UL 1703

STANDARD FOR SAFETY

Flat-Plate Photovoltaic Modules and Panels

UL Standard for Safety for Flat-Plate Photovoltaic Modules and Panels, UL 1703

Third Edition, Dated March 15, 2002

SUMMARY OF TOPICS

The revision of UL 1703 dated May 15, 2024 is being issued to remove the ANSI logo and approval from the title page. No other changes have been made.

NOTE – The Standard for Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements for Construction, UL 61730-1, and the Standard for Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements for Testing, UL 61730-2, are currently published as the ANSI-approved standards covering PV Modules.

Text that has been changed in any manner or impacted by ULSE's electronic publishing system is marked with a vertical line in the margin.

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UL 1703

Standard for Flat-Plate Photovoltaic Modules and Panels

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This UL Standard for Safety consists of the Third Edition including revisions through May 15, 2024.

Comments or proposals for revisions on any part of the Standard may be submitted to ULSE at any time. Proposals should be submitted via a Proposal Request in the Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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INTRODUCTION

1 Scope

1.1 These requirements cover flat-plate photovoltaic modules and panels intended for installation on or integral with buildings, or to be freestanding (that is, not attached to buildings), in accordance with the National Electrical Code, NFPA 70, and Model Building Codes.

1.2 These requirements cover modules and panels intended for use in systems with a maximum system voltage of 1500 V or less.

1.3 These requirements also cover components intended to provide electrical connection to and mounting facilities for flat-plate photovoltaic modules and panels.

1.4 These requirements do not cover:

a) Equipment intended to accept the electrical output from the array, such as power conditioning units (inverters) and batteries;

b) Any tracking mechanism;

c) Cell assemblies intended to operate under concentrated sunlight;

d) Optical concentrators; or

e) Combination photovoltaic-thermal modules or panels.

1.5 *Deleted*

2 Glossary

2.1 For the purpose of this standard, the following definitions apply.

2.2 AIR MASS (AM) – A dimensionless quantity, the ratio of:

a) The actual path length of radiation through the atmosphere to

b) The vertical path length of radiation through the atmosphere to sea level. At sea level, for all but very high zenith angles (θ_z) (the angle subtended by the zenith and the line of sight to the sun),

$$AM = \sec \theta_z$$

2.3 ARRAY – A mechanically-integrated assembly of modules or panels with a support structure and foundation, tracking, thermal control, and other components, if used, to form a dc power-producing unit.

2.3.1 BIFACIAL PV MODULE – A PV module that is constructed to allow illumination from the super and substrate to be transmitted to the PV cells that are capable of generating power from both front and back surfaces.

2.3.2 BIFACIALITY COEFFICIENT – The ratios between the main electrical characteristics of the rear side and the front side of a bifacial PV module, at Standard Test Conditions (STC) unless otherwise specified for short circuit current, open circuit voltage and maximum power point.

2.4 BLOCKING DIODE – A diode used to block reverse current into a photovoltaic-source circuit.

2.5 BYPASS DIODE – A diode connected across one or more cells, modules, or panels in the forward current direction to allow current to bypass such cells, modules, or panels.

2.6 CELL – The basic photovoltaic device that generates electricity when exposed to sunlight.

2.7 ELECTRIC SHOCK – A risk of electric shock is considered to exist at a part if the potential between the part and earth ground or any other accessible part is more than 30 Vdc and the leakage current exceeds the values specified in Table 21.1.

2.8 ENCAPSULANT – Transparent insulating material enclosing the cells and cell interconnects.

2.8.1 INHERENTLY LIMITED – Refers to a type of Class 2 Power Source which does not require a separate means to automatically reduce the output levels or de-energize the output circuit as a means of remaining within Class 2 Power Source limits.

2.9 INTERCONNECT – A conductor within a module that provides a mechanism for conducting electricity between cells.

2.10 MAXIMUM POWER (P_{max}) – The point on the current-versus-voltage curve of a module, at STC, where the product of current and voltage is maximum.

2.11 MAXIMUM SYSTEM VOLTAGE – The sum of the maximum open-circuit voltages of the maximum number of modules or panels to be connected in series in a system.

2.12 METALLIZATION – An electrically conductive metal coating on the surface of a cell.

2.13 MODULE (FLAT-PLATE) – The smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts, such as interconnects and terminals, intended to generate dc power under unconcentrated sunlight. The structural (load-carrying) member of a module can either be the top layer (superstrate), or the back layer (substrate), in which:

a) The superstrate is the transparent material forming the top (light-facing) outer surface of the module. If load-carrying, this constitutes a structural superstrate.

b) The substrate is the material forming the back outer surface of a module. If load-carrying, this constitutes a structural substrate.

2.14 NOMINAL OPERATING CELL TEMPERATURE (NOCT) – The equilibrium cell junction temperature corresponding to nominal module service operating conditions in a reference environment of 80 mW/cm^2 irradiance, 20°C (68°F) ambient air temperature, 1 m/s wind across the module from side to side, an electrically open circuit, and a mounting method in accordance with 19.6 and 19.7.

2.15 PANEL (FLAT-PLATE) – A collection of modules mechanically fastened together, wired, and designed to provide a field-installable unit.

2.16 RATED OPERATING VOLTAGE – The voltage, ±10 percent, at which maximum power is available from the module or panel under STC.

2.16.1 REVERSE CURRENT – Current flowing in a reverse direction to the normal direction resulting from a normally illuminated PV module.

2.17 STANDARD TEST CONDITIONS (STC) – Test conditions consisting of:

a) 100 mW/cm^2 irradiance,

b) AM 1.5 spectrum, and

c) 25°C cell temperature.

2.18 UNCONDITIONED MODULES OR SPECIMENS – Modules or specimens that have not been previously subjected to tests or environmental exposures.

3 Units of Measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

4 Components

4.1 Except as indicated in 4.2, a component of a product covered by this standard shall comply with the requirements for that component. See Appendix A for a list of standards covering components generally used in the products covered by this standard.

4.2 A component need not comply with a specific requirement that:

a) Involves a feature or characteristic not needed in the application of the component covered by this standard, or

b) Is superseded by a requirement in this standard.

4.3 A component shall be used in accordance with its rating established for the intended conditions of use.

4.4 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

5 References

5.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

CONSTRUCTION

6 General

6.1 A module shall be completely assembled when shipped from the factory. A panel may be completely assembled when shipped from the factory, or may be provided in subassemblies, provided assembly of the panel does not involve any action that is likely to affect compliance with the requirements of this standard.

Exception: An assembly part need not be affixed to the module at the factory.

6.2 A module or panel assembly bolt, screw, or other part shall not be intended for securing the complete device to the supporting surface or frame.

6.3 Incorporation of a module or panel into the final assembly shall not require any alteration of the module or panel unless specific details describing necessary modification(s) for alternate installation(s) are provided in the installation instructions. If a module or panel must bear a definite relationship to another for the intended installation and operation of the array (for example, to allow connectors to mate), it shall be constructed to permit it to be incorporated into the array in the correct relationship without the need for alteration.

6.4 The construction of a product shall be such that during installation it will not be necessary to alter or remove any cover, baffle, insulation, or shield that is required to reduce the likelihood of:

a) Excessive temperatures, or

b) Unintentional contact with a part that may involve a risk of electric shock.

Exception: A cover of a wiring compartment providing access to a connection means that may involve a risk of electric shock may be removable to allow for the making of electrical connections.

6.5 Parts shall be prevented from loosening or turning if such loosening or turning may result in a risk of fire, electric shock, or injury to persons.

6.6 Friction between surfaces is not acceptable as the sole means to inhibit the turning or loosening of a part, but a lock washer properly applied is acceptable for this purpose.

6.7 An adjustable or movable structural part shall be provided with a locking device to reduce the likelihood of unintentional shifting, if any such shifting may result in a risk of fire, electric shock, or injury to persons.

6.8 Metals used in locations that may be wet or moist shall not be employed in combinations that could result in deterioration of either metal such that the product would not comply with the requirements in this standard.

6.9 Edges, projections, and corners of photovoltaic modules and panels shall be such as to reduce the risk of injury to persons.

6.10 Whenever a referee measurement is necessary to determine that a part as mentioned in 6.9 is not sufficiently sharp to constitute a risk of injury to persons, the method described in the requirements in the Standard for Tests for Sharpness of Edges on Equipment, UL 1439, is to be employed.

7 Polymeric Materials

7.1 A polymeric material system serving as the enclosure of a part involving a risk of fire or electric shock shall comply with the applicable requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, concerning:

a) Flammability,

b) Ultraviolet light exposure,

c) Water exposure and immersion, and

d) Hot-wire ignition (HWI).

Exception: The flammability tests prescribed in UL 746C do not apply to the superstrate, encapsulation, and substrate. These materials shall comply with 7.4.

7.2 A polymeric material that is in contact with or in close proximity, less than 0.8 mm (1/32 in), to uninsulated live parts shall:

a) Have a flammability classification of HB, V-2, V-1, or V-0 determined in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94;

b) Have a minimum High-Current Arc Ignition performance level category (PLC) in accordance with the following:

Flammability classification	High-current arc ignition, PLC
HB	1
V-2	2
V-1	2
V-0	3

c) Have a Comparative Tracking Index performance level category (PLC) as determined in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, and as defined in Table 7.1, when the system voltage rating is 600 V or less;

Exception No. 1: The CTI rating is not required when both the material and live part are completely encapsulated by potting material such that there is no surface upon which tracking may occur, and the potting material has been evaluated according to UL 746C, Table 6.1, for Electric Strength, Resistance to Electrical Ignition Sources (HAI and HWI), and Thermal Endurance.

Exception No. 2: The CTI rating is not required when both the material and live part are completely coated by a conformal coating that has been evaluated to the requirements of the Standard for Polymeric Materials - Industrial Laminates, Filament Wound Tubing, Vulcanized Fibre, and Materials Used in Printed Wiring Boards, UL 746E, Section 22, at the rated thickness such that there is no surface upon which tracking may occur.

Exception No. 3: Single component silicone rubber based room temperature vulcanizing (RTV) materials when applied in accordance with Exception No. 2 is considered a suitable conformal coating without further evaluation.

d) Have an Inclined Plane Tracking (ASTM D2303) rating of 1 h using the time to track method at the higher of system voltage or 1000 V when the system voltage is in the range of 601 – 1500 V, as specified in Table 7.1; and

Exception No. 1: The 1 hr rating is not required when both the material and live part are completely encapsulated by a potting material such there is no surface upon which tracking may occur, and the potting material has been evaluated according to UL 746C, Table 6.1, for Electric Strength, Resistance to Electrical Ignition Sources (HAI and HWI), and Thermal Endurance.

Exception No. 2: The 1 hr rating is not required when both the material and live part are completely coated by a conformal coating that has been evaluated to the requirements of UL 746C, Section 43A, at the rated thickness such that there is no surface upon which tracking may occur.

Exception No. 3: Single component silicone rubber based room temperature vulcanizing (RTV) materials when applied in accordance with Exception No. 2 is considered a suitable conformal coating without further evaluation.

e) Comply with the requirements for exposure to ultraviolet light as determined in accordance with the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, when exposed to light during normal operation of the product. Polymeric materials that are exposed to sunlight and are protected by glass, or other transparent medium, shall be tested with an equivalent layer of that medium attenuating the ultraviolet light exposure during the test.

Exception: Encapsulant materials between the substrate and the superstrate are not required to comply with the requirements of 7.2.

Table 7.1
Determination of comparative tracking index performance level category (PLC)

Voltage	Creepage distance	IPT 1 hr rating required	CTI PLC of 2 or better required
0 – 30	Any	No	No
> 30 – 600	< 12.7 mm	No	Yes
> 30 – 600	≥ 12.7 mm	No	No
> 600 – 1000	< 16.0 mm	Yes	No
> 600 – 1000	≥ 16.0 mm	No	No
1001 – 1500	< 24.0 mm	Yes	No
1001 – 1500	≥ 24.0 mm	No	No

Note – Voltage is determined as follows:

Between live parts: the maximum potential difference during normal use

Between live parts and dead metal parts that may be grounded in service: maximum system voltage

Between live parts and any surface exposed to contact: maximum system voltage

7.3 A polymeric substrate or superstrate shall have a thermal index (TI/RTE/RTI), both electrical and mechanical, as determined in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, or Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results, IEC 60216-1, not less than 90°C (194°F). In addition, the thermal index (TI/RTE/RTI) shall not be less than 20°C (36°F) above the measured operating temperature of the material. All other polymeric materials shall have a thermal index (TI/RTE/RTI) (electrical and mechanical) 20°C above the measured operating temperature. The measured operating temperature is the temperature measured during the open-circuit mode for Temperature Test, Section 19, or the temperature during the short-circuit mode, whichever is greater.

7.4 A polymeric material that serves as the outer enclosure for a module or panel that:

a) is intended to be installed in a multi-module or multi-panel system; or

b) has an exposed surface area greater than 10 ft^2 (0.93 m^2) or a single dimension larger than 6 ft (1.83 m)

shall have a flame spread index of 100 or less as determined under the Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source, ASTM E162-2001.

Exception No. 1: A material that serves as the outer enclosure for a small cover or box used for electrical connections is not required to have an index of 100 or less.

Exception No. 2: A material that serves as the outer enclosure for a module or panel complying with 16.1 meets the intent of this requirement.

7.5 A barrier or liner of polymeric insulating material providing the sole insulation between a live part and an accessible metal part or between uninsulated live parts not of the same potential shall be of adequate thickness and of a material appropriate for the application. The barrier or liner shall be held in place and shall not be adversely affected to the extent that its necessary properties may fall below the minimum acceptable values for the application.

