cargo.

b. Vibration profile utilized and test duration.

c. Pre- and post- module performance data.

2.3.4 Drop.

The intent of the drop test is to determine the structural and functional integrity of a panel subjected to drop while being transported (in transit case) or while being deployed. Testing shall be conducted in accordance with MIL-STD-810H, Test Method 516.8, Shock, Procedure IV - Transit Drop; however, this section of the TOP outlines and modifies the procedures to represent the drop conditions typically encountered during PV panel transit and setup. All panels shall be tested with these drop heights and conditions to ensure all PV systems are being tested to the same parameters regardless of system weight, size, deployment mechanism, and material.

2.3.4.1 Drop - Instrumentation and Equipment.

Shock and impulse data are not typically collected during drop testing, so no specific instrumentation is required other than test apparatus required for dropping and slinging the item, such as a quick release hook or drop tester. The drop surface shall be normal to the direction of the impact and nominally flat.

2.3.4.2 Drop - Required Test Conditions.

2.3.4.2.1 Transit Drop.

The required transit drop test heights for various types of PV, separated by the manner in which the PV is typically transported, are presented in Table 6. The two categories are as follows:

a. Man-packed or man-portable. PV modules typically transported on the body of the Warfighter in rucksacks or similar bags.

b. Non-man portable. PV modules shipped to the area of deployment via vehicle or material handling equipment. Non-man portable PV systems are typically transported in a rigid style transit case (but other means of packaging the PV modules for transport are possible).

TABLE 6. TRANSIT DROP TEST CONDITIONS

TYPE OF PV	HEIGHT OF DROP, centimeter (cm)/(inch)	NUMBER OF DROPS
Man-packed or man portable	122/(48)	Drop on each face, edge and corner; total of 26 drops
Non-man portable	76/(30)	Drop on each corner; total of 8 drops

2.3.4.2.2 Deployment Drop.

The required deployment drop test heights for various types of PV are presented in Table 7. These drop test conditions are to represent drop conditions that may be experienced when the panels are being removed from their transit case just prior to deployment.

TABLE 7. DEPLOYMENT DROP TEST CONDITIONS

TYPE OF PV	HEIGHT OF DROP, cm (inch)	NUMBER OF DROPS	IMPACT SURFACE
Man-packed or man portable	1.5 (5)	Drop on each face, edge and corner, of the panel in a folded configuration; total of 26 drops.	Steel backed by concrete. (Note: the steel plate shall be at least 2.5 cm (1 inch) thick.)
Non-man portable (foldable panels)	1.5 (5)	Drop on each face, edge and corner, of the panel in a folded configuration; total of 26 drops while folded.	
Non-man portable (rigid panels)	See Figure 17, height is dependent on overall panel length.	Four drops as shown in Figure 17.	

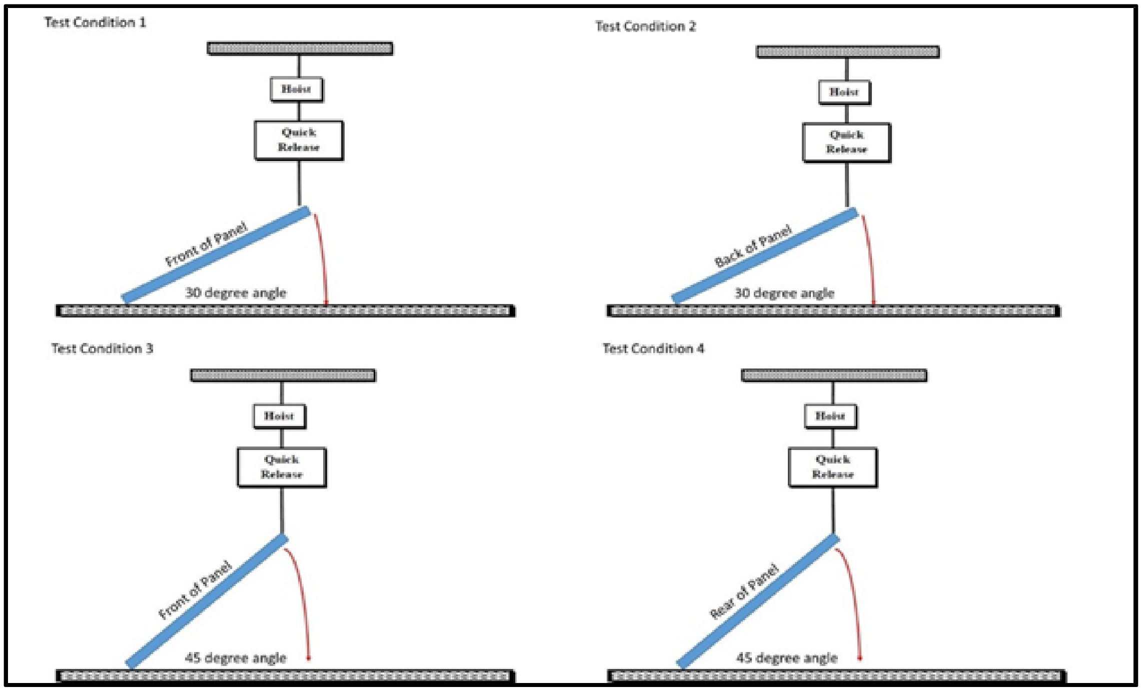


Figure 17. Non-man portable, deployment drop test heights (rigid panels) (representative drop configurations).

2.3.4.3 Drop - Test Procedures.

a. Measure the module pre-drop power output and panel efficiency as per paragraph 2.1.2. If a power measurement was performed on this module at the conclusion of the preceding test, that measurement may be used as the pre-drop panel efficiency test

b. The transit drop testing outlined in Table 6 shall be conducted prior to conducting the deployment drop tests outlined in Table 7. Transit drop testing shall be conducted with the PV modules configured in their transit case or bag as delivered to the Warfighter. Multiple PV modules may be required to conduct this testing if they are typically deployed with more than one module per transit case. If multiple PV panels need to be subjected to the transit drop test, each should be characterized for pretest performance as outlined in paragraph 2.1.2. If transit drop testing is not applicable, proceed to step g.

c. Perform the required transit drops outlined in Table 6 using the apparatus and requirements of paragraphs 2.3.4.1 and 2.3.4.2.

d. Document impact point or surface of each drop and any obvious damage to the transit case. The PV modules do not need to be removed from the transit case after each drop.

e. After completing the last drop outlined in Table 6, remove the modules from the transit case and inspect for any obvious damage to the modules.

f. Measure the module post-drop panel efficiency as per paragraph 2.1.2. If multiple modules were tested during transit drop testing, the output power of each panel shall be measured.

g. Perform the required deployment drops outlined in Table 7 using the apparatus and requirements of paragraphs 2.3.4.1 and 2.3.4.2.

h. Document impact point or surface of each drop and any obvious damage to the module.

i. Measure the module post-deployment drop panel efficiency as per paragraph 2.1.2. If multiple modules were tested during transit drop testing, the output power of each panel shall be measured.

2.3.4.4 Drop - Procurement Document Requirements.

The following items must be specified in the individual procurement document for the module:

a. Any deviation in the number of drops or drop heights outlined in this TOP.

b. Maximum allowable degradation in performance allowed as a result of drop testing.

2.3.4.5 Drop - Data Required and Sample Data.

The following data shall be collected and presented as part of the drop test.

a. Results of visual inspections and operational checkouts.

b. Drop heights and orientations and number of drops.

c. Pre- and post-drop performance data.

d. Any damage.

e. Photographs.

2.3.5 Junction Box Strength.

The junction box is the electrical transition point and stress relief between the panel and the external connector wire. The junction box pull strength test is designed to determine whether the module junction box can withstand pull force exerted on it during operation either from manual pulling on the box, wind gusts, or while being removed from stowage. There should not be any visible damage of the junction box module or loss of electrical continuity or module performance. Reference test IEC 61215-2 (MQT 14 (4.1(4)) Robustness of Terminations.