8 Current-Carrying Parts and Internal Wiring

8.1 A current-carrying part and wiring shall have the mechanical strength and ampacity necessary for the service.

8.2 A current-carrying part shall be of silver, a copper-base alloy, stainless steel, aluminum, or other material appropriate for the application.

8.3 Wiring used in a module or panel shall be insulated and acceptable for the purpose, when considered with respect to temperature, voltage, and the conditions of service to which the wiring is likely to be subjected within the equipment.

8.4 A splice shall be provided with insulation equivalent to that required for the wires involved.

8.5 A joint or connection shall be mechanically secure and shall provide electrical contact without strain on connections and terminals. Soldered connections between interconnects and metallizations are considered mechanically secure when held by encapsulation systems.

8.6 An uninsulated live part, including a terminal, shall be secured to its supporting surface by a method other than friction between surfaces so that it will be prevented from turning or shifting in position if such motion may result in reduction of spacings to less than required in Table 12.1 and Table 12.2.

8.7 Strain relief shall be provided so that stress on a lead intended for field connection, or otherwise likely to be handled in the field, including a flexible cord, is not transmitted to the connection inside the module or panel.

8.8 The wiring of a module or panel shall be located so that after installation of the product in the intended manner it will not be exposed to the degrading effects of direct sunlight.

Exception: Wiring rated sunlight resistant need not be so located.

9 Wireways

9.1 An enclosure for wire shall be smooth and free from sharp edges, burrs, or the like that may damage insulation or conductors.

10 Connection Means

10.1 In 10.2 – 10.10, connection means are considered to be those to which field-installed wiring is connected when the product is installed. Connection means may be within a wiring compartment, may be connectors outside of a wiring compartment, or may be another means acceptable for the application.

10.2 A module or panel shall be capable of accommodating at least one of the acceptable wiring systems described in the National Electrical Code, NFPA 70.

10.3 A module or panel shall be provided with wiring terminals, connectors, or leads to accommodate current-carrying conductors of the load circuit.

10.4 The connection means for a module or panel shall be so located that after installation of the product in the intended manner they will not be exposed to the degrading effects of direct sunlight.

Exception: Connection means rated for use in direct sunlight need not be so located.

10.5 A lead that is intended to be spliced in the field to a circuit conductor shall not be smaller than 18 AWG (0.82 mm^2) and the insulation shall not be less than 1/32 in (0.8 mm) thick.

10.6 The free length of a lead for field connection shall be at least 6 in (152 mm).

10.7 A wire-binding screw or stud- and nut-type terminal used to terminate conductors not larger than 10 AWG (5.3 mm^2) shall comply with the following:

a) A threaded screw or stud shall be of nonferrous metal, stainless steel, or plated steel appropriate for the application, shall not have more than 32 threads/in, and shall not be smaller than No. 8 when used to terminate 10 or 12 AWG (5.3 or 3.3 mm^2) wire; and not smaller than No. 6 when used to terminate 14 AWG (2.1 mm^2) and smaller wire. A wire-binding screw or stud- and nut-type terminal shall be provided with upturned lugs, a cupped washer, a barrier, or other equivalent means to retain the wire in position. The head of a wire-binding screw used to terminate 12 AWG or smaller wire shall have a minimum diameter of 0.275 in (7.0 mm) and the head of a screw used to terminate 10 AWG wire shall have a minimum diameter of 0.327 in (8.3 mm).

b) A tapped terminal plate shall:

1) Be of nonferrous metal,

2) Not have less than two full screw threads, and

3) Be of metal not less than 0.050 in (1.27 mm) thick when used to terminate 10 or 12 AWG wire and not less than 0.030 in (0.76 mm) thick when used to terminate a 14 AWG or smaller wire. Unextruded metal for screw threads obtained by extruding a hole shall have a thickness not less than the pitch of the screw thread.

10.8 A connector intended for use on the output wiring of a module or panel shall comply with the Standard for Connectors for use in Photovoltaic Systems, UL 6703.

10.9 A separable multipole connector shall be polarized. If two or more separable connectors are provided, they shall be configured or arranged so that the mating connector for one will not be accepted by the other, and vice-versa, if such is an improper connection.

10.10 For a connector incorporating a grounding member, the grounding member shall be the first to make and the last to break contact with the mating connector.

11 Bonding and Grounding

11.1A **Grounding Terminology.** The term “grounding” encompasses two types of connection to Earth. One connection is a functional or system grounding where one of the circuit conductors (also known as a current-carrying conductor) is connected to a grounding system and then connected to earth. Functional grounding may or may not be implemented in any particular system. The second use of the grounding term refers to protective (earth) or equipment grounding where any exposed metallic conductive surfaces that may become energized (unintentionally) are connected to the grounding system and then connected to earth. The grounding system is composed of the grounding electrode (the actual connection to earth), and the grounding-electrode conductor (between the grounding electrode and a common grounding point). The common grounding point is where the functional/system-grounding conductor (if required) and the equipment/protective grounding conductor(s) (if required) connect to the grounding electrode conductor. The bonding and grounding material discussed in this section pertains only to equipment/protective grounding.

11.1B **Factory Bonding.** The process of bonding entails the electrical connection of the exposed conductive pieces of the module frame or other exposed conductive surfaces to create an equipotential conductive surface. The bonding process is carried out in the factory under carefully controlled conditions using methods and hardware that must be identified and remain relatively controlled. These bonding methods and hardware are evaluated through the requirements in this standard. Changes in the hardware used in the bonding process must be revaluated through the tests described in this standard. The overall bonding connections are evaluated through the Bonding Path Resistance Test, Section 25.

11.1C **Field Grounding.** The process of grounding involves the connection of a field-installed conductor or assembly to the exposed conductive parts of a module that connects the exposed conductive parts of a module to earth in a manner prescribed by the National Electrical Code (NEC). The instruction manual provided with each PV module will describe the location and method of making this field installed connection. These connections will, in general, not be made under factory-controlled conditions nor will each and every field connection be evaluated by the Bonding Path Resistance Test, Section 25. Normally, the methods and hardware used to make electrical bonding connections in the factory will not be applicable to field installed grounding connections. Such hardware items may be used in making the grounding connections if, and only if, the hardware is supplied with the PV module and has been evaluated for use as a grounding device/method through the requirements in this standard. Only listed grounding devices may be used to ground PV modules.

11.1D **Insulating Coatings.** Clear coatings, anodizing, and the rapid oxidation of aluminum make electrical connections to module frames in the field difficult. In many cases, the clear coating, anodizing, and oxidation film will have to be penetrated or removed and an anti-oxidation compound applied to the bare aluminum surface before a good electrical connection can be made.

11.1 A module or panel shall have a means for grounding all accessible conductive parts. The grounding means shall comply with the applicable requirements in Connection Means, Section 10. The grounding means shall be bonded to each conductive part of the module or panel that is accessible during normal use. The grounding means shall be described in detail in the installation manual. See Installation and Assembly Instructions, Section 48.

Exception: When the grounding means is a module or panel mounting member intended to contact an array structural member, the module or panel grounding means are not required to comply with the requirements for Connection Means, Section 10.

11.2 Routine maintenance of a module or panel shall not involve breaking or disturbing the bonding path. A bolt, screw, or other part used for bonding purposes within a module or panel shall not be intended for securing the complete device to the supporting surface or frame.

11.3 Bonding shall be by a positive means, such as clamping, riveting, bolted or screwed connections, or welding, soldering (see 11.5) or brazing. The bonding connection shall penetrate nonconductive coatings, such as paint or vitreous enamel.

11.4 A bolted or screwed connection that incorporates a star washer under the screwhead or a serrated screwhead may be acceptable for penetrating nonconductive coatings. If the bonding means depends upon screw threads, two or more screws or two full threads of a single screw shall engage the metal.

11.5 All joints in the bonding path shall be mechanically secure independent of any soldering.

11.6 A separate bonding conductor or strap shall:

a) Be of copper, copper alloy, or other material acceptable for use as an electrical conductor;

b) Be protected from mechanical damage; and

c) Not be secured by a removable fastener used for any purpose other than bonding, unless the bonding conductor is unlikely to be omitted after removal and replacement of the fastener.

11.7 A ferrous metal part in the grounding path shall be protected against corrosion by metallic or nonmetallic coatings, such as painting, galvanizing, or plating. Stainless steel is acceptable without additional coating.

11.8 A metal-to-metal multiple-bearing pin-type hinge is considered to be an acceptable means for bonding.

11.9 A terminal of a module or panel (for example, a wire-binding screw, a pressure wire connector, or a nut-on-stud) intended to accommodate an equipment grounding conductor shall be identified by being marked "G," "GR," "GROUND," "GROUNDING," or the like, or shall have a green-colored part. No other terminal shall be so identified.

11.10 If a marking is used to identify an equipment grounding terminal, it shall be located on or adjacent to the terminal, or on a wiring diagram affixed to the module or panel near the terminal.

11.11 If a green-colored part is used to identify the equipment-grounding terminal, it shall be readily visible during and after installation of the equipment-grounding conductor and the portion of the terminal that is green shall not be readily removable from the remainder of the terminal.

11.12 The surface of a lead of a module or panel intended for the connection of an equipment-grounding conductor shall be identified by insulation colored green, or green with yellow stripe(s). No other lead shall be so identified.

12 Spacings

12.1 The spacings between uninsulated live parts not of the same potential and between a live part and an accessible metal part, shall not be less than the values specified in Table 12.1, Table 12.2, and Table 12.3.

Exception No. 1: These spacing requirements do not apply to the inherent spacings of a component; such spacings shall comply with the requirements for the component in question.

Exception No. 2: These distances do not apply to solid insulation materials when used as cemented joints, potting, encapsulant or conformal coating at the perimeter and at other locations with exposed edges of a module. Those insulation properties can be assessed through the tests outlined in the General Section 18, and Cemented Joints, Section 42A.

Exception No. 3: These distances do not apply to insulation materials when used as coatings at the interconnection of a module and a junction box. A coating intended to be used on a module to provide a Pollution Degree 1 shall comply with the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, Section 15, Printed Wiring Board Coating Performance Test.

NOTE 1: The minimum through material distance for solid insulation at the perimeter and at other locations with exposed edges of a module must be greater than or equal to the creepage distances defined in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, Table 9.1, using Pollution Degree 1.

NOTE 2: Minimum through distance for coatings at the interconnection of a module and a junction box must be greater than or equal to the creepage distances defined in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, Table 9.1, using Pollution Degree 1.

Table 12.1
Minimum acceptable spacings at wiring terminals

Potential involved, V	Through air and over surface	
	in	(mm)
0 – 50	1/4	(6.4)
51 – 300	3/8	(9.5)
301 – 600	1/2	(12.7)
601 – 1000	5/8	(15.9)
1001 – 1500	15/16	(24)

Table 12.2
Minimum acceptable spacings elsewhere than at wiring terminals

Potential involved, V	Through air		Over surface	
	in	(mm)	in	(mm)
0 – 50	1/16	(1.6)	1/16	(1.6)
51 – 300	1/8	(3.2)	1/4	(6.4)
301 – 600	1/4	(6.4)	3/8	(9.5)
601 – 1000	3/8	(9.5)	1/2	(12.7)
1001 – 1500 [a]	9/16	(14)	19/32	(15)

[a] For edge spacings (live parts to the accessible edge of the module) the values in Table 12.2 are for metallic framed modules. Double the over-surface and through-air distances for edge spacings of modules without metallic frames.

Table 12.3
Minimum acceptable spacings for creepage distances using Pollution Degree 1

Potential involved, V	Over surface	
	in	(mm)
600	0.066	(1.68)
1000	0.126	(3.20)
1500	0.205	(5.20)

Note: Distances for 600 V and 1500 V are based on linear interpolation of the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, Table 9.1, using Pollution Degree 1.

12.2 The spacings at a field-wiring terminal are to be measured with and without wire connected to the terminal. The wire is to be connected as it would be in actual use. If the terminal will properly accommodate it, and if the product is not marked to restrict its use, the wire is to be one size larger than that required; otherwise, the wire is to be the size required.

12.3 Surfaces separated by a gap of 0.013 in (0.33 mm) or less are considered to be in contact with each other for the purpose of judging over surface spacings.

12.4 In Table 12.1 and Table 12.2, the potential involved is the maximum voltage that may exist between parts during any anticipated use of the module or panel.

12.5 A barrier or liner of electrical grade fiber providing the sole insulation between a live part and an accessible metal part or between uninsulated live parts not of the same potential shall not be less than

0.028 in (0.71 mm) thick. The barrier or liner shall be held in place and shall not be adversely affected to the extent that its necessary properties may fall below the minimum values required for the application.

13 Wiring Compartments

13.1 General

13.1.1 A wiring compartment shall comply with the requirements specified in 13.1.2 – 13.3.4.

13.1.2 The internal volume of the wiring compartment shall be in accordance with Table 13.1. The volume shall be calculated for each conductor intended to be installed, including integral conductors of the module or panel. In the space being evaluated for the minimum required volume, no enclosure dimension shall be less than 3/4 in (19.1 mm). The internal volume shall be determined using water as prescribed for the Volume Verification Test in the Standard for Metallic Outlet Boxes, UL 514A.

Table 13.1
Volume required per conductor

Size of conductor, AWG	Free space within box for each conductor, in^3
18	1.50
16	1.75
14	2.00
12	2.25
10	2.50
8	3.00
6	5.00
For SI units: 1 cubic in = 16.4 cm^3	

13.1.3 A wiring compartment shall have provision for accommodating a wiring system employing a raceway or cable.

13.1.4 A wiring compartment shall have no more than one opening when the module or panel is shipped from the factory. Tapped holes with screwed-in plugs and knockouts are not considered openings.

13.1.5 Gaskets and seals shall not deteriorate beyond limits during accelerated aging, and shall not be used where they may be subject to flexing during normal operation. See Accelerated Aging Test, Section 32.

13.1.6 A wiring compartment that is secured to a substrate by means of an adhesive shall comply with Wiring Compartment Securement Test, Section 42.

13.2 Metallic wiring compartments

13.2.1 A wiring compartment of sheet steel shall have a wall thickness of not less than 0.053 in (1.35 mm) if uncoated, or 0.056 in (1.42 mm) if zinc coated.

13.2.2 A wiring compartment of sheet aluminum shall have a wall thickness of not less than 0.0625 in (1.59 mm).

13.2.3 A wiring compartment of cast iron, aluminum, brass, or bronze shall have a wall thickness of not less than 3/32 in (2.4 mm).

13.2.4 A threaded hole in a metal wiring compartment intended for the connection of rigid metal conduit shall be reinforced to provide metal not less than 1/4 in (6.4 mm) thick, and shall be tapered unless a conduit end stop is provided.

13.2.5 If threads for the connection of conduit are tapped all the way through a hole in a compartment wall, or if an equivalent construction is employed, there shall not be less than 3-1/2 nor more than five threads in the metal and the construction shall be such that a conduit bushing can be attached as intended.

13.2.6 If threads for the connection of conduit are not tapped all the way through a hole in a compartment wall, there shall not be less than five full threads in the metal and there shall be a smooth, rounded inlet hole for the conductors which shall afford protection to the conductors equivalent to that provided by a standard conduit bushing. The throat diameter of an inlet hole shall be within the limits specified in the Standard for Metallic Outlet Boxes, UL 514A.

13.2.7 For a nonthreaded opening in a metal wiring compartment intended to accommodate rigid metallic conduit, a flat surface of sufficient area as described in the Standard for Metallic Outlet Boxes, UL 514A, shall be provided around the opening to accept the bearing surfaces of the bushing and lock washer.

13.3 Nonmetallic wiring compartments

13.3.1 The considerations mentioned in 7.1 concerning polymeric materials serving as the enclosure apply to nonmetallic wiring compartments.

13.3.2 A nonmetallic wiring compartment intended to accommodate nonmetallic conduit shall have:

a) One or more unthreaded conduit-connection sockets integral with the compartment that comply with the requirements in the Standard for Nonmetallic Outlet Boxes, Flush-Device Boxes, and Covers, UL 514C,

b) One or more threaded or unthreaded openings for a conduit-connection socket, or

c) One or more knockouts that comply with UL 514C.

13.3.3 With reference to 13.3.2(b), a module or panel provided with a nonmetallic wiring compartment having a threaded opening shall be marked in accordance with 47.8.

13.3.4 In a nonmetallic compartment, a socket for the connection of nonmetallic conduit shall provide a positive end stop for the conduit; and the socket diameters, the throat diameter at the entrance to the box, the socket depths, and the wall thickness of the socket shall be within the limits specified in the Standard for Nonmetallic Outlet Boxes, Flush-Device Boxes, and Covers, UL 514C.

13.3.5 A knockout or opening in a nonmetallic wiring compartment intended to accommodate rigid nonmetallic conduit shall comply with the requirements in the Standard for Nonmetallic Outlet Boxes, Flush-Device Boxes, and Covers, UL 514C.

14 Corrosion Resistance

14.1 Sheet steel having a thickness of 0.12 in (3.05 mm) or more that may be exposed to the weather shall be made corrosion-resistant by one of the following coatings:

a) Hot-dipped mill-galvanized sheet steel conforming with the coating designation G60 or A60 in the Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot Dip Process, ASTM A653/A653M-01, with not less than 40 percent of the zinc on any side, based on the minimum single spot-test requirement in this ASTM specification. The weight of zinc coating may be determined by any method; however, in case of question, the weight of coating shall be established in accordance with the Standard Test Method for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles, ASTM A90-81 (1991).

b) A zinc coating, other than that provided on hot-dipped mill-galvanized sheet steel, uniformly applied to an average thickness of not less than 0.00041 in (0.010 mm) on each surface with a minimum thickness of 0.00034 in (0.009 mm). The thickness of the coating shall be established by the Metallic Coating Thickness Test, Section 38.

c) An organic or inorganic protective coating system on both surfaces, applied after forming. The results of an evaluation of the coating system shall demonstrate that it provides protection at least equivalent to that provided by the zinc coating described in 14.1(a). See Polymeric Materials, Section 7 and Corrosive Atmosphere Test, Section 37.

d) Any one of the means specified in 14.2.

14.2 Sheet steel having a thickness of less than 0.12 in (3.05 mm) which may be exposed to the weather shall be made corrosion-resistant by one of the following coatings:

a) Hot-dipped, mill-galvanized sheet steel conforming with the coating designation G90 in the Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot Dip Process, ASTM A653/A653M-01, with not less than 40 percent of the zinc on any side, based on the minimum single spot-test requirement in this ASTM specification. The weight of zinc coating may be determined by any acceptable method; however, in case of question, the weight of coating shall be established in accordance with the Standard Test Method for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles, ASTM A90-81 (1991).

b) A zinc coating, other than that provided on hot-dipped mill-galvanized sheet steel, uniformly applied to an average thickness of not less than 0.00061 in (0.015 mm) on each surface with a minimum thickness of 0.00054 in (0.014 mm). The thickness of the coating shall be established by the Metallic-Coating Thickness Test, Section 38. An annealed coating shall also comply with 14.5 and 14.6.

c) A cadmium coating not less than 0.0010 in (0.025 mm) thick on both surfaces. The thickness of the coating shall be established by the Metallic Coating Thickness Test, Section 38.

d) A zinc coating conforming with 14.1(a) or 14.1(b) with one coat of outdoor paint. The coating system shall comply with 14.3.

e) A cadmium coating not less than 0.00075 in (0.019 mm) thick on both surfaces with one coat of outdoor paint on both surfaces, or not less that 0.00051 in (0.013 mm) thick on both surfaces with two coats of outdoor paint on both surfaces. The thickness of the cadmium coating shall be established by the Metallic Coating Thickness Test, Section 38, and the coating system shall comply with 14.3.

14.3 With reference to 14.2(d) and 14.2(e), the results of an evaluation of the coating system shall demonstrate that it provides protection at least equivalent to that provided by the zinc coating as described (G90) in 14.2(a). See Polymeric Materials, Section 7 and Corrosive Atmosphere Test, Section 37.

14.4 With reference to 14.1 and 14.2, other finishes, including paints, other metallic finishes, and combinations of the two may be accepted when comparative tests with galvanized sheet steel (without annealing, wiping, or other surface treatment) conforming with 14.1(a) or 14.2 as applicable, indicate they provide equivalent protection. See Corrosive Atmosphere Test, Section 37.

14.5 An annealed coating on sheet steel that is bent or similarly formed or extruded or rolled at edge of holes after annealing shall additionally be painted in the bent or formed area if the bending or forming process damages the zinc coating. If flaking or cracking of a zinc coating at the outside radius of a bent or formed section is visible at 25 power magnification, the zinc coating is considered damaged.

14.6 Simple sheared or cut edges and punched holes are not required to be additionally protected.

14.7 Iron or steel serving as a necessary part of the product but not exposed to the weather shall be plated, painted, or enameled for protection against corrosion.

14.8 Aluminum, stainless steel, and polymeric materials may be used without corrosion-resistant coatings or platings.

14.9 Materials not specifically mentioned in this section shall be evaluated on an individual basis. The tests described in Polymeric Material, Section 7, and Corrosive Atmosphere Test, Section 37, may be used for the evaluation.

15 Accessibility of Uninsulated Live Parts

15.1 An accessible part of a module or panel shall not involve a risk of electric shock.

Exception: A part that is not energized when it is accessible need not comply with this requirement.

15.2 In determining whether a part is energized, the module or panel is to be evaluated:

a) Not connected, and

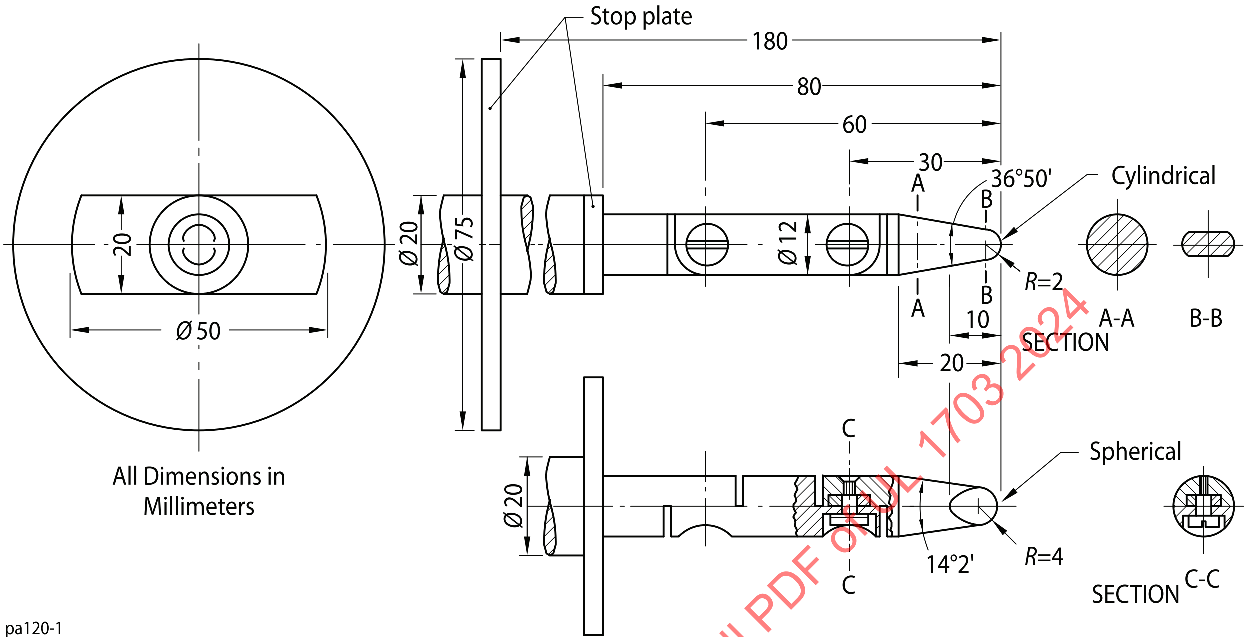
b) Connected in any implied or described acceptable manner. In both cases, the module or panel is to be in the state described in 15.4 and in the environment described in 20.2.

15.3 For voltages and currents between parts of the individual unconnected product, voltage is to be determined in accordance with 20.2. For voltages and currents between parts of the assembly of products, voltage is to be the maximum system voltage, current is to be the available current.

15.4 A part is considered accessible if, in a fully assembled module or panel (that is, with all covers in place) the part may be touched by the probe illustrated in Figure 15.1. A cover that may be removed without the use of a tool is to be removed for purposes of this requirement. A cover that may be removed (with or without a tool) for routine maintenance such as cleaning, or to gain access to tools, is to be removed for purposes of this requirement.

Figure 15.1

Probe for determining accessibility of live parts



15.5 The probe illustrated in Figure 15.1 shall be applied to any depth that the opening will permit; and shall be rotated or angled before, during, and after insertion through the opening to any position that is necessary to examine the product. The probe shall be applied in any possible configuration; and, if necessary, the configuration shall be changed after insertion through the opening. The probe is to be used as a measuring instrument to judge the accessibility provided by an opening, and not as an instrument to judge the strength of a material; as such, it is to be applied with the minimum force necessary to accurately determine accessibility.

16 Fire Performance – PV Modules or Panels and Roofs

16.1 A photovoltaic module or panel intended to be mounted or installed on a roof shall be evaluated for fire performance in accordance with 16.2 or 16.3, whichever applies. System Fire Class Ratings A, B, or C are only relevant for PV modules or panels with mounting systems in combination with a fire rated roof covering. Mounting systems evaluated in accordance with 16.3 may be tested with specific “types” of modules as characterized in accordance with 16.4.1.

16.2 Modules or panels intended for installation integral with or forming a part of the building’s roof structure are referred to in this standard as building-integrated photovoltaics (BIPVs) and shall be evaluated in accordance with the Standard for the Standard Test Methods for Fire Tests of Roof Coverings, UL 790, as a Class A, B, or C roof covering material or roof covering system.

16.3 Modules or panels that are not BIPVs and are intended for stand-off or rack mounting in combination with a roof covering shall be evaluated in accordance with the tests described in Fire Tests, Section 31, and as shown by Table 31.2 with respect to the fire performance requirements for Class A, B, or C when the module or panel is marked as being fire rated as specified in 47.11. The module or panel with its mounting system is to be evaluated for Class A, B, or C so that the appropriate System Fire Class Rating can be used for building code compliance purposes.

16.4 The specimens selected for testing are to be representative of the construction series being investigated with regard to components and design. A module or panel intended for mounting on a roof may be represented by type in accordance with 16.4.1 to simplify the evaluation of module or panel types, roof-mounting configurations, and mounting systems.