2.3.5.1 Junction Box Strength - Instrumentation and Equipment.

The instrumentation required for this test consists of an apparatus that can be used to apply a pull force on the junction box cable. This force is defined by a 100-pound (lb) weight or spring gauge with a 100-lb range. Clamps should be used to hold the module and allow for uniform distribution of the load across the module in opposition to the pulling force; grommets on the module can be used (this is not a grommet load test). The module electrical leads should also be clamped near the connector. The 100-lb (445-Newton (N)) pull strength may be increased or decreased based on panel size and as determined in actual use; this change shall be provided by the procurement agency.

2.3.5.2 Junction Box Strength - Required Test Conditions.

The integrity of the connector junction box should be examined prior to loading; any blemishes or non-functional flaws in the box and cable should be noted. The module should be dry and at room temperature. Clamping locations should be applied and tested for grip strength; they should be set to oppose the direction of the pull on the junction box. Testing should be conducted at the following standard ambient conditions.

a. Temperature: 25°C ± 10 °C (77 °F ± 18 °F).

b. Relative humidity: 20 to 80 percent.

c. Atmospheric pressure: site pressure.

2.3.5.3 Junction Box Strength - Test Procedures.

A test apparatus should be assembled with enough room to allow for free movement of the pulling force, as shown in Figure 18. Necessary safety precautions should be taken when handling large pull forces and weights. Note that the connector cable may pull free from the junction box, and debris may come away in all directions.

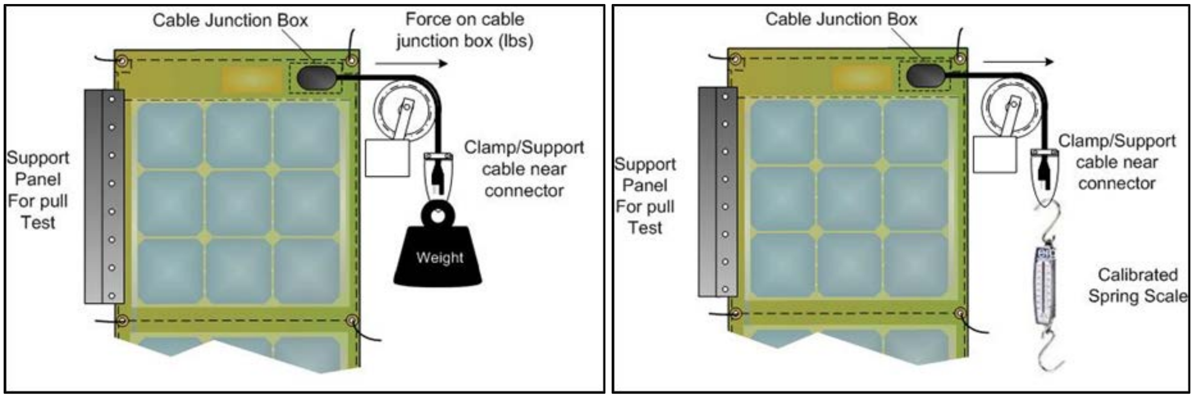


Figure 18. Weight pull (left) and spring scale pull (right) test setups.

a. Build and secure pull force apparatus.

b. Connect clamps and grommet hold downs of test module as necessary to oppose pull force on junction box.

c. Secure clamp or holding device to connector cable near connector.

d. Test integrity of assembly.

e. Apply pull force for a period of 10 ± 1 seconds; note any elongation of the cable, bare or exposed wiring and damage to junction box.

f. Remove the clamp, remove the module from the apparatus, and inspect the module for physical damage to wiring and junction box.

g. Test continuity of cable; if access to the wires is not possible, measure module performance.

h. Orient the apparatus 90 degrees and repeat the test for all three orthogonal directions, pulling upward and sideways.

2.3.5.4 Junction Box Strength - Procurement Document Requirements.

The procurement agency shall outline any deviations from this TOP, notably any specific changes in terms of pull force, direction of pull, and test duration.

2.3.5.5 Junction Box Strength - Data Required and Sample Data.

The following data shall be collected and presented as part of the junction box strength test.

a. Results of visual inspections and operational checkouts.

b. Pre- and post-drop performance data.

c. Photographs of any visual damage.

2.3.6 Panel Folding.

The panel folding test is designed to assess the durability of panel folding under a predetermined number of fold cycles and various environmental conditions. The electrical conductors internal to the panel are expected to degrade under certain number of folding and unfolding cycles. Further, flexible panels with polymer encapsulation will delaminate further degrading the overall performance of the panel.

2.3.6.1 Panel Folding - Instrumentation and Equipment.

Thermocouples shall be connected to the front and back of the panel. A thermocouple shall be attached to record the ambient temperatures. To measure electrical performance, test leads shall be connected to the output of the panel.

2.3.6.2 Panel Folding - Required Test Conditions.

The required conditions are at temperatures of 25 ± 2 °C (77 ± 3.6 °F). Folding tests conducted in a low- or high-temperature environment are optional and maybe selected by the procuring agency.

2.3.6.3 Panel Folding - Test Procedures.

Specific test procedures shall be developed based on the panel design, and those procedures shall be approved by the procurement agency prior to test conduct. Test procedures may vary based on the number of physical folds per panel (i.e., bifold, trifold, map-like folded panels, etc.). These test procedures shall include the following:

a. Whether the folds will be accomplished physically by a human or an automated folding fixture/system.

b. Any unique mounting or holding of the panel while conducting of the individual folds.

c. Order in which folds will be conducted.

2.3.6.4 Panel Folding - Procurement Document Requirements.

The following must be specified within the procuring agency’s documents:

a. Number of fold cycles.

b. Environmental temperatures where tests are conducted.

c. Value for objective and threshold performance criteria (e.g., panel must be 80 percent operational after test).

2.3.6.5 Panel Folding - Data Required and Sample Data.

The following data shall be collected and presented as part of the panel folding test:

a. Number of fold cycles.

b. Back panel temperature.

c. Front panel temperature.

d. Pre- and post- module performance data.

2.3.7 Thermal Cycling.

a. Thermal cycling accelerated testing helps determine whether the module can withstand thermal mismatch, fatigue, and other stresses caused by repeated changes of temperature. In particular, it helps pull open mechanical weaknesses (such as cell cracks or failing solder bonds) created during other stress tests (e.g., drop test) so that these weaknesses are evident in the final power evaluation. Thermal cycling mimics day/night thermal cycling that the product will experience in the field. It is performed in an accelerated manner (i.e., more extreme upper and lower temperatures), so that several years of product lifetime may be examined in a test lasting only days. The test time and stress levels in this test are based on a desired three to five year deployed product lifetime, and published analyses of solder bond fatigue as a function of field exposure and accelerated stress. (See, for example, publications by N. Bosco, et al.[9])

b. The test procedure is based largely on IEC 61215-2 (MQT 11), with a few important differences:

(1) The number of thermal cycles is adjusted downward to match the desired product lifetime.

(2) Current is not applied during the test.

(3) Very large panels may be tested in a partially folded configuration.

c. Current is not applied during the test for two reasons. First, the procurement cycle is likely to be significantly (or indefinitely) delayed if the manufacturer is required to provide special modules that do not contain blocking diodes and thus allow the IEC-specified current to be applied. Second, the addition of current flow to the IEC thermal cycling test has shown not to result in more modules failing the test. (See, for example, G. TamizhMani et al.[10])

2.3.7.1 Thermal Cycling - Instrumentation and Equipment.

The following equipment is required for this test:

a. A climatic chamber with automatic temperature control capable of producing the thermal cycle in Figure 9 of IEC 61215-2, with means to circulate the air inside the chamber and minimize condensation on the module.

b. Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that for practical purposes, the module(s) are thermally isolated.

c. Measurement instrumentation having an accuracy of ± 2.0 °C (3.6 °F) and repeatability of ± 0.5 °C (0.0 °F) for measuring the temperature of the module(s).