16.4.1 The use of module or panel types in this Section is optional. A module or panel intended for mounting on a roof (but not BIPVs) can be classified according to type based on its construction and the results of the fire tests detailed in Section 31.1.2, Spread of Flame on Top Surface, and Section 31.1.3, Burning Brand on Top Surface. Module or panel construction types shall be evaluated based on the following characteristics of PV module and panel construction: (1) the superstrate material; (2) the encapsulant material; (3) the substrate material; and, (4) the frame type and geometry (if any). The following types, described in 16.4.2 – 16.4.7, are representative of common module and panel constructions and their associated fire characteristics:

16.4.2 A Type 1, 4, or 7 module or panel meets the following requirements:

a) Construction: Glass superstrate of 0.14 ±0.03 in (3.6 ±0.8 mm); a polymeric encapsulant between the superstrate and cells with a pre-lamination thickness of 0.02 ±0.012 in (0.5 ±0.3 mm); either a polymeric encapsulant between the cells and substrate with a pre-lamination thickness of 0.02 ±0.012 in (0.5 ±0.3 mm) and a polymeric substrate with nominal thickness no less than 0.012 in (0.30 mm) and no more than 0.025 in (0.64 mm) thickness or a combined substrate and encapsulant that meets the pre-lamination total thickness equal to an encapsulant thickness of 0.018 ±0.008 in (0.45 ±0.2 mm) and a polymeric substrate with nominal thickness no less than 0.012 in (0.30 mm) and no more than 0.025 in thickness (0.64 mm); and metallic framing protecting the edge of the laminate.

b) Spread of Flame Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.2. For Type 1, the allowable spread of flame of 6 feet (1.82 m) or less in 10 minutes. For Type 4, the allowable spread of flame is 13 feet (3.96 m) or less in 4 minutes. For Type 7, the allowable spread of flame is 8 feet (2.4 m) or less in 10 minutes.

c) Burning Brand Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.3 using a C Brand. For Type 1, 4, and 7, passing results using a C Brand shall be demonstrated.

16.4.3 A Type 2, 5, or 8 module or panel meets the following requirements:

a) Construction: Glass superstrate of 0.14 ±0.03 in (3.6 ±0.8 mm); a polymeric encapsulant between the superstrate and cells with a pre-lamination thickness of 0.02 ±0.012 in (0.5 ±0.3 mm); either a polymeric encapsulant between the cells and substrate with a pre-lamination thickness of 0.02 ±0.012 in (0.5 ±0.3 mm) and a polymeric substrate with nominal thickness between 0.001 in (0.025 mm) and 0.012 in thickness (0.30 mm) or a combined substrate and encapsulant that meets the prelamination total thickness equal to an encapsulant thickness of 0.02 ±0.012 in (0.5 ±0.3 mm) and a polymeric substrate with nominal thickness between 0.001 in (0.025 mm) and 0.012 in thickness (0.30 mm); and metallic framing protecting the edge of the laminate.

b) Spread of Flame Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.2. For Type 2, the allowable spread of flame of 6 feet (1.82 m) or less in 10 minutes. For Type 5, the allowable spread of flame is 13 feet (3.96 m) or less in 4 minutes. For Type 8, the allowable spread of flame is 8 feet (2.4 m) or less in 10 minutes.

c) Burning Brand Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.3 using a C Brand. For Type 2, 5, and 8, passing results using a C Brand shall be demonstrated.

16.4.4 A Type 3, 6, 9-15, or a 19-27 module or panel meets the following requirements:

a) Construction: Glass superstrate of 0.105 ±0.030 in (2.67 ±0.76 mm); polymeric encapsulant with a total pre-lamination thickness of 0.035 ±0.02 in (0.9 ±0.5 mm); glass substrate of 0.105 ±0.030 in (2.67 ±0.76 mm) with metallic framing (Types 19-27) or without metallic framing (Types 3, 6, 9-15).

b) Spread of Flame Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.2. For Type 3, 10, 13, 19, 22 and 25, the allowable spread of flame of 6 feet (1.82 m) or less in 10 minutes. For Type 6, 11, 14, 20, 23 and 26, the allowable spread of flame is 13 feet (3.96 m) or less in 4 minutes. For Type 9, 12, 15, 21, 24 and 27, the allowable spread of flame is 8 feet (2.4 m) or less in 10 minutes.

c) Burning Brand Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.3. For Type 3, 6, and 9, passing results using a C Brand shall be demonstrated. For Type 10, 11, and 12, passing results using a B Brand shall be demonstrated. For Type 13, 14, and 15, passing results using an A Brand shall be demonstrated.

16.4.5 A Type 16, 17, or 18 module or panel meets the following requirements:

a) Construction: Glass superstrate of 0.14 ±0.03 in (3.6 ±0.8 mm); a polymeric encapsulant between the superstrate and cells with a pre-lamination thickness of 0.020 ±0.012 in (0.5 ±0.3 mm); a polymeric encapsulant between the cells and substrate with a prelamination thickness of 0.020 ±0.012 in (0.5 ±0.3 mm) and a glass substrate of 0.14 ±0.03 in (3.6 ±0.8 mm); and metallic framing protecting the edge of the laminate.

b) Spread of Flame Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.2. For Type 16, the allowable spread of flame of 6 feet (1.82 m) or less in 10 minutes. For Type 17, the allowable spread of flame is 13 feet (3.96 m) or less in 4 minutes. For Type 18, the allowable spread of flame is 8 feet (2.4 m) or less in 10 minutes.

c) Burning Brand Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.3 using a C Brand. For Type 16, 17, and 18, passing results using a C Brand shall be demonstrated.

16.4.6 A Type 28, 29 or 30 module or panel meets the following requirements:

a) Construction: Glass superstrate of 0.105 ±0.030 in (2.67 ±0.76 mm); a polymeric encapsulant between the superstrate and cells with a pre-lamination thickness of 0.020 ±0.012 in (0.5 ±0.3 mm); a polymeric encapsulant between the cells and substrate with a prelamination thickness of 0.020 ±0.012 in (0.5 ±0.3 mm) and a glass substrate of 0.105 ±0.030 in (2.67 ±0.76 mm); and without metallic frame (Type 28) or with metallic framing (Type 29 or 30).

b) Spread of Flame Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.2. For Type 28, 29 and 30, the allowable spread of flame of 6 feet (1.82 m) or less in 10 minutes.

c) Burning Brand Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.3. For Type 28 and 29, passing results using a C Brand shall be demonstrated. For Type 30, passing results using an A Brand shall be demonstrated.

16.4.7 A Type 31, 32, 33 module or panel meets the following requirements:

a) Construction: Glass superstrate of 0.09 ±0.02 in (2.4 ±0.4 mm); a polymeric encapsulant between the superstrate and cells with a pre-lamination thickness of 0.02 ±0.012 in (0.5 ±0.3 mm); either a polymeric encapsulant between the cells and substrate with a pre-lamination thickness of 0.02 ±0.012 in (0.5 ±0.3 mm) and a polymeric substrate with nominal thickness between 0.001 in (0.025 mm) and 0.012 in thickness (0.30 mm) or a combined substrate and encapsulant that meets the pre-lamination total thickness equal to an encapsulant thickness of 0.02 ±0.012 in (0.5 ±0.3 mm) and a polymeric substrate with nominal thickness between 0.001 in (0.025 mm) and 0.012 in thickness (0.30 mm); and metallic framing protecting the edge of the laminate.

b) Spread of Flame Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.2. For Type 31, the allowable spread of flame of 6 feet (1.82 m) or less in 10 minutes. For Type 32, the allowable spread of flame is 13 feet (3.96 m) or less in 4 minutes. For Type 33, the allowable spread of flame is 8 feet (2.4 m) or less in 10 minutes.

c) Burning Brand Test on Top Surface: The test shall be conducted using the procedure given in Section 31.1.3 using a C Brand. For Type 31, 32, and 33, passing results using a C Brand shall be demonstrated.

16.4.8 New types of PV modules with other constructions and fire performance can be defined as needed. Table 16.1 lists the types of PV modules based on construction and fire performance. The fire performance of these other constructions shall be tested in accordance with 31.1.2 and 31.1.3.

Table 16.1
Construction and fire performance for PV module types [a]

	Superstrate	Encapsulant (Super/Cell)	Encapsulant (Cell/Sub)	Substrate	Frame	Fire Performance	
Type	Material/ Thickness	Material/ Thickness	Material/ Thickness	Material/ Thickness	Material	Spread of Flame	Burning Brand
1	Glass / 0.14 ±0.03 in (3.6 ±0.8 mm)	Polymer / 0.02 ±0.012 in (0.5 ±0.3 mm)	Polymer / 0.02 ±0.012 in (0.5 ±0.3 mm)	Polymer / 0.012 in (0.30 mm) ≤ thickness ≤ 0.025 in (0.64 mm)	Metallic	6 feet (1.82 m) or less in 10 minutes	C Brand
4						13 feet (3.96 m) or less in 4 minutes	
7						8 feet (2.4 m) or less in 10 minutes	
2				Polymer / 0.001 in (0.025 mm) ≤ thickness < 0.012 in (0.30 mm)		6 feet (1.82 m) or less in 10 minutes	
5						13 feet (3.96 m) or less in 4 minutes	
8						8 feet (2.4 m) or less in 10 minutes	
16				Glass / 0.14 ±0.03 in (3.6 ±0.8 mm)		6 feet (1.82 m) or less in 10 minutes	
17						13 feet (3.96 m) or less in 4 minutes	
18						8 feet (2.4 m) or less in 10 minutes	
3	Glass / 0.105 ±0.030 in (2.67 ±0.76 mm)	N/A	Polymer / 0.035 ±0.02 in (0.9 ±0.5 mm)	Glass / 0.105 ±0.030 in (2.67 ±0.76 mm)	None	6 feet (1.82 m) or less in 10 minutes	C Brand
6						13 feet (3.96 m) or less in 4 minutes	
9						8 feet (2.4 m) or less in 10 minutes	
19					Metallic	6 feet (1.82 m) or less in 10 minutes	
20						13 feet (3.96 m) or less in 4 minutes	
21						8 feet (2.4 m) or less in 10 minutes	
10					None	6 feet (1.82 m) or less in 10 minutes	B Brand
11						13 feet (3.96 m) or less in 4 minutes	
12						8 feet (2.4 m) or less in 10 minutes	
13						6 feet (1.82 m) or less in 10 minutes	A Brand
14						13 feet (3.96 m) or less in 4 minutes	
15						8 feet (2.4 m) or less in 10 minutes	
22					Metallic	6 feet (1.82 m) or less in 10 minutes	B Brand
23						13 feet (3.96 m) or less in 4 minutes	
24						8 feet (2.4 m) or less in 10 minutes	
25						6 feet (1.82 m) or less in 10 minutes	A Brand
26						13 feet (3.96 m) or less in 4 minutes	
27						8 feet (2.4 m) or less in 10 minutes	

Table 16.1 Continued on Next Page

Table 16.1 Continued

<table>
<tr><th></th><th>Superstrate</th><th>Encapsulant (Super/Cell)</th><th>Encapsulant (Cell/Sub)</th><th>Substrate</th><th>Frame</th><th colspan="2">Fire Performance</th></tr>
<tr><th>Type</th><th>Material/ Thickness</th><th>Material/ Thickness</th><th>Material/ Thickness</th><th>Material/ Thickness</th><th>Material</th><th>Spread of Flame</th><th>Burning Brand</th></tr>
<tr><td>28</td><td rowspan="3"></td><td rowspan="6">Polymer / 0.020 ±0.012 in (0.5 ±0.3 mm)</td><td rowspan="6">Polymer / 0.020 ±0.012 in (0.5 ±0.3 mm)</td><td rowspan="3"></td><td>None</td><td>6 feet (1.82 m) or less in 10 minutes</td><td rowspan="2">C Brand</td></tr>
<tr><td>29</td><td rowspan="2">Metallic</td><td>6 feet (1.82 m) or less in 10 minutes</td></tr>
<tr><td>30</td><td>6 feet (1.82 m) or less in 10 minutes</td><td>A Brand</td></tr>
<tr><td>31</td><td rowspan="3">Glass / 0.09 ±0.02 in (2.4 ±0.4 mm)</td><td rowspan="3">Polymer / 0.001 in (0.025 mm) ≤ thickness < 0.012 in (0.30 mm)</td><td rowspan="3">Metallic</td><td>6 feet (1.82 m) or less in 10 minutes</td><td rowspan="3">C Brand</td></tr>
<tr><td>32</td><td>13 feet (3.96 m) or less in 4 minutes</td></tr>
<tr><td>33</td><td>8 feet (2.4 m) or less in 10 minutes</td></tr>
<tr><td colspan="8">[a] Full requirements in 16.4.2 – 16.4.7 supersede this table.</td></tr>
</table>

17 Superstrate

17.1 A module or panel superstrate shall comply with at least one of the following:

a) The requirements in the Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1-1984; or

b) The requirements in the Code of Federal Regulations, Title 16 CPSC Part 1201 – Safety Standard for Architectural Glazing Materials; or

c) The Impact Test, Section 30.

Exception No. 1: Thin-film flexible glazing material having a thickness of 0.01 in (0.254 mm) or less need not comply with this requirement.

Exception No. 2: Encapsulant that is protected with wire screen or other similar means having openings that will not pass a 1/2-in (12.7-mm) diameter hemispherically tipped probe applied with a force of 1 lb (4.4 N).

PERFORMANCE

18 General

18.1 The same test procedures shall be used for the electrical performance measurements required by the Temperature Test, Section 19, Voltage, Current, and Power Measurements Test, Section 20, and Hot-Spot Endurance Test, Section 39 The test procedures described in the following standard shall be applied where applicable:

a) Standard Tables for Terrestrial Solar Spectral Irradiance at Air Mass 1.5 for 37 Degree Tilted Surface, ASTM G159-1998;

b) Standard Specifications for Solar Simulation for Terrestrial Photovoltaic Testing, ASTM E927-91;

c) Standard Methods of Testing Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells, ASTM E1036-96;

d) Procedures for Temperature Irradiance Corrections to Measured I-V Characteristics of Crystalline Silicon Photovoltaic Devices, IEC 891;

e) Photovoltaic Devices, Part 1: Measurement of Photovoltaic Current-Voltage Characteristics, IEC 904-1; and

f) Photovoltaic Devices, Part 3: Measurement Principles for Terrestrial Photovoltaic (PV) Solar Devices With Reference Spectral Irradiance Data, IEC 904-3.

18.2 With reference to the tests mentioned in 18.1, parameters may be measured under conditions other than specified irradiance, air mass, or temperature, and the values at the specified conditions calculated using correction coefficients described in the referenced standards.

18.3 Samples of the module or panel, or partial or representative samples, shall be subjected to the tests indicated in Table 18.1. The order of the tests in Table 18.1 is for convenience only. It is not intended to imply that any one sample be subjected to the complete sequence or a partial sequence of tests unless specifically stated in Figure 18.1. Unless one sample is to be subjected to a specific sequence of tests, separate samples are able to be used for each test.

Exception: Samples of a module or panel with a system open-circuit voltage rating less than 30 V and a short-circuit current rating less than 8 A is only required to be subjected to the Temperature, Voltage and Current Measurement, Strain Relief, Push, Bonding Path Resistance, and Dielectric Voltage-Withstand Tests.

Table 18.1
Module and panel performance

Section	Test	Number of samples
19	Temperature test[c]	1
20	Voltage and current measurements test[c]	1
21	Leakage current test	3
22	Strain relief test[c]	1
23	Push test[c]	1
24	Cut test	1
25	Bonding path resistance test	3
26	Dielectric voltage-withstand test[c]	3
27	Wet insulation-resistance test	3
28	Reverse current overload test	1
29	Terminal torque test	1
30	Impact test	1
31	Fire test	a
33	Water spray test	1
34	Accelerated aging test	b
35	Temperature cycling test	3
36	Humidity test	3
37	Corrosive atmosphere test	2
38	Metallic coating thickness test	1

Table 18.1 Continued on Next Page

Table 18.1 Continued

Section	Test	Number of samples
39	Hot-spot endurance test	1
41	Mechanical loading test	1
42	Wiring compartment securement test	1
42A	Cemented joints	d

[a] A function of the physical size of the module.

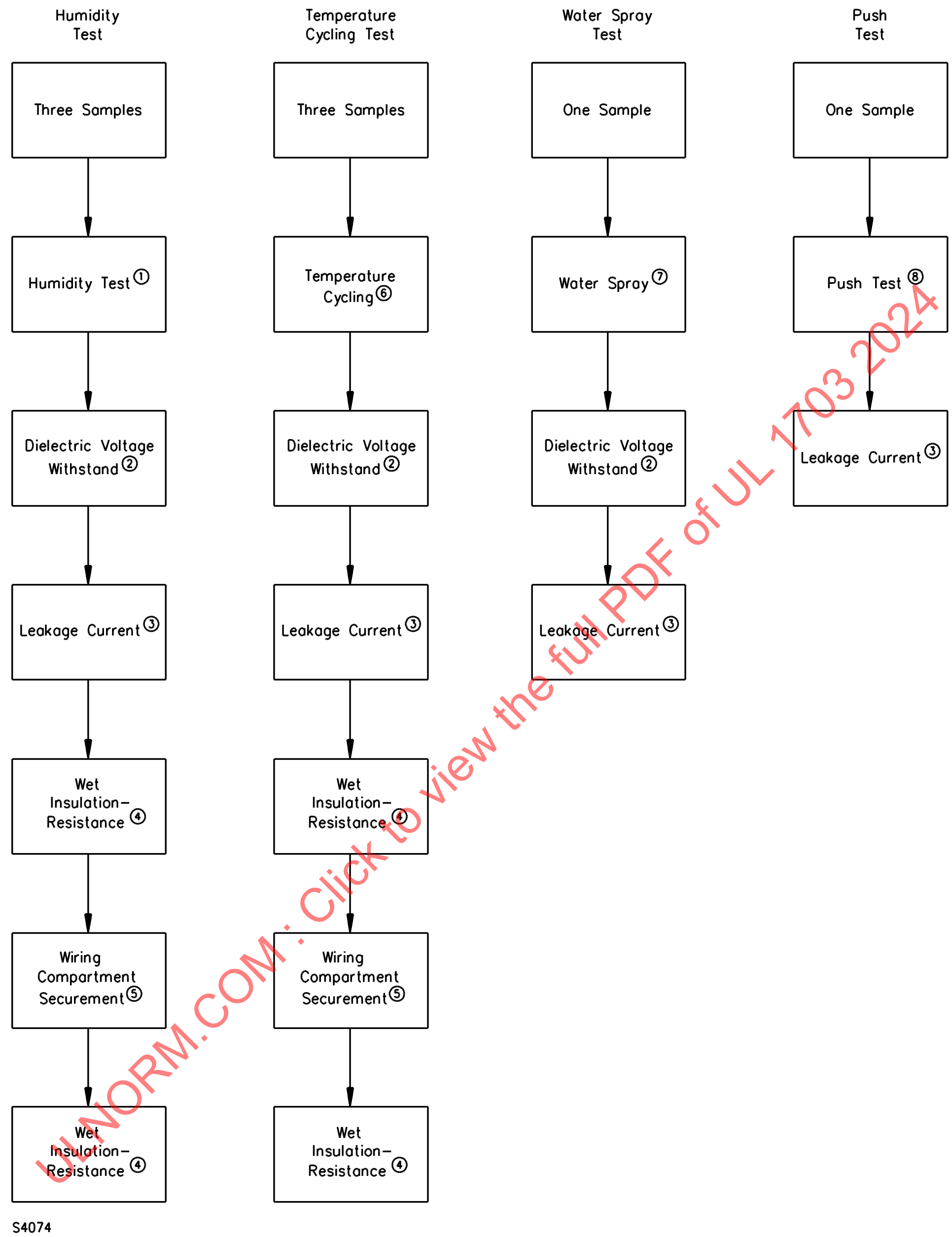
[b] A function of the physical size of the gasket and seal material.

[c] With reference to the Exception to 18.3, only these tests are needed for a module or panel with the specified ratings.

[d] No additional modules are needed for the Cemented Joint test as the performance tests are covered by the tests of Sections 26, 27, 35 and 36. All other tests are performed at the component level.

Figure 18.1

Test sequences and samples



NOTES –

1 = Section 36

2 = Section 26

3 = Section 21

4 = Section 27

5 = Section 42

6 = Section 35

7 = Section 33

8 = Section 23

18A Thin-Film Modules

18A.1 As a result of the testing in 18A.2 stabilized ratings for thin-film photovoltaic (PV) modules and panels shall comply with the voltage and current measurements test as described in 20.1 – 20.3.

18A.2 The sequence of voltage and current testing for thin-film photovoltaic (PV) modules and panels shall be:

a) Initial voltage and current measurements test on as received samples,

b) Light soaking exposure in accordance with Clauses 10.19.1 – 10.19.3 of the Standard for Thin-Film Terrestrial Photovoltaic (PV) Modules – Design qualification and type approval, IEC 61646,

c) Final voltage and current measurements test, and

d) Hot-spot Endurance Test in accordance with 39.1.1 and Clause 10.9 of IEC 61646.

Exception: The hot-spot endurance test may be conducted on a separate sample that has not been subjected to the light soaking exposure sequence. See 39.1.1.

18B Bifacial Modules

18B.1 General

18B.1.1 Bifacial modules shall comply with all construction and performance requirements in this standard with the modifications to specific performance tests as described in 18B.2 – 18B.4.

18B.2 Voltage, current and power measurements test

18B.2.1 Bifacial modules shall follow the procedure described in Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices, IEC TS 60904-1-2 (under development, use 82/1403/DTS) for performance measurement in accordance with 20.1 – 20.3.

Note: Three methods are allowed in IEC TS 60904-1-2 and all three are allowed.

18B.3 Reverse current overload test

18B.3.1 The Reverse Current Overload Test described in Section 28 shall be conducted without modification in accordance with a fuse rating that has been determined to comply with 47.10.1A.

18B.4 Hot-spot endurance test

18B.4.1 Module constructions that allow individual cells to be accessed shall be tested according to the Section 39 with the following modification:

Maximum current limit, I_L (front and back) = 1.30 × I_{SC}

where I_{SC} is the short-circuit of an average cell at 100 mW/cm^2 front-surface illumination only and at NOCT

18B.4.2 Modules constructed with glass super- and sub-strates, or using material combinations such that individual cells are inaccessible shall be tested in accordance with MQT 09.1 of the Standard for Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures, UL 61215-2.

18B.4.3 Cell selection shall follow the procedure described for monofacial selection using a flash simulator in accordance with the Standard for Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures, UL 61215-2, Clause 4.9.5.2 (a) – (e).

18B.4.4 For testing bifacial modules, the Standard for Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures, UL 61215-2, Clause 4.9.4, shall be used with the following modifications:

a) Front surface only irradiance source of (130 ±10) mW/cm^2; or

b) Apparatus for front- and back-surface illumination with (100 ±10) mW/cm^2 for the front-surface and (30 ±5) mW/cm^2 for the back-surface.

18B.4.5 Once cells have been selected they shall be tested as described in the Standard for Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures, UL 61215-2, Clause 4.9.5.2 (f), with the following modifications:

a) An illumination of (130 ±10) mW/cm^2 is required for front-surface only exposure and follow the UL 61215-2 procedure without further modifications (front shading only).

b) If an apparatus is used to provide front and back-side illumination, expose the front-surface to (100 ±10) mW/cm^2 and the back-surface to (30 ±5) mW/cm^2 resulting in a combined bifacial irradiance level of (130 ±10) mW/cm^2.

1) Follow the procedure to identify worst case front-surface shading and let temperature stabilize. Record values.

2) Add the same shade to the back-surface, let the temperature stabilize. Refer to 19.1A for guidance on establishing thermal equilibrium (stabilization).

3) Remove the shade on the front-surface, let the temperature stabilize.

4) Use the highest temperature condition from either (1), (2) or (3) to test the sample in accordance with UL 61215-2, Clause 4.9.5.2 (i).

18B.4.6 In addition to the cells described in 18B.4.2, if some cells are permanently shaded by design (e.g., junction box or backrails) those cells shall be included in hot-spot testing.

19 Temperature Test

19.1 When a module or panel is at thermal equilibrium in its intended application mounting at electrical open circuit and reverse voltage hot-spot heating associated with operation as short-circuit – see 19.5; no part shall attain a temperature that would:

a) Ignite materials or components;

b) Cause the temperature limits of surfaces, materials, or components, as described in Table 19.1, to be exceeded; or

c) Cause creeping, distortion, sagging, charring or similar damage to any part of the product, if such damage or deterioration may impair the performance of the product under the requirements of this standard.

19.1A With reference to 19.1, thermal equilibrium is attained when three successive readings indicate no change in temperature. These readings shall be taken at the conclusion of three consecutive, equal intervals of time; each interval having a duration of 10 minutes minimum test time. Wind speed and irradiance are to be factored into each measurement.

19.2 Material and component temperatures are to be determined for an ambient temperature of 40°C (104°F), AM 1.5 spectrum, 100 mW/cm^2 irradiance as measured in the plane of the module or panel, and 1 m/s (2.237 mph) average wind speed. The ambient temperature may be in the range of 10 to 55°C (50 to 131°F), in which case each observed temperature shall be corrected by the addition (if the ambient temperature is below 40°C) or subtraction (if the ambient temperature is above 40°C) of the difference between 40°C and the observed ambient temperature. If the irradiance is other than 100 mW/cm^2, temperatures for numerous irradiance levels are to be determined, and a linear extrapolation conducted to determine the temperature under 100mW/cm^2 irradiance.

19.3 If an unacceptable performance is encountered during the temperature test, and the performance is attributed to a test condition that, although within the limits specified, may be considered more severe than necessary; for example an ambient temperature near the limits allowed (10 or 55°C), the test may be reconducted under conditions closer to the norm.

19.4 For the determination of temperatures, a module or panel is to be operated under both open- and short-circuit conditions.

19.5 To cover the hot-spot heating effect caused by reverse voltage operation of a cell, a cell is to be shadowed during the short-circuit condition of the temperature test by covering one-half of one of the cells of the module or panel with black vinyl tape, 0.007 in (0.18 mm) thick in direct contact with the superstrate so that this cell is not fully irradiated. During this test, the modules or panels are to be connected in series without bypass diodes to the extent that is permitted by the marking specified in 47.9. The temperatures of the shaded cell and adjacent area are to be measured.

19.6 A module or panel is to be installed according to the instructions provided with it. If the instructions do not describe the accommodating structure, spacings, and the like, the module or panel is to be mounted as described in 19.8 – 19.10.

19.7 With reference to 19.8 and 19.9, the type of mounting intended, (for example, stand-off, direct, and the like) is to be determined from the construction of the module or panel. If more than one type of mounting is possible, the module or panel is to be tested in each such mounting, unless one mounting can be shown to represent all.

19.8 A module or panel intended for direct mounting on a roof or wall surface is to be mounted on a platform constructed of wood, pressed wood, or plywood, 3/4 in (19 mm) thick (See Figure 19.1). The platform is to be painted flat black on the side facing the test sample. The platform is to extend at least 2 ft (0.6 m) beyond the module or panel on all sides.

19.9 A module or panel intended for stand-off or rack mounting on a roof, wall, or the ground is to be mounted on a frame constructed from 2 in by 4 in (trade size) lumber. Two frame members are to be located at the outside edges of the underside of the module or panel, and are to be oriented longitudinally along the long axis of the module or panel. Additional frame members are to be located at the outside edges of the underside of the module or panel along its short axis. If the distance between the two outer short axis members exceeds 2 ft (0.6 m), an additional frame member is to be located at the center line of the module or panel assembly. The frame is to be secured to a platform as described in 19.8 with a 4-ft (1.22-m) spacing between the back of the module or panel and the platform (See Figure 19.2). The frame is to be painted flat black on the side facing the test sample.