2.3.7.2 Thermal Cycling - Required Test Conditions.

Samples shall undergo 22 cycles of the type described in Figure 9 of IEC 61215-2. The thermal cycle extends from -40 to 85 °C (-40 to 185 °F), with a cycle time between 3 and 6 hours. Twenty-two cycles at these temperatures are calculated, for solder bond fatigue, to be roughly the equivalent of a 3-year exposure in Tucson, Arizona (a stressful climate for thermal cycling).

2.3.7.3 Thermal Cycling - Test Procedures.

The test shall be performed as described in paragraph 4.11.3 of IEC 61215-2, with the following exceptions:

a. There shall be no current flow during the test. Disregard instructions related to current flow.

b. The number of cycles shall be 22.

c. It is preferable that flexible modules are mounted in the chamber fully deployed (i.e., unfolded). However, if fully unfolding the module is not possible due to space constraints in the chamber, the module should be unfolded as much as space allows, and the configuration documented in the chamber. Modules should not be packed tightly in the chamber. Air must be able to circulate between them.

2.3.7.4. Thermal Cycling - Procurement Document Requirements.

The procurement agency shall specify a minimum performance retention (e.g., 80 percent) for each module that undergoes a “mechanical and thermal stress” sequence (e.g., drop test + thermal cycling + humidity freeze).

2.3.7.5 Thermal Cycling - Data Required and Sample Data.

The test report shall contain, at a minimum, the following data:

a. If modules were subjected to test in any configuration other than fully unfolded, a photo and/or description of the mounting configuration shall be included.

b. Any deviation from the intended thermal cycle, or interruptions of the cycle, during the test shall be noted.

c. The panel shall be visually inspected after the test. Any change in physical appearance of the module shall be noted.

d. Pre- and post- module performance data.

2.3.8 Humidity Freeze.

a. The humidity freeze test helps determine the ability of the module to withstand freeze-thaw cycles. The test may also make apparent damage that has happened in previous mechanical stressing, if water penetrates the package and then expands. For example, a small backsheet crack may occur during the panel folding test. During the humidity-freeze test, as water freezes and thaws inside the crack, the crack may become substantially enlarged.

b. The test procedure is based largely on IEC 61215-2 (MQT 12), with a few important differences:

(1) Current is not applied during the test. The procurement cycle is likely to be significantly (or indefinitely) delayed if the manufacturer is required to provide special modules that do not contain blocking diodes and thus allow the IEC-specified current to be applied.

(2) Very large panels may be tested in a partially folded configuration.

2.3.8.1 Humidity Freeze - Instrumentation and Equipment.

Required equipment is described in IEC 61215-2, section 4.12.2.a through c. (Item d from 61215-2 section 4.12.2 is not needed, since current is not applied in this variation of the test.)

2.3.8.2 Humidity Freeze - Required Test Conditions.

Samples shall undergo 10 cycles of the type described in Figure 10 of IEC 61215-2. The thermal cycle extends from -40 to 85 °C (-40 to 185 °F), and a controlled 85-percent relative humidity while at the elevated temperature of 85 °C (185 °F), with a cycle time around 24 hours.

2.3.8.3 Humidity Freeze - Test Procedures.

The test shall be performed as described in IEC 61215-2, section 4.12.3, with the following exceptions:

a. There shall be no current flow during the test. Disregard instructions related to current flow, including attaching a power supply.

b. It is preferable that flexible modules are mounted in the chamber fully deployed (i.e., unfolded). However, if fully unfolding the module is not possible due to space constraints in the chamber, the module should be unfolded as much as space allows, and the configuration documented in the chamber. Modules should not be packed tightly in the chamber. Air must be able to circulate between them.

2.3.8.4 Humidity Freeze - Procurement Document Requirements.

The procurement agency shall specify a minimum performance retention (e.g., 80 percent) and maximum wet leakage current for each module that undergoes a “mechanical and thermal stress” sequence (e.g., drop test + thermal cycling + humidity freeze).

2.3.8.5 Humidity Freeze - Data Required and Sample Data.

The test report shall contain at a minimum the following data:

a. If modules were subjected to test in any configuration other than fully unfolded, a photo and/or description of the mounting configuration shall be included.

b. Any deviation from the intended thermal cycle, or interruptions of the cycle, during the test shall be noted.

c. The panel shall be visually inspected after the test. Any change in physical appearance of the module shall be noted.

d. Modules shall be evaluated for efficiency, wet leakage current later in the test flow, as a part of final inspection and characterization, but not as a part of this test.

2.4 Physical Stresses (To The Module Packaging When Deployed).

2.4.1 Salt Fog.

The salt fog test is performed to determine the effectiveness of protective coatings and finishes on materials. It may also be applied to determine the effects of salt deposits on the physical and electrical aspects of materiel.

2.4.1.1 Salt Fog - Instrumentation and Equipment.

No specific test instrumentation is required for salt fog testing other than that which is outlined in MIL-STD-810H (Test Method 509.7), or needed to characterize pre- and post-module performance with the corresponding sections of this TOP.

2.4.1.2 Salt Fog - Required Test Conditions.

Unless otherwise specified in the procurement document, salt fog testing should be performed following the procedures outlined in MIL-STD-810H, Test Method 509.7, paragraph 2.2.

2.4.1.3 Salt Fog - Test Procedures.

Follow the procedures outlined in MIL-STD-810H, Test Method 509.7, paragraph 4.5. Testing should be conducted in the operational configuration with all connections made, and surrogate connectors are to be used when necessary. Unless otherwise specified in the procurement document, the salt fog procedure is not tailorable and should be performed as described in MIL-STD-810H, Test Method 509.7.

2.4.1.4 Salt Fog - Procurement Document Requirements.

The following items must be specified in the individual procurement document for the module:

a. Any deviation in the temperature of the exposure zone for the test item.

b. Any deviation in the time duration for salt fog exposure of the test item.

c. Any deviation in the salt concentration.

d. Any deviation from test item configuration.

e. Maximum allowable degradation in performance allowed as a result of salt fog testing.

2.4.1.5 Salt Fog - Data Required and Sample Data.

The following data shall be collected:

a. Photographs of the pre- and post- salt fog inspections including damage (if applicable).

b. Test conditions data as required.

c. Pre- and post-salt fog operational checkout results.

2.4.2 Immersion.

The immersion test is performed to determine whether materiel can withstand full or partial immersion in water and operate following immersion.

2.4.2.1 Immersion - Instrumentation and Equipment.

Any water that penetrates into the materiel or packaging is not able to be collected during testing, so no specific test instrumentation is required for immersion testing other than that which is required for the test to be conducted, such as a chamber with graduated measurements and a thermometer.

2.4.2.2 Immersion - Required Test Conditions.

Unless otherwise specified in the procurement document, immersion testing should be performed in salt water following the procedures outlined in MIL-STD-810H, Test Method 512.6, Paragraph 2.3.

2.4.2.3 Immersion - Test Procedures.

Follow the procedures outlined in MIL-STD-810H, Test Method 512.6, paragraph 4.4, Procedure I (paragraph 4.4.2). Testing should be conducted in two conditions: with the test item packaged as it normally would be for transportation, and in transportation configuration but not in a transit or shipping case. Unless otherwise specified in the procurement document, the immersion procedure should be performed as described in MIL-STD-810H, Test Method 512.6, and the test item should be conditioned to a temperature 27 °C (49 °F) above the water temperature to represent exposure to solar heating immediately prior to immersion.