19.10 A module or panel intended for integral mounting within a roof or wall is to be tested while mounted on a platform constructed as described in 19.8 with the module or panel boxed in on all sides by 1-in thick (trade size) wood boards that are wide enough to cover the entire outer edge (See Figure 19.3). The boards are to be painted flat black on the side facing the sample.

Table 19.1
Maximum temperatures

Part, material, or component		Temperature	
		°C	(°F)
1.	Insulating materials:[d]		
	Polymeric	a	a
	Varnished cloth	85	185
	Fiber	90	194
	Laminated phenolic composition	125	257
	Molded phenolic composition	150	302
2.	Sealing compound[d]	b	b
3.	Field wiring terminals[c]	60	140
4.	Field wiring compartments that wires may contact[c]	60	140
5.	Insulated conductors	Rated Temperature	
6.	Wood and wood products	90	194
7.	Surfaces accessible to contact	e	e
8.	Mounting surface and adjacent structural members[d]	90	194

[a] For the open-circuit mode, the thermal index (TI/RTE/RTI), less 20°C (36°F). For reverse voltage hot-spot heating under short-circuit conditions, the thermal index (TI/RTE/RTI).

[b] The maximum sealing compound temperature, when corrected to a 40°C (104°F) ambient temperature, is to be 15°C (27°F) less than the softening point of the compound as determined by the Standard Test Method for Softening Point by Ring and Ball Apparatus, ASTM E28-99.

[c] If a marking is provided in accordance with 47.5, the temperatures observed on the terminals and at points within a wiring compartment may exceed the value specified but shall not attain a temperature higher than 90°C (194°F).

[d] Higher temperatures than specified are acceptable if it can be determined that the higher temperatures will not cause a risk of fire or electric shock or conditions not in compliance with 19.1(a) or 19.1(c).

[e] Only for reverse voltage hot-spot heating under short-circuit conditions; for nonmetallic surfaces 40°C (72°F) above the temperature achieved during open-circuit conditions; for metallic surfaces, 20°C (36°F) above the temperature achieved during open-circuit conditions.

Figure 19.1

Fixture for test products for direct mounting

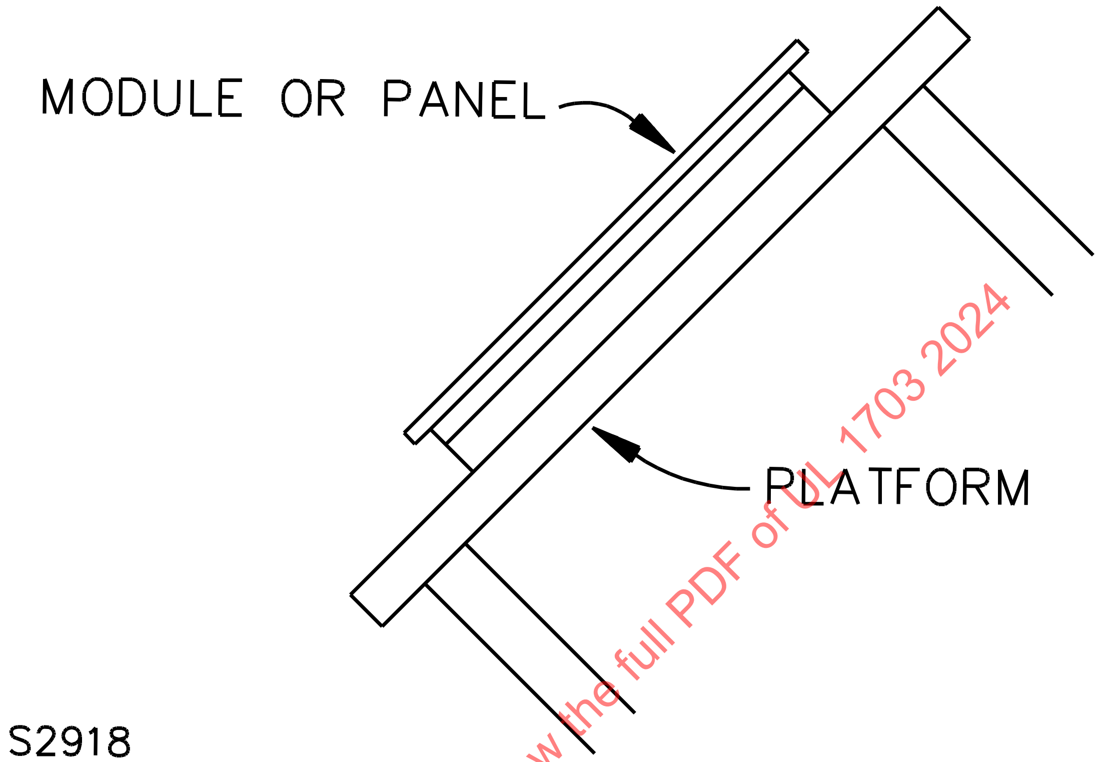


Figure 19.2

Fixture for test products for stand-off or rack mounting

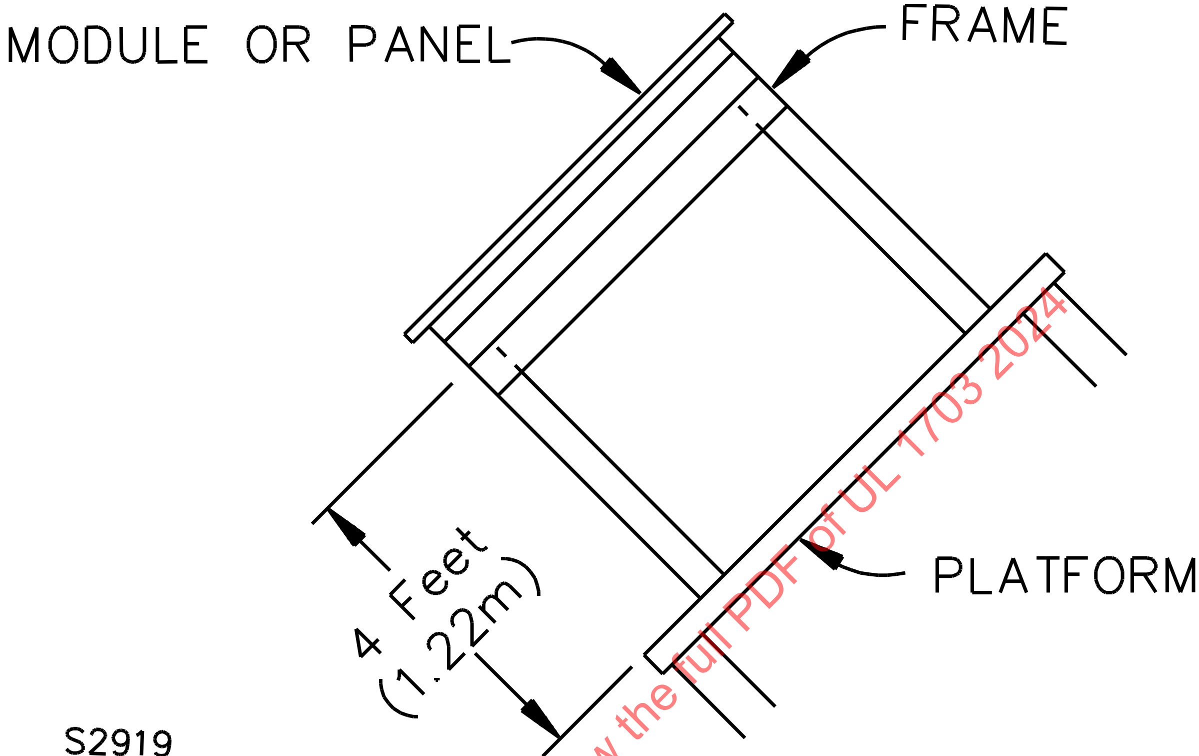


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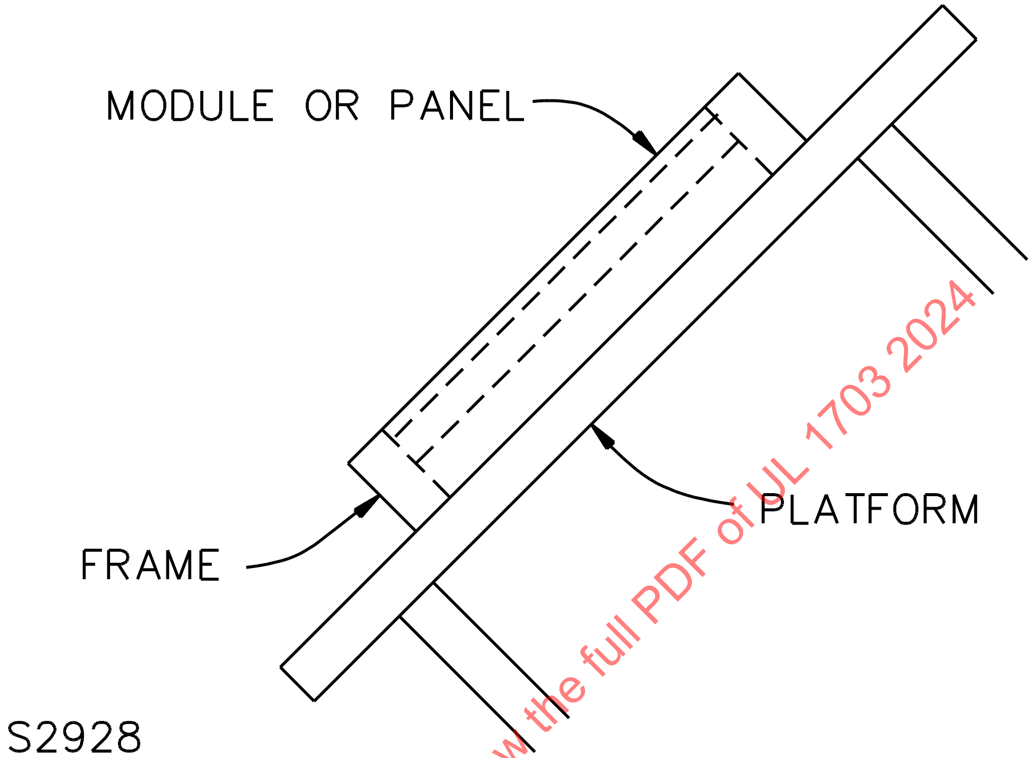
Figure 19.3

Fixture for test products for integral mounting



19.11 Temperatures are to be measured by means of thermocouples. Thermocouples exposed to irradiation are to be shielded from the direct effect of such irradiation. A thermocouple junction is to be securely held in positive thermal contact with the surface of the material the temperature of which is being measured. Thermal contact may be achieved by securely cementing the thermocouple in place. For a metal surface, brazing, welding, or soldering the thermocouple to the metal may be used. A thermocouple junction may be secured to wire insulation or wood surfaces by taping.

19.12 Thermocouples consisting of 30 AWG (0.05 mm^2) iron and constantan wires are to be employed. However, when it is not practical to use iron and constantan thermocouples some other type that conforms with the Tolerances on Initial Values of EMF versus Temperature tables in the Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples, ANSI/ASTM E230/E230M, is to be used.

20 Voltage, Current and Power Measurements Test

20.1 The short-circuit current (I_{SC}), rated current (I_r) maximum power (P_{max}), and open-circuit voltage (V_{OC}) shall be within ± 10 percent of the rated value – See 43.1 and 44.1(c) – under conditions of:

a) Standard test conditions (STC) and

b) For I_r and P_{max}, also at normal operating cell temperature (NOCT).

20.2 For purposes of accessibility to individual module or panel live parts as specified in 15.3, the voltage is to be determined under conditions of open circuit, an irradiance of 100 mW/cm^2, AM1.5 and a cell temperature of – 20°C (– 4°F). In accordance with Section 18B, bifacial modules may be tested at an irradiance above 100 mW/cm^2 in order to properly account for the effects of bifaciality on these products.

20.3 The short-circuit current (I_{SC}), rated current (I_r) maximum power (P_{max}), and open-circuit voltage (V_{OC}) measurements for thin-film modules and panels, regardless of technology, shall be taken in both the as-received condition and following the light soak exposure conditioning as described in 18A.2. The results of the as-received voltage and current measurements tests are to be included in the installation manual in addition to the stabilized ratings verified during the voltage and current measurements test conducted following light soaking. See 18A.2, 46.2 and 48.1.

21 Leakage Current Test

21.1 The leakage current of a module having a marked maximum system voltage of more than 30 V shall not be greater than the values specified in Table 21.1 when tested as described in 21.2 – 21.7.

21.2 The test is to be conducted on three unconditioned modules, and the modules that have been subjected to the Water Spray Test, Section 31; the Temperature Cycling Test, Section 33; and the Humidity Test, Section 34. The leakage current of the unconditioned modules is to be measured with the module cell temperature at 25 ±3°C (77 ±5°F), and then with the cells at NOCT ±2°C (±3.6°F). If panels are used for the Water Spray Test, a module of a panel is to be used for the Leakage Current Test.

Table 21.1
Allowable leakage current

Surface or part from which measurement is made	Maximum current (dc)
Accessible conductive frame, pan, or the like	10 μA
Accessible circuit parts	1 mA
Conductive foil over accessible insulating surfaces	1 mA

21.3 Leakage current refers to all currents that may be conveyed between accessible parts of a module when the module is connected to the source described in 21.4 and 21.5.

21.4 The dc test voltage is to be at a level equal to the rated maximum system voltage.

21.5 All accessible parts and surfaces are to be tested for leakage current. The positive and negative terminals of an unilluminated module are to be connected together and to one terminal of a dc power supply. Both polarities of the source connection are to be used, unless it can be shown that one polarity will represent both. Leakage currents are to be measured between the part or surface and the other terminal of the power supply. Leakage current is to be measured with the meter described in 21.7.

21.6 When leakage current is measured at an insulating surface, a 40 cm by 20 cm conductive foil is to be in contact with the surface, and the measurement is to be made from the foil. If the surface is less than 40 cm by 20 cm, the foil is to be the same size as the surface.

21.7 With reference to 21.5, the meter for the measurement is to be responsive to dc only, and is to have an input impedance of 500 ohms.

22 Strain Relief Test

22.1 A lead or cable for connection to external wiring, or a lead or cable terminated at both ends on the product but which may be subjected to handling during installation or routine servicing of a module or panel shall withstand for 1 min a force of 20 lb (89 N) applied in any direction permitted by the construction, without damage to the lead or cable, its connecting means, and the module or panel.

22.2 A separable connector not enclosed by a wiring compartment, and such connector's joining to its mating connector, shall withstand for 1 min a force of 20 lb (89 N) applied in any direction permitted by the construction, either directly or through any wire or cable attached to the mating connector, without damage to the connector, the module or panel, or the mounting of the connector to the module or panel, or separation of the two mating connectors.

23 Push Test

23.1 A module or panel shall be capable of withstanding for 1 min the application to any point of:

a) A 20 lb (89 N) force applied by a 1/2-in (12.7-mm) diameter steel rod, the end of which is rounded to a 1/2-in diameter hemisphere, and

b) A 4 lb (17.8 N) force applied by a 1/16-in (1.6-mm) diameter steel rod, the end of which is rounded to a 1/16-in diameter hemisphere,

without creating a risk of fire, electric shock, or injury to persons.

23.2 A risk of fire is considered to exist, if, as a result of the application of either probe, parts of the module are displaced to the extent that arcing between parts of available current and voltage in the "ARC TEST" zone, Figure 40.1, is likely.

23.3 A risk of electric shock is considered to exist if:

a) A part involving a risk of electric shock is contacted by the applied probe;

b) A part involving a risk of electric shock is rendered accessible (transitory or permanent) as a result of the application of either probe; or

c) There is a reduction in resistance between a part involving a risk of electric shock and an accessible part such that the module or panel would not comply with the Leakage Current Test, Section 21.

23.4 A risk of injury to persons is considered to exist, if, as a result of the application of either probe, parts are displaced or broken resulting in an exposed edge that does not comply with the requirements for sharp edges in 6.9 and 6.10.

24 Cut Test

24.1 A module or panel shall withstand the application of a sharp object drawn across its superstrate and substrate surfaces without creating a condition described in 2.7.

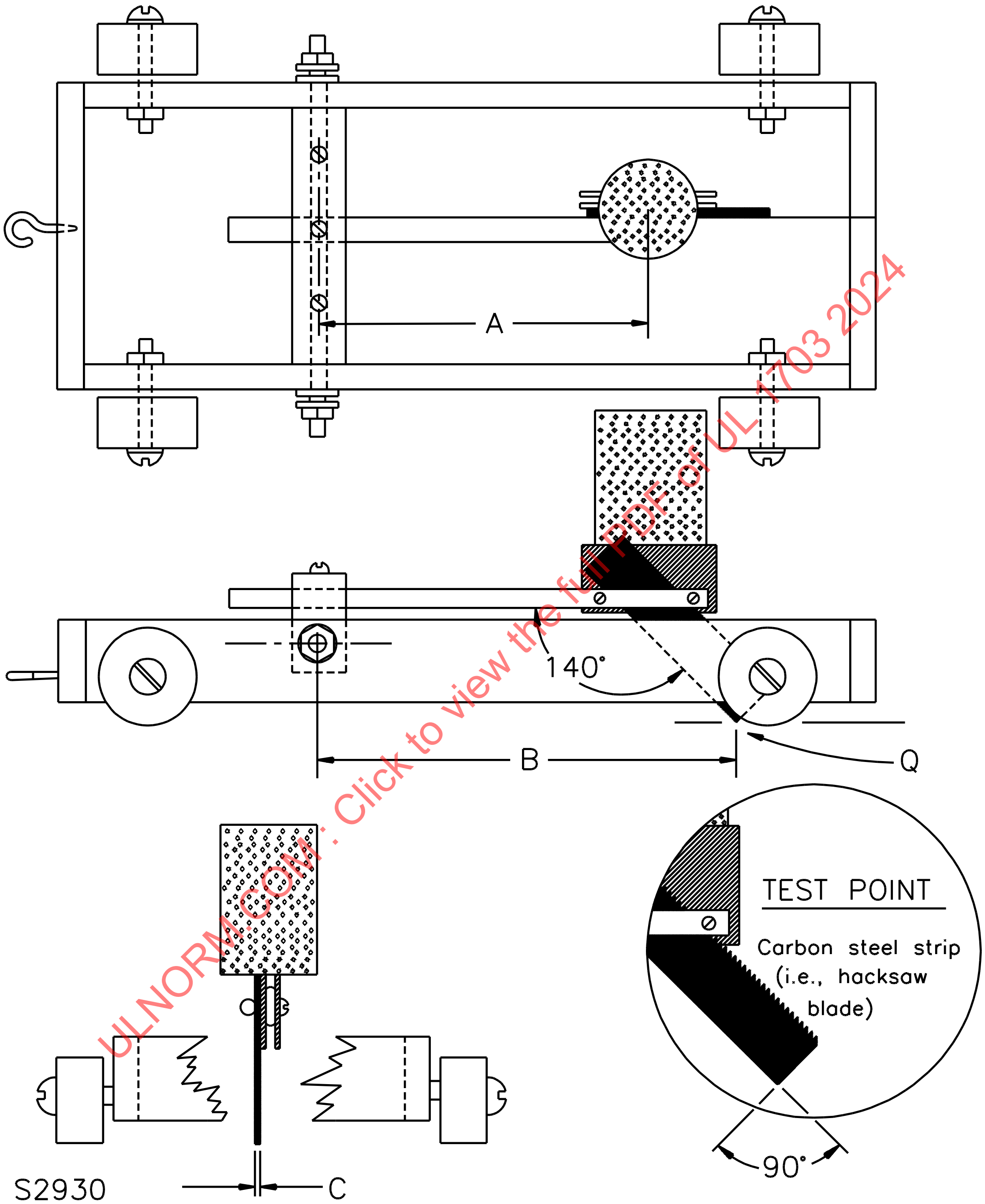
Exception: Glass surfaces are not required to be tested.

24.2 The module or panel is to be positioned in a horizontal plane with the surface to be tested facing upward. The tool illustrated in Figure 24.1 is to be placed on the surface for 1 min, and then drawn across the test surface of the module or panel at a speed of 6 ±1.2 in/s (152.4 ±30.5 mm/s).

24.3 A condition as described in 2.7 exists when the blade of the tool illustrated in Figure 24.1, contacts a part described in 2.7, or such a part is rendered accessible (transitory or permanent) as a result of the placement of the blade on, or the drawing of the blade across, the surface.

Figure 24.1

Cut test tool



A – 5-7/8 in (149 mm) from axis to center of weight.

B – 6-5/8 in (168 mm) from axis to test point.

C – Test point – 0.025 in (0.64 mm ± 0.05 mm) thick carbon steel strip, corner angle 90° ± 2°, corner radius 0.115 mm ± 0.025 mm, in accordance with the Standard Specification for Steel Blades Used with the Photovoltaic Module Surface Cut Test, ASTM E2685.

Q – Total force exerted at test point Q; 2 lb (907 g).

25 Bonding Path Resistance Test

25.1 The resistance between the grounding terminal or lead and any accessible conductive part shall not be more than 0.1 ohm when measured in accordance with 25.2.

25.2 A current equal to twice the fuse ampere rating specified in accordance with 47.10 is to be passed between the grounding terminal or lead and the conductive part. The resistance is to be calculated using the voltage drop measured between the grounding terminal or lead and a point within 1/2 in (12.7 mm) of the point of current injection.

25.3 If more than one test is needed to evaluate all the paths of conduction between accessible metal parts, there is to be a cooling time of at least 15 min between tests.

25.4 The test is to be conducted on three unconditioned samples.

26 Dielectric Voltage-Withstand Test

26.1 The insulation and spacings between live parts and accessible conductive parts and between live parts and exposed nonconductive surfaces shall withstand the application of a dc test voltage equal to two times the system voltage plus 1000 V without the leakage current between these two points exceeding 50 μA dc. The voltage is to be applied in both polarities.

Exception: For a module or panel with a system voltage rating of 30 V or less, the applied voltage is to be 500 V.

26.2 The test voltage is to be applied between all current-carrying parts and all accessible parts.

26.3 The voltage is to be increased from zero at a substantially uniform rate as described in 26.4, so as to reach the specified test potential in approximately 5 s, and then is to be held at the required test voltage until the leakage current is stabilized for at least 1 min. The module or panel is to be observed during the test and there are to be no signs of arcing or flash-over.

26.4 With reference to 26.3, the test voltage is to be gradually and smoothly increased to the specified value so that:

a) There are no transients that may cause the instantaneous voltage to exceed the peak value specified, and

b) The flow of capacitive current, due to charging, does not cause the test device to indicate breakdown.

26.5 The test is to be conducted on three unconditioned samples, and the samples that have been subjected to the Water Spray Test, Section 33; the Temperature Cycling Test, Section 35; the Humidity Test, Section 36; and the Corrosive Atmosphere Test, Section 37. The unconditioned samples are to be at both room temperature and also as heated from the short-circuit operation portion of the temperature test in Section 19.

26.6 For tests on exposed surfaces of insulating parts, the part is to be covered with conductive foil or the equivalent.

26.7 The equipment for conducting the dielectric voltage-withstand test is to have the following characteristics:

a) A means for indicating the test voltage that is being applied to the product under test;

b) A sensitivity such that a current in excess of 50 μA across the output indicates unacceptable performance; and

c) A capacity of at least 500 VA.

Exception: The capacity may be lower if the means for indicating the test voltage is located in the output circuit – to maintain the potential indicated in 26.1 except in the case of breakdown. The voltage of the source is to be continuously adjustable.

27 Wet Insulation-Resistance Test

27.1 As a result of the test described in 27.2 and 27.3:

a) There shall not be dielectric breakdown or surface tracking as a result of the applied dc voltage;

b) For a module with an area 0.1 m^2 or less, the insulation resistance shall not be less than 400 MΩ; and

c) For a module 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 MΩ•m^2.

27.2 The laminate portion of the module or panel is to be immersed in a non-corrosive liquid agent (surfactant) solution. The liquid agent is to have 35 ohm-meter maximum resistance and a temperature of 22 ±3°C (72 ±5°F). Terminal boxes and pigtail-leads or other connectors are to be maintained above the solution level and are to be thoroughly wetted by pouring the solution over these areas. Uninsulated terminations are not to be wetted.

27.3 After two min of immersion in the solution, the insulation resistance between the shorted output terminals of the module or panel and the solution is to be measured, in both polarities, with an instrument having a voltage of 500 Vdc.

28 Reverse Current Overload Test

28.1 The maximum external module surface temperature during the test as located by infrared camera and measured by thermocouples shall not exceed 150°C (302°F) and there shall be no flaming of the module or panel itself for 15 s or more, nor charring of the module or underlying support, when a reverse current equal to 135 percent of the module or panel series overcurrent protective device rating current (See 47.10) is caused to flow through the module or panel in accordance with 28.1A. The type of thermocouples are to be appropriate for the maximum permitted temperature (for example types T, K and E per the IEC 60584 standards for thermocouples). The test shall be conducted at ambient air temperature of 20 ±5°C (68 ±9°F) in an environment where the ambient air is still with no forced circulation.

Note: The Technical Specification for Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 3: Photovoltaic modules and plants – Outdoor infrared thermography, IEC TS 62446-3, provides guidance on the use of IR-cameras.

28.1A A reverse current equal to 135 percent of the module or panel series overcurrent protective device rating current is be applied to the module or panel. After 1 h, the hottest point(s) is to be determined, e.g. by using an infrared camera. The current is to then be switched off, the module or panel cooled down to room temperature and then a thermocouple is to be attached to this point(s) using a means that is compatible with the highest temperature allowed. The module or panel is to be reheated by reapplying a reverse current equal to 135 percent of the module or panel series overcurrent protective device rating current for 2 h (See 28.5). The temperature(s) measured by the thermocouple(s) are to be recorded at the end of the test.

Note: Annex B of the Standard for Photovoltaic System Performance – Part 1: Monitoring, UL 61724-1, covers guidelines for PV module temperature measurement for performance measurements or for monitoring. Attachment of thermocouples per this reference is recommended. Tape may not be a likely candidate for the attachment means.

28.2 To determine whether a module or panel complies with the requirements in 28.1, a module or panel shall be mounted with the module sunny side down. The front to underlying surface clearance shall be the clearance specified in the manufacturer's mounting instructions. If the instructions offer more than one option, the option providing the worst-case clearance shall be used. If no indications have been provided for spacing, or if the module manufacturer allows mounting flush to the supporting surface within the product mounting guidelines, the module front shall be mounted in contact on a solid support that has sufficient mechanical strength to avoid warping under temperature influence. The thermal conductivity of the support shall be not higher than 0.5 W/(m·K)

28.3 For the test required by 28.1, any blocking diode provided as a part of the module or panel is to be defeated (short-circuited).

28.4 The test required by 28.1 is to be conducted in an area free of forced air circulation, and at an ambient temperature of 20 ±5°C (68 ±9°F), and the irradiance on the module or panel is to be less than 5 mW/cm^2.

28.5 The test required by 28.1 is to be continued for 2 h or until ultimate results are known, whichever occurs first.

29 Terminal Torque Test

29.1 A wire-binding screw or nut on a wiring terminal shall be capable of withstanding 10 cycles of tightening to and releasing from the applicable value of torque specified in Table 29.1 without:

a) Damage to the terminal supporting member,

b) Loss of continuity, or

c) Short circuiting of the electrical circuit to accessible metal.