2.4.2.4 Immersion - Procurement Document Requirements.

The following items must be specified in the individual procurement document for the module:

a. Any deviation in the temperature of immersion water versus test item.

b. Any deviation in the time elapsed for immersion of test item.

c. Any deviation in the depth at which the test item is immersed in water.

d. Any deviation from immersion being conducted in salt water.

e. Maximum allowable degradation in performance allowed as a result of immersion testing.

2.4.2.5 Immersion - Data Required and Sample Data.

The following data shall be collected and presented:

a. Photographs of the pre- and post-immersion inspections including damage (if applicable).

b. Pre- and post-immersion operational checkouts.

2.4.3 Contamination By Fluids.

The contamination by fluids test is designed to determine how the module is affected by exposure to contaminating fluids that may be encountered during its life cycle.

2.4.3.1 Contamination by Fluids - Instrumentation and Equipment.

No specific test instrumentation is required for contamination by fluids testing other than that which is outlined in MIL-STD-810H (Test Method 504.3), or needed to characterize pre- and post- module performance with the corresponding sections of this TOP.

2.4.3.2 Contamination by Fluids - Required Test Conditions.

Unless otherwise specified in the procurement document, contamination by fluids testing shall be performed at standard ambient conditions as described in MIL-STD-810H, Part One, paragraph 5.1, and provided below:

a. Temperature: 25°C ± 10 °C (77 °F ± 18 °F).

b. Relative humidity: 20 to 80 percent.

c. Atmospheric pressure: site pressure.

2.4.3.3 Contamination by Fluids - Test Procedures.

Follow the procedures outlined in MIL-STD-810H, Test Method 504.3, paragraph 4.5.5 (Procedure I). Unless otherwise specified in the procurement document, total exposure time is 8 hours. If exposure to multiple fluids is required, use different sections of the module for each fluid. MIL-STD-810H, Test Method 504.3, Procedure I is tailorable. Exposure times, temperatures, fluids, and methods (sequential/simultaneous) can all be modified to best represent the expected module life cycle environment or to best assess expected module weaknesses.

2.4.3.4 Contamination by Fluids - Procurement Document Requirements.

The procurement document must specify contamination fluids. Contamination fluids may be selected from the list of fluids in MIL-STD-810H, Table 504.3-I, but contamination fluids need not be limited by those listed in that table. The procurement document may specify exposure time, fluid temperature, test item temperature, ambient temperature, sequential or simultaneous exposure, and cleaning methods known to not damage the module.

2.4.3.5 Contamination by Fluids - Data Required and Sample Data.

Any deterioration should be noted. Deterioration may include softening, color changes, cracking, or dissolving of material. Any deterioration incurred during testing should be documented with photographs.

2.4.4 Blowing Sand and Dust.

a. Dust (< 150 μm particle size) testing is performed to help determine the ability of materiel to resist the effects of dust that may obstruct openings, penetrate into cracks, crevices, joints, and to assess the effectiveness of filters (where applicable).

b. Sand (150 to 850 μm particle size) testing is performed to help assess the ability of materiel to be stored and operated in blowing sand conditions without degrading performance, effectiveness, reliability, and maintainability due to abrasion (erosion) or clogging effects of large, sharp-edged particles.

c. Unless otherwise specified in the procurement document, sand and dust testing should be conducted following the procedures outlined in MIL-STD-810H, Test Method 510.7, paragraph 2.3. If larger modules are to be tested, procedures shall be derived from TOP 01-2-621[11].

2.4.4.1 Blowing Sand and Dust - Instrumentation and Equipment.

No specific test instrumentation is required for sand and dust testing other than that which is outlined in MIL-STD-810H (Test Method 510.7), or needed to characterize pre- and post-module performance with the corresponding sections of this TOP.

2.4.4.2 Blowing Sand and Dust - Required Test Conditions.

Unless otherwise specified in the procurement document, sand and dust testing should be performed following the procedures outlined in MIL-STD-810H, Test Method 510.7, paragraph 2.3

2.4.4.3 Blowing Sand and Dust - Test Procedures.

Follow the procedures outlined in MIL-STD-810H, Test Method 510.7, paragraph 4.1 for dust testing and paragraph 4.2 for sand testing. Testing should be conducted in the operational configuration.

2.4.4.4 Blowing Sand and Dust - Procurement Document Requirements.

The following items must be specified in the individual procurement document for the module:

a. Any deviation in the exposure time for the test item.

b. Any deviation from test item configuration.

c. Any deviation in the dust concentration.

d. Any deviation in the sand concentration.

e. Maximum allowable degradation in performance allowed as a result of sand and dust testing.

2.4.4.5 Blowing Sand and Dust - Data Required and Sample Data.

The following data shall be collected and presented:

a. Photographs of the pre- and post- sand and dust inspections including damage (if applicable).

b. Test conditions data as required.

c. Pre- and post- sand and dust operational checkouts.

2.4.5 Fungus.

The fungus test is designed to determine the extent to which the module will support fungal growth and how that fungal growth may affect module performance during its life cycle. Key objectives are to determine whether the module will support fungal growth, how rapidly the fungus will grow on the module, how the fungus may affect the module either directly or indirectly, whether the module can be stored effectively in a field environment, and whether there is a simple method of cleaning the fungus from the module. Potential direct and indirect effects of fungal growth are outlined in MIL-STD-810H, Test Method 508.8, paragraph 2.1.1.

2.4.5.1 Fungus - Instrumentation and Equipment.

The instrumentation, facilities, and controls outlined in MIL-STD-810H (Test Method 508.8) are sufficient for this test. No modifications or adaptations are required.

2.4.5.2 Fungus - Required Test Conditions.

Unless otherwise specified in the procurement document, the required test conditions are outlined in MIL-STD-810H (Test Method 508.8).

2.4.5.3 Fungus - Test Procedures.

The procedures outlined in MIL-STD-810H (Test Method 508.8) shall be followed. This test should not be performed on a module that has previously undergone salt fog, sand and dust, or humidity testing. The post-test inspection should be performed immediately at the end of the incubation period. If the module must be removed from the chamber for the inspection and operation to be performed, they must be completed within 4 hours. If it takes longer than 4 hours to complete the inspection and operation, the module should be returned the chamber or a similar humid environment for a minimum of 2 hours before completing the inspection and operation. Additional information can be found in MIL-STD-810H, Test Method 508.8, paragraphs 4.5.3 and 4.5.4. The module shall be decontaminated in accordance with MIL-STD-810H, Test Method 508.8, Annex A, prior to other testing or return of the module to the procurement office.

2.4.5.4 Fungus - Procurement Document Requirements.

The minimum test duration is 28 days. Since indirect and interference effects are unlikely to occur in that relatively short time frame, the procurement office may want to consider extending the duration to 84 days if a greater amount of certainty in determining fungal growth effects is desired. Substitution of fungus species is not recommended. Additional species may be used. If additional species are used, their selection should be based on prior knowledge of specific material deterioration. Additional information can be found in MIL-STD-810H, Test Method 508.8, paragraph 2.2.2.

2.4.5.5 Fungus - Data Required and Sample Data.

Chamber temperature and humidity versus time should be recorded. Photographs and narrative descriptions of fungal growth should be captured. Any deterioration or damage to the module should be noted. Any deterioration incurred during testing should be documented with photographs. Any effects on performance should be documented on the module as it is received from the chamber and after removal of fungal growth.

2.5 Damp Heat.

2.5.1 Damp Heat Test.

a. The damp heat test is designed to determine the ability of the module to withstand the effects of long-term penetration of humidity. In published studies, humidity has been observed to cause delamination, increased transparent conductor resistance, increased electrically conductive adhesive resistance, or decreases in semiconductor minority carrier lifetime in some products. The test uses high levels of relative humidity and temperature to accelerate these processes; i.e., 1 hour in test is equivalent to more than 1 hour of field exposure. This acceleration allows one to learn about product behavior over time periods that are longer than the procurement cycle. The test is designed to promote the diffusion of water vapor through the pristine module package. It is not intended to investigate liquid water penetration into a damaged package.

b. This test is based on that included in IEC 61215-2 (MQT 13), which refers to procedures in IEC 60068-2-78[12]. Two differences distinguish this test from MQT 13: the test duration is shortened, and flexible modules may be stressed in a partially-folded configuration if necessary due to space constraints. The duration of the test should be equivalent to 3 years of exposure in Miami for the least moisture-stable $CuIn_xGa_{1-x}Se_2$ modules, based on published measurements and calculations[13].

2.5.1.1 Damp Heat - Instrumentation and Equipment.

Required equipment is described in IEC 60068-2-78, Section 4.1.

2.5.1.2 Damp Heat - Required Test Conditions.

The sample shall be exposed to conditions of 85-percent relative humidity (RH) and 85 °C (185 °F) for a period of 400 hr (~17 days).

2.5.1.3 Damp Heat - Test Procedures.

a. Test procedures are described in IEC 60068-2-78, Section 4.1, with the following modifications: the exposure time shall be for a period of 400 hr, with a tolerance of +19 hours, - 0 hours.

b. Modules shall not be packed tightly in the chamber. Air must be able to circulate between them. It is preferable that flexible modules are mounted in the chamber fully deployed (i.e., unfolded). However, if fully unfolding the module is not possible due to space constraints in the chamber, the module should be unfolded as much as space allows, and the configuration documented in the chamber.

2.5.1.4 Damp Heat - Procurement Document Requirements.

The procurement agency shall specify a minimum performance retention (e.g., 80 percent) for modules subjected to this stress. Performance (i.e., power output) after stress is measured during the "final inspection" portion of the test flow.

2.5.1.5 Damp Heat - Data Required and Sample Data.

a. If modules were tested in any configuration other than fully unfolded, a photo and/or description of the mounting configuration shall be included.

b. Any deviation from the intended test conditions, or interruptions of the exposure, during the test shall be noted.

c. The panel shall be visually inspected after the test. Any change in physical appearance of the module shall be noted.

d. Modules shall be assessed for efficiency and wet leakage current later in the test flow, as a part of final inspection and characterization, but not as a part of this test.

2.6 Final Inspection and Characterization.

2.6.1 Light Soak.

Testing shall be conducted in accordance with paragraph 2.1.1 of this TOP. The data will be compared with pretest light soak data.

2.6.2 Final Panel Efficiency.

Testing shall be conducted in accordance with paragraph 2.1.2 of this TOP. The data will be compared with pretest efficiency data to determine whether any performance was degraded as a result of testing.

2.6.3 Final Wet Leakage Current.

A final wet leakage current test shall be conducted on each PV module in accordance with paragraph 2.1.3 of this TOP. The data will be compared with pretest wet leakage current data and the provided minimum allowable insulation resistance.

3. DATA REQUIRED.

The data required during testing are specified in each subtest.

4. PRESENTATION OF DATA.

Examples of data presentation are provided in the various subtests and Appendix A.

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

Prior to measuring current-voltage (IV) curves to be used in the Photovoltaic Test Operations Procedure (PVTOP), the lab performing the IV test must document their proficiency in IV measurement best practices by performing the steps below. The resulting report is to be provided as supplemental information with every PVTOP test report in which that lab has performed IV measurements. The requirements for the report are detailed specifically in the last section, titled “Self-Documentation Checklist”.

As long as there is no change in the test lab’s IV procedure, the test lab may attach the same self-documentation to a PVTOP report over the course of executing many such tests and reports.

The self-documentation must be performed again if there is any change in the lab’s IV measurement procedure. Any hardware change other than connectors to the panel requires the self-documentation be performed again. Examples of hardware changes that would require the self-documentation to be performed again would be use of a different power supply, solar simulator, reference module, or meter. Procedural changes (such as changes in how one positions the module on the simulator, or changes to the values of the power supply settings in the software) also require the self-documentation to be performed again.

The sections below describe requirements for best practices to be satisfied for the total uncertainty in power output to be less than or equal to ±5 percent.

A.1. SAMPLE POSITIONING.

Written (either on paper or online) instructions for how to position the sample (or reference module) relative to the irradiance source must exist. These instructions must be detailed enough that anyone operating the IV tester would position a module with previously un-encountered dimensions in the same way. The instructions might specify, for example, where to put module edges or the center. For sample positioning to be completely reproducible, the instructions must also specify how to orient the longer versus shorter dimension, and toward which side the junction box should be positioned. For modules that are unfolded, the instructions must specify how to maintain a flat surface during measurement.

A.2. LIGHT SOURCE.

a. Uniformity.

(1) The uniformity of the light source shall be documented over the largest dimensions that will be used in PVTOP measurements. The test lab shall create an irradiance map to be included in the self-documentation, using a small reference cell. The reference cell used for the intensity map cell shall not measure more than 10 cm on a side, and irradiance measurements shall be evenly spaced and made at most in 10-cm steps. The largest area that will be used for module measurement shall be outlined on the irradiance map. This largest area is

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

called the "allowable test area" in the description below. An example of such an irradiance map is shown in Figure A-1.

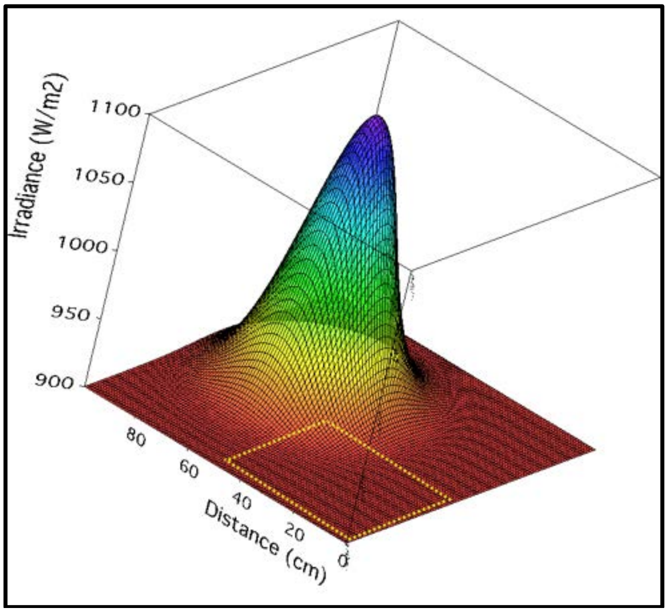


Figure A-1. Example irradiance map also showing largest allowable test area (dotted yellow lines).

(2) Several calculations shall be made using the irradiance map:

(a) G_{max} = largest irradiance in the allowable test area.

(b) G_{min} = smallest irradiance in the allowable test area.

(c) G_{ave} = average of all the irradiance measurements in the allowable test area.

(3) The exact relationship between spatial nonuniformity in irradiance and percent of uncertainty depends on the spatial distribution, the test module design, reference module design, and the calibration procedure. A rough estimate is given here based on simulations reported in the literature from: C. Monokroussos, D. Etienne, K. Morita, V. Fakhfouri, J. Bai, C. Dreier, U. Therhaag, W. Herrmann, "IMPACT OF CALIBRATION METHODOLOGY INTO THE POWER RATING OF C-SI PV MODULES UNDER INDUSTRIAL CONDITIONS" EUPVSEC 28, 2013, DOI: 10.4229/28th EUPVSEC 2013-4DO.1.1.

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

(4) If the written instructions set the light source intensity via calibration to the reference module short-circuit current, then the percent uncertainty due to spatial nonuniformity of irradiance is:

$$U_{spatial} = 100 \text{ x } (G_{max} - G_{min}) / (2 \text{ x } G_{ave}) \qquad \textit{(Equation A-1)}$$

(5) If the written instructions set the light source intensity via calibration to the reference module maximum power current, then the percent uncertainty due to spatial nonuniformity of irradiance is:

$$U_{spatial} = 100 \text{ x } (G_{max} - G_{min}) / (10 \text{ x } G_{ave}) \qquad \textit{(Equation A-2)}$$

(6) The literature referenced in paragraph A.2.a(3), and related studies, provide more information on how calibration to reference module I_{mp} rather than I_{sc} affects uncertainty.

(7) If IV measurements are performed outdoors, $U_{spatial} = 0$. However, outdoor measurement is not recommended, due to larger uncertainties from other factors. Those factors include temperature control, irradiance stability, and stability of measurement equipment exposed to ambient temperatures and sunlight.

b. Irradiance.

The light source shall be capable of maintaining an average irradiance between 800 and 1100 W/m^2. IV measurements shall only be conducted when irradiance is in this range. The irradiance for each measurement shall be recorded. If, during calibration, the irradiance is increased to match the reference module current, it may be recorded as 1000 W/m^2. If measurements are not taken at 1000 W/m^2, a method to correct the IV curve to the correct intensity will be performed and documented in the instructions.

c. Short-Term Stability.

(1) The test lab shall establish written start-up procedures for the light source that are supported with measurements. The minimum allowable time between turning on the light source and intensity calibration or measurement shall be clearly specified.

(2) The light source shall exhibit adequate stability over the course of a typical measurement period, after following the written start-up procedures. For self-documentation, the test lab shall measure the IV curve of a single module every five minutes over the course of one hour. All the short-circuit current values resulting from this measurement series (i.e., at least 13 values) shall be plotted as a function of elapsed time. If the test lab believes that a typical operation period to measure a set of products is longer than one hour, then the stability test

should be executed over that longer time period. The graph of short-circuit current versus time shall be included in the self-documentation report.

(3) Calculation of the uncertainty due to intensity stability shall be performed using the short-circuit current values from the graph. The following quantities shall be calculated or identified:

(a) $I_{sc,average}$ = average short-circuit current = sum of all values / number of values.

(b) I_{max} = largest short-circuit current value.

(c) I_{min} = smallest short-circuit current value.

(d) U_{int} = ± % uncertainty due to intensity stability = $100 \text{ x } (I_{max} - I_{min}) / (2 \text{ x } I_{sc,average})$.

(4) The description of light-source start-up applies to the simulator, rather than outdoor measurement. Measurement utilizing a simulator is recommended due to the additional challenges of outdoor measurement. These challenges are related to temperature control, finding times of sufficient irradiance, finding times when irradiance is stable over the course of one measurement (typically clear-sky days), and stability of measurement equipment exposed to ambient temperatures and sunlight. If outdoor measurement is performed, the criteria for choosing acceptable measurement days or times shall be documented in the operating instructions. The acceptable irradiance range for measurement is the same for indoor or outdoor measurements: 800 to 1100 W/m^2. The operating instructions shall also specify how real-time intensity monitoring is used to correct the raw outdoor IV curve to 1000 W/m^2. The one-hour stability graph described at the beginning of this section shall be generated with the outdoor data, following the written instructions, including the prescribed intensity correction. The percent uncertainty due to intensity stability shall then be calculated from the graph in the same way described above.

A.3. TEMPERATURE.

a. Temperature of modules shall be monitored and recorded during IV measurement. The operating instructions shall specify the location and means of temperature measurement. Use of thermocouples, rather than infrared sensing is recommended. Infrared temperature measurements are easily skewed by several degrees due to reflections from the light source. Standard test conditions are 25 °C (77 °F). The operating instructions shall specify the temperature window over which the operator is allowed to perform the measurement. If temperature correction is applied to IV measurements, the source of the temperature coefficients must be recorded.

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

b. The following information shall be identified for the self-documentation report and associated calculations:

(1) T_{min} = minimum temperature allowed for IV measurement.

(2) T_{max} = maximum temperature allowed for IV measurement.

(3) ‘T correction’ = “Yes” or “No” = Does written and automated procedure use temperature coefficients to correct the IV curve to 25 °C (77 °F)?

(4) $U_T = \pm$ % uncertainty due to temperature.

(5) If ‘T correction’ = “Yes”, then $U_T = \{(0.4)^2 + [(T_{max} - T_{min}) \text{ x } 0.4 \text{ x } 0.1 /2]^2\}^{0.5}$

(6) If ‘T correction’ = “No”, then $U_T = \{(0.4)^2 + [(T_{max} - T_{min}) \text{ x } 0.4 /2]^2\}^{0.5}$

c. The above calculation for U_T makes the conservative (i.e., resulting in a low U_T) assumptions of ± 1 °C offset between the measured and actual module temperature, power temperature coefficients of -0.4 percent per degree K, and typical uncertainty in temperature coefficients of approximately ± 10 percent relative. Information derived from:
C. Monokroussos et al., “Energy Rating of Commercial Mono- and Polycrystalline PV-modules in accordance with IEC 61853 -1,-2,-3 and Impact on the Annual Energy Yield”, 33rd EUPVSEC, 25th - 27th Sep. 2017, Amsterdam, Netherlands.

A.4. REFERENCE MODULE.

a. The test lab shall utilize a reference module to calibrate the light source intensity. Requirements exist on the reference module size, calibration history, and spectral response. A test lab may utilize more than one reference module. Each reference module shall meet these requirements.

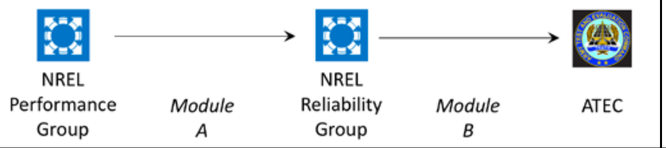
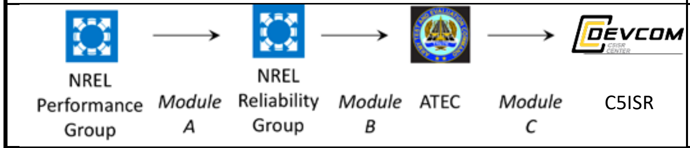
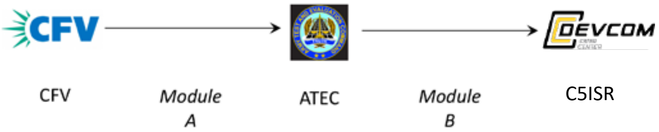
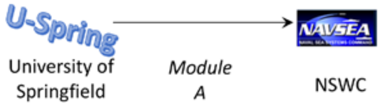
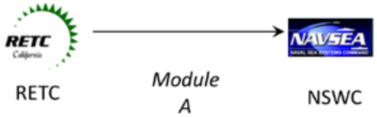
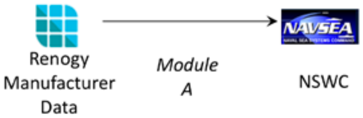
b. Ideally, the reference module size, cell arrangement, and cell technology matches that of the products to be tested. Reference modules shall have a total area of at least 0.5 m^2.

c. Each reference module shall have a documented calibration history. This history shall involve no more than one secondary calibration step beyond an accredited test laboratory. An accredited test laboratory may be one that is accredited to International Organization for Standardization (ISO) 17025[14] standards for calibration of modules, or one that is certified to perform IEC 61215-2. Examples of test labs in the United States that meet these criteria are the NREL Photovoltaic Cell and Module Performance group, UL, RETC, CFV, DNVGL, and Intertek. In a secondary calibration step, a non-accredited tester, but one who has performed self-documentation procedures, uses a module calibrated by an accredited lab to establish the

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

performance of a second module, which is then used as a reference module. It is important to use reference modules with no more than one secondary calibration step, since additional uncertainty is introduced with each such step. Manufacturer data are not acceptable in place of data from an accredited test lab. A substantial fraction of label or datasheet values are either not precise enough or not accurate enough to function as reference module data. Some examples of possible reference module calibration histories are shown in Table A-1. Some of the histories in Table A-1 produce a reference module that are acceptable to satisfy the self-documentation procedure, whereas others do not. It is noted in the middle column whether or not each example results in an acceptable reference module. The history of all reference modules that the tester may use for PVTOP IV measurements shall be detailed in the self-documentation.

TABLE A-1. EXAMPLES OF REFERENCE MODULE HISTORY

Reference Module History	Results in Acceptable Reference Module for Self-Documentation?	Comments
	Yes	
	No	Too many secondary calibrations – NREL Reliability Group is not accredited
	Yes*	*acceptable once ATEC has completed self-documentation
	No	University of Springfield is not accredited
	Yes	
	No	Manufacturer data is not an acceptable substitute for an accredited measurement
	Yes*	*acceptable once NRL has completed self-documentation

d. A lower limit of uncertainty due to reference module calibration is U_{refmod} = ±0.6 percent (derived from Daniela Dirnberger, Ulli Kraling, “Uncertainty in PV Module Measurement - Part I: Calibration of Crystalline and Thin-Film Modules,” IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 3, NO. 3, JULY 2013).

e. The spectral response of reference modules shall be adequately matched to the test device to keep error from spectral mismatch low. Such matching may be achieved by either using a reference module that has very similar spectral response to the test module, or by utilizing a “spectral mismatch factor,” which is particular to the tester’s light source, and accounts for how different technologies yield different currents for that light source.

f. Information on how to calculate and use a spectral mismatch factor can be found on-line (for example, https://www.nrel.gov/pv/text-spectral-mismatch-corrections.html , https://www2.pvlighthouse.com.au/calculators/spectral%20mismatch%20calculator/spectral%20mismatch%20calculator.aspx , and http://assets.newport.com/webDocuments-EN/images/Spectral_Mismatch-App_Note_51.PDF) and in the literature. Note that the spectral mismatch factor is particular to the tester’s light source. Thus, a tester cannot simply use the spectral mismatch factor that an accredited lab has provided, which is specific to the light source at the accredited lab. Calculation and utilization of a spectral mismatch factor will require the spectral responses (quantum efficiencies) of the test and the reference modules, as well as the simulator spectrum. Quantum efficiencies may be measured by the test lab, provided by the manufacturer, or taken from the literature if information from cells of the same materials and structure is available.

g. If the test lab will utilize spectral mismatch correction, the details of this correction shall be documented. The self-documentation shall contain a graph of the light source intensity and the reference module(s) spectral response(s). The written operator instructions shall describe when and how to apply the spectral mismatch correction.

h. The calculation of the tester’s IV measurement uncertainty shall include a component due to spectral mismatch. A lower limit for uncertainty due to spectral mismatch, $U_{spectral}$, is 0.4 percent. Spectral mismatch may be much larger if a reference module with cells of a different band gap than those of the test module is utilized to set the light source intensity. Thus, to maintain a total uncertainty <5 percent, either reference and test modules must be composed of cells of similar band gaps, or a spectral mismatch calculation must be performed. These requirements are summarized in Table A-2.

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

TABLE A-2. REQUIREMENTS FOR KEEPING SPECTRAL MISMATCH ERROR WITHIN ACCEPTABLE LEVELS

Test Module Cell Technology	Reference Module Cell Technology	Spectral Mismatch Correction Required?
Multi x-Si, mono x-Si, or CIGS	Multi x-Si, mono x-Si, or CIGS	No
CdTe	CdTe or GaAs	No
CdTe	Multi x-Si, or mono x-Si	Yes
Single-junction a-Si	Single Junction a-Si	No
Single-junction a-Si	Multi x-Si, or mono x-Si	Yes
GaAs	CdTe or GaAs	No
GaAs	Multi x-Si, or mono x-Si	Yes
Multi-junction devices	Require different measurement procedures. Not covered in this document.	

i. Adhering to the requirements of Table A-2 may imply that a test lab has completed the self-documentation for some, but not all, cell technologies. For example, suppose a test lab uses one Si reference module but has no knowledge of their light source spectrum (which would be required to perform a spectral mismatch correction). Then, as described in Table A-2, the test lab is equipped to measure x-Si or CIGS modules, but not CdTe, a-Si, or GaAs.

A.5. CURRENT-VOLTAGE SWEEP.

The electronics used to perform the current-voltage sweep shall be capable of measuring from zero voltage (i.e., short-circuit current) to open-circuit voltage (i.e., zero current). The procedure shall yield a single IV curve and single values for the parameters V_{oc}, I_{sc}, V_{mp}, I_{mp}, P_{mp}, and ff. Obtaining the IV curve and parameters shall not require any subjective judgment from the operator or any other personnel, such as choosing a “best” value out of a family of curves. The IV curve shall be free from major artifacts: In tracing from low voltage to high voltage, the current must decrease monotonically. There must not be portions of the IV curve where current increases with voltage. Such glitches may result from the electronics or the light source, but are not characteristics of a solar panel without integrated electronics. All steps necessary for obtaining the IV sweep shall be documented in the instructions.

A.6. LONG-TERM REPEATABILITY CHECK.

a. For self-documentation, the test lab shall perform an assessment of long-term repeatability. This assessment shall require at least five weeks. The test lab shall make six measurements of the same test module, with at least one week elapsing between each measurement. The measurements shall be made following the written instructions for obtaining an STC IV curve. Between measurements, the test module shall be completely removed from the measurement setup. No attempt shall be made to prevent typical laboratory operations in the vicinity of the measurement setup during the repeatability assessment. Such typical operations may include work near the measurement setup or work using the same measurement set up. For each of the six measurements, the IV measurement will be performed according to written instructions without any variations to reproduce a previous result.

b. The power output from each of the six measurements shall be tabulated in the self-documentation. The largest and smallest power measurement from this data set shall differ by no more than 5 percent (i.e., $(P_{\text{largest}} – P_{\text{smallest}})/ P_{\text{largest}} \leq 0.05$.

c. If long-term repeatability does not meet the above requirement, the test lab will not meet the ± 5 percent total uncertainty requirement, even if state-of-the-art values are achieved for all components of uncertainty specified in this document.

A.7. REPRODUCIBILITY CHECKS.

It is recommended, though not required in the self-documentation, that test labs also trade modules on a yearly basis to check for agreement in power output measurements. In those experiments, the PVTOP IV procedure should be performed, including ascertaining whether stabilization is needed for a given product. An individual lab testing against a manufacturer label or datasheet value is not considered sufficient, as many cases have been observed where the module power output is more than 5 percent different than the nameplate value, or a very wide range for power output is stated on the nameplate.

A.8. MINIMIZING OPERATOR ERROR.

In order to minimize the likelihood of operator error, two requirements must be met. First, all procedures must be documented (as described in previous sections), and this documentation must be gathered in one place. Second, all operations that can reasonably be automated should be accomplished by software. Such operations are likely to include, at a minimum, changing power supply settings and operating the power supply, adjusting the simulator intensity to match the reference module output, recording temperatures, and correcting IV curves for temperature or intensities not at standard conditions.

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

A.9. LIGHT SOAKING.

The test lab will have the ability to perform light soaking, as described in the PVTOP procedure, for stabilization prior to the IV curve.

A.10. CALCULATING TOTAL UNCERTAINITY.

a. The total measurement uncertainty, U_{total}, will be estimated using the various components of uncertainty obtained in the previous section using the following formula:

$$U_{total} = [(U_{int})^2 + (U_{spatial})^2 + (U_T)^2 + (U_{refmod})^2 + (U_{spectral})^2]^{0.5} \qquad \textit{(Equation A-3)}$$

$$= [(U_{int})^2 + (U_{spatial})^2 + (U_T)^2 + (0.6)^2 + (0.4)^2]^{0.5}$$

$$= [(U_{int})^2 + (U_{spatial})^2 + (U_T)^2 + 0.52]^{0.5}$$

b. To perform IV measurements for the PVTOP, the lab must achieve $U_{total} < 5$ (i.e., total measurement uncertainty is < ± 5 percent).

c. It is expected that initial attempts to complete the self-documentation will result in $U_{total} > 5$. In this case the test lab must take steps to reduce the individual components of uncertainty. Such steps may include narrowing the temperature range over which measurements are allowed, using only the most uniform part of the simulator (i.e., reducing the allowable test area and adjusting sample position procedures accordingly), using averaging at each voltage for flickering simulators, or refining procedures for better for long-term repeatability. The data in the self-documentation report should reflect the final choices and procedures that meet the uncertainty requirements.

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

SELF-DOCUMENTATION CHECKLIST AND ATTACHMENTS TO BE PROVIDED WITH EACH PVTOP REPORT

TO BE COMPLETED BY THE LABORATORY PERFORMING IV TESTS

Please evaluate the following by the requirements detailed in the preceding sections.

1. Do complete written instructions for reproducible sample positioning exist?	☐ YES ☐ NO
2.a.i. Graph of irradiance versus position is attached, including largest allowable test area.	________
2.a.ii. Dimensions of largest allowable test area, including units.	________
2.a.iii. Calculated value of $U_{spatial}$.	________
2.b.i. Are IV measurements performed only at 1000 W/m^2?	☐ YES ☐ NO
2.b.ii. If not, is the procedure for correcting to 1000W/m^2 included in the written instructions?	☐ YES ☐ NO ☐ NA
2.c.i. If using a simulator, do written instructions for light source start-up exist?	☐ YES ☐ NO ☐ NA
2.c.ii. Calculated value of U_{int}	________
2.c.iii. If measuring outdoors, are there written instructions detailing the criteria for choosing acceptable measurement times, and how real-time intensity monitoring is used to correct the raw outdoor IV curve to 1000 W/m^2?	☐ YES ☐ NO ☐ NA
3. Calculated value of U_T	________
4.a. List of calibrated reference modules, meeting criteria in section 4, is attached.	☐ YES ☐ NO
4.b. Does the lab have the capability to perform spectral mismatch corrections, including knowledge of the simulator spectrum?	☐ YES ☐ NO
4.c. If the lab will be performing spectral mismatch corrections, attach a graph of the simulator spectrum.	☐ YES ☐ NO ☐ NA
4.d. Based on the answers to 4a-4c, what cell technologies are this lab qualified to measure?	________
5. Do the electronics meet the criteria described in section 5?	☐ YES ☐ NO

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

SELF-DOCUMENTATION CHECKLIST AND ATTACHMENTS TO BE PROVIDED WITH EACH PVTOP REPORT

TO BE COMPLETED BY THE LABORATORY PERFORMING IV TESTS

6.a. Is a list of the data from the long-term reproducibility check attached?	☐ YES	☐ NO
6.b. Is the long-term reproducibility criterion in section 6 met?	☐ YES	☐ NO
8.a. Are all steps of the IV measurement documented, in one location?	☐ YES	☐ NO
8.b. Are all steps automated where this can be reasonably achieved?	☐ YES	☐ NO
9. Does the lab have light soaking capability?	☐ YES	☐ NO
10.a. Calculated value of U_{total}	______________	
10.b Is $U_{total} < 5$?	☐ YES	☐ NO

____
Test lab representative name (printed)

______________________________ ______________
Signature Date

______________________________ ______________
Test lab representative phone number E-mail address

Attach the following:

- Graph of irradiance versus position, including location of largest allowable test area.
- List of qualifying reference modules by cell type, identifier (e.g. serial number), location of primary calibration, and location of secondary calibration (if applicable).
- Tabulated data from the long-term reproducibility check.

Test lab: Each time you complete the self-documentation process, please mail or e-mail a copy of this checklist, with the required attachments, to the following addresses:

APPENDIX A. TEST LAB SELF-DOCUMENTATION FOR CURRENT-VOLTAGE MEASUREMENT.

SELF-DOCUMENTATION CHECKLIST AND ATTACHMENTS TO BE PROVIDED WITH EACH PVTOP REPORT

TO BE COMPLETED BY THE LABORATORY PERFORMING IV TESTS

John Wills
U.S. Army Aberdeen Test Center
358 Michaelsville Road
APG, MD 21005-5059
john.p.wills.civ@mail.mil

and

David Scheiman
Optoelectronics & Radiation Effects Branch, Code 6818;
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The checklist and attachments were sent to the above recipients by

e-mail / mail (circle one), on ________________________________ (date).

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APPENDIX B. ABBREVIATIONS.

AM	Air Mass
ASTM	American Society for Testing and Materials
ATEC	U.S. Army Test and Evaluation Command
°C	degrees Celsius
C5ISR	U.S Army Combat Capabilities Development Command, Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance and Reconnaissance Center
CIGS	copper indium/gallium di-selenide
cm	centimeter
°F	degrees Fahrenheit
ff	fill factor
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
I_{mp}	current at maximum power
IR	infrared
I_{sc}	short-circuit voltage
ISO	International Organization for Standardization
IV	current-voltage
km	kilometer
kW-hr/m^2	kilowatt - hour per meter squared
lb	pound
m	meter
mA	milliamp
m/s	meters per second
MIL-STD	Military Standard
mm	millimeter
MPPT	Maximum Power Point Tracker
MQT	Module Quality Test
N	Newton
nm	nanometer
NMOT	Normal Module Operating Temperature
P_{mp}	parameters maximum power
PV	photovoltaic
PVSC	Photovoltaic Specialists Conference
PVTOP	Photovoltaic Test Operations Procedure

APPENDIX B. ABBREVIATIONS.

RH	Relative Humidity
SDP	Self-Documentation Procedure
STC	Standard Test Conditions
TOP	Test Operations Procedure
UV	ultraviolet
VDC	Volts Direct Current
V_{mp}	voltage at maximum power
V_{oc}	open-circuit voltage
W/m^2	watts per meter squared

APPENDIX C. REFERENCES.

1. IEC 61215, Terrestrial Photovoltaic (PV) Modules - Design Qualification and Type Approval, 9 March 2016.

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8. ASTM E1038-10, Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls, 2015.

9. Bosco, Nick; Silverman, Timothy J.; Kurtz, Sarach, “Climate specific thermomechanical fatigue of flat plate photovoltaic module solder joints,” Microelectronics Reliability 62, (2016), 124-129.

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11. TOP 01-2-621, Outdoor Sand and Dust Testing, 6 February 2009.

12. IEC 60068-2-78, Basic Environmental Testing Procedures - Part 2-78: Tests - Test Cab: Damp Heat, Steady State, 30 October 2012.

APPENDIX C. REFERENCES.

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14. ISO 17025, General Requirements for the Competence of Testing and Calibration Laboratories, 2017.

APPENDIX D. APPROVAL AUTHORITY.

CSTE-CI 23 January 2020

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure 09-2-291 Environmental and Performance Testing of Photovoltaic Systems, Approved for Publication

1. Test Operations Procedure (TOP) 09-2-291 Environmental and Performance Testing of Photovoltaic Systems, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP describes procedures for conducting environmental and performance tests for photovoltaic systems used in fixed and dismounted operations. These tests involve characterizing performance under various solar incidence conditions as well as under unique environmental abuse conditions.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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MICHAEL J. ZWIEBEL
Director, Directorate for Capabilities
Integration (DCI)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-CI-P), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Support Equipment Division (TEAT-WFE), U.S. Army Aberdeen Test Center, Aberdeen Proving Ground, Maryland 21005-5059. Additional copies can be requested through the following website: https://www.atec.army.mil/publications/documents.html, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.