Table 29.1
Torque requirements

Screw size	Torque	
	Lbf-in	(N·m)
No. 6	12	(1.4)
No. 8	16	(1.8)
No. 10	20	(2.3)

30 Impact Test

30.1 A polymeric material serving as the enclosure of a part involving a risk of fire or electric shock and a superstrate material evaluated in accordance with 17.1(c) are to be subjected to the tests described in 30.2 and 30.3.

30.2 When a module or panel is impacted as described in 30.3, there shall be no accessible live parts as defined in Accessibility of Uninsulated Live Parts, Section 15. Breakage of the superstrate material is acceptable provided there are no particles larger than 1 square in (6.5 cm^2) released from their normal mounting position.

30.3 A module or panel is to be mounted in a manner representative of its intended use, and is to be subjected to a 5 ft-lb (6.78 J) impact normal to the surface resulting from a 2-in (51-mm) diameter smooth steel sphere weighing 1.18 lb (535 g) falling through a distance of 51 in (1.295 m). The module or panel is to be struck at any point considered most vulnerable. If the construction of a module or panel does not permit it to be struck free from above by the free falling sphere, the sphere is to be suspended by a cord and allowed to fall as a pendulum through the vertical distance of 51 in with the direction of impact normal to the surface. For a polymeric wiring enclosure, the test is to be performed on the enclosure at 25°C (77°F) and also after being cooled and maintained for 3 h at a temperature of minus 35.0 ±2.0°C (minus 31.0 ±3.6°F).

31 Fire Tests

31.1 Type tests for fire performance characterization of modules and panels independent of roof coverings

31.1.1 General

31.1.1.1 To label a module or panel as a specific “Type” as defined in 16.4.1 so that it may be labeled in accordance with 47.11.1, it shall be subjected to a spread-of-flame test and a burning brand test as described in the Standard Test Methods for Fire Tests of Roof Coverings, UL 790, as modified in accordance with Sections 31.1.2 and 31.1.3. The specific tests to be conducted for new "Types" are outlined in Table 31.1.

Table 31.1
Required tests for fire performance of PV modules or panels independent of mounting system and roof covering

Test	Fire Performance Characteristics		
Spread of Flame On Top Surface of Module or Panel (Section 31.1.2)	Flame Spread less than 6 ft. in 10 minutes	Flame spread less than 8 ft. in 10 minutes	Flame spread less than 13 ft. in 4 minutes
Burning Brand on Surface of Module or Panel (Section 31.1.3)	A Brand	B Brand	C Brand
One test is required for each of the above required tests.			

31.1.2 Spread of flame on top surface

31.1.2.1 The spread-of-flame tests shall be conducted on PV modules or panels. Tests shall be conducted using the apparatus as described in the Standard Test Methods for Fire Tests of Roof Coverings, UL 790, and the tests modified as follows. Tests shall be conducted with the module or panel oriented such that the ignition flame is directed on the top surface of the module or panel. The module or panel shall be mounted upon a noncombustible surface at standoff height of 5 inches (127 mm). If the module or panel length is less than the maximum allowable flame spread of the intended fire class of the test, then additional modules or panels shall be used to meet or exceed the flame spread length criteria.

31.1.2.2 At no time during the tests shall:

a) Any portion of the module or panel be blown off or fall off the test deck in the form of flaming or glowing brands;

b) The flame spread on the module or panel surfaces beyond 6 ft (1.82 m) in 10 minutes, 8 ft (2.4 m) in 10 minutes, or 13 ft (3.9 m) in 4 minutes depending upon the definition of the module or panel “Type” the test is being performed to verify in accordance with 16.4.1. The flame spread is to be measured from the leading edge of the test deck. Spread-of-flame includes flaming on both the top and bottom surface of the module or panel; or

c) There be significant lateral spread-of-flame on the module or panel. Significant lateral spread shall be considered to have occurred when surface flaming beyond 1 foot (0.3 m) from the lead edge extends laterally on the module or panel to the full 40-inch (1016 mm) width of the test deck assembly. Lateral flame spread includes flame spread under or along the equipment under test.

With respect to (a), any piece of PV module or panel, that continues to glow or flame for 5 seconds or more upon landing on the test room floor is a glowing or flaming brand, respectively. A module or panel is not required to be usable after any of the tests of this Section.

31.1.3 Burning brand on top surface

31.1.3.1 Tests shall be conducted as described in the Standard Test Methods for Fire Tests of Roof Coverings, UL 790, and the tests modified as follows. Tests shall be conducted on the top surface of the module or panel with no roof covering below the module or panel using the specific type of brand (A, B or C) as specified in the definition of the "Type" of module or panel the test is being performed to verify in accordance with 16.4.1.

31.1.3.2 At no time during the tests shall:

a) Any portion of the module or panel or be blown off or fall off the test deck in the form of flaming or glowing brands;

b) The brand burn a hole through any part of the module or panel;

c) There be sustained flaming of the module or panel. Sustained flaming is considered any flaming which continues uninterrupted for 5 seconds or more.

With respect to (a), any piece of PV module or panel, that continues to glow or flame for 5 seconds or more upon landing on the test room floor is a glowing or flaming brand, respectively. A module or panel is not required to be usable after any of the tests of this Section.

31.1.4 Recording

31.1.4.1 The fire performance for a module or panel shall be recorded as follows:

a) Observations of the burning characteristics of the PV module or panel during and after test exposure, and

b) Results of tests relative to the corresponding conditions of acceptance for the "Type" of module the tests are being performed to verify in accordance with 16.4.1.

31.2 System Fire Class Rating of module or panel with mounting systems in combination with roof coverings

31.2.1 General

31.2.1.1 For both the Spread-Of-Flame and Burning-Brand Tests, the test severity (Class A, B, or C) shall be commensurate with the intended designated System Fire Class Rating for building code compliance purposes as outlined in Table 31.2.

Table 31.2
Required tests for System Fire Class Rating of PV module or panel with mounting system in combination with roof coverings

Test	Tests Over Representative Roof Coverings		
	Class A	Class B	Class C
Spread of Flame On Top Surface of Module or Panel (Section 31.1.2)[a]	Flame Spread less than 6 ft. in 10 minutes	Flame spread less than 8 ft. in 10 minutes	Flame spread less than 13 ft. in 4 minutes
Spread of Flame at Roof and Module or Panel Interface Over Representative Steep Sloped Roof [31.2.2.1(a)][b]	Pass	Pass	Pass
Spread of Flame at Roof and Module or Panel Interface Over Representative Low Sloped Roof [31.2.2.1(b)][b]	Pass	Pass	Pass
Burning Brand on Surface Over Representative Steep Sloped Roof [31.2.3.1(a)][b]	A Brand	B Brand	C Brand
Burning Brand Between Module or Panel and Representative Steep Sloped Roof [31.2.3.1(b)][b]	Pass	Pass	Pass

[a] Requirement can be met by either with a type tested module (16.4.1) or by performing the test in Section 31.1.2 on the top surface of a module or panel in the mounting system being qualified in 31.2. For non-type tested products, the product must pass two consecutive tests for each required test.

[b] Two consecutive tests for each test must be passed unless not required by the terms of 31.2.1.3, Section 31.2.2 or Section 31.2.3. For the purpose of this standard, Steep and Low Sloped Roof are defined in 31.2.1.2.

31.2.1.2 A fire rated module or panel intended for stand-off or rack mounting in combination with roof coverings shall be installed as shown in this Section and according the manufacturer's installation instructions for both the module and mounting system with respect to the fire performance requirements for Class A, B, or C when the module or panel is marked as being fire rated as specified in 47.11. For installations that are wider than the 40 inch (1016 mm) standard test deck, supports may need to be fabricated on which to mount the mounting system. Any support system is to be developed to ensure consistency with installation instructions and field conditions. The mounting system with installed PV module(s) or panel(s) shall be centered on the test deck and extend to the edges of the test deck. The mounted modules or panels shall be tested in combination with the following roof constructions:

Steep-Sloped Systems – Spread of Flame: When designed for steep-sloped roofs for slopes greater than or equal to 2 in/ft (167 mm/m), a module or panel intended for stand-off or rack mounting in combination with a roof covering shall be tested in combination with the following roof construction:

a) Roofing substrate: 15/32 inch (12 mm) thick plywood;

b) Underlayment: ASTM D226 Type 1 Roofing Underlayment (also known as 15 lb Roofing Felt); and

c) Roof Covering: Listed Class A 3 tab asphalt shingle, ASTM D3462, "Standard Specifications for Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules." As an alternate roof construction it is permitted to use any Classified rolled asphalt membrane mechanically secured over a noncombustible substrate.

The roof covering system must demonstrate a flame extension of at least 48 inches (1219 mm) and not more than 72 inches (1829 mm) in the average of three baseline tests.

Low-Sloped Mounting Systems – Spread of Flame: When designed for low-sloped roofs for slopes less than 2 in/ft (167 mm/m), a module or panel intended for stand-off or rack mounting in combination with a roof covering shall be tested in combination with the following roof construction:

a) Roofing substrate: 15/32 inch (12 mm) thick plywood;

b) Insulation: 4 inch (102 mm) polyisocyanurate insulation; and

c) Roof Covering: Single-ply, mechanically attached, membrane with the system having demonstrated a Class A fire rating. One roof covering system that has been found to comply is an EPDM rubber membrane, minimum thickness of 0.060 inch (1.5 mm).

The roof covering system must demonstrate a flame extension of at least 48 inches (1219 mm) and not more than 72 inches (1829 mm) in the average of three baseline tests.

Steep-Sloped Systems – Burning Brand: When designed for steep-sloped roofs for slopes greater than or equal to 2 in/ft (167 mm/m), a module or panel intended for stand-off or rack mounting in combination with a roof covering shall be tested in combination with the following roof construction:

a) Roofing substrate: 3/8 inch (9.5 mm) thick plywood;

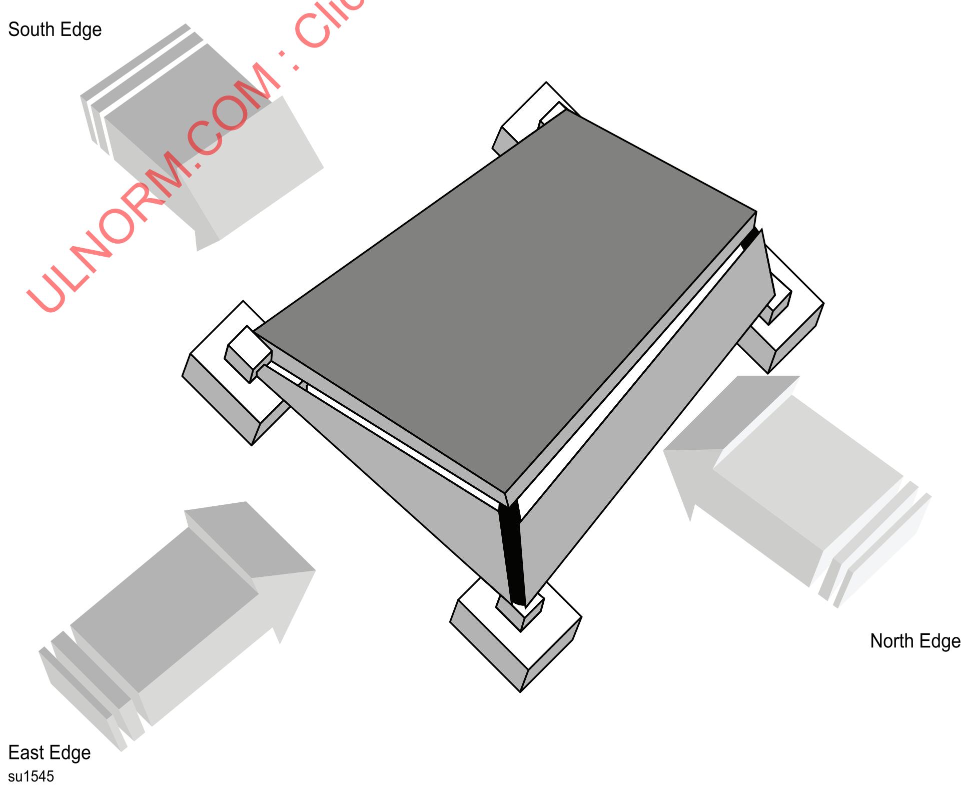
b) Underlayment: ASTM D226 Type 1 Roofing Underlayment (also known as 15 lb Roofing Felt); and

c) Roof Covering: Listed Class A 3 tab asphalt shingle, ASTM D3462, "Standard Specifications for Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules."

31.2.1.3 For low-sloped mounting systems with an asymmetrical edge configuration (e.g. sloped ballasted system), the spread of flame test for low-sloped mounting systems described in 31.2.1.2 shall be performed at (1) the south edge, (2) east edge, and (3) the north edge of a typical perimeter array block used for the mounting system. All required wind deflectors and ballast shall be installed when performing the test. Each test shall be performed with new modules or panels. See Figure 31.1 for clarification on the three required flame test locations for the asymmetrical mounting system.

Figure 31.1

Demonstration of the three test locations



31.2.1.4 For both the Spread-Of-Flame and Burning-Brand Tests, the module or panel is to be installed in accordance with the manufacturer's instructions for both the module and the mounting system, except where described in 31.2.3.1. The mounting hardware furnished with the module or panel, or the mounting means recommended in the instructions, is to be used to mount the module or panel for the test.

31.2.1.5 For steep sloped roofs, the inclination of the module or panel with respect to the roof is to be the minimum module or panel inclination specified in the installation instructions. The slope of the simulated roof deck shall be 5 in/ft (416 mm/m).

31.2.1.6 For low sloped roofs, the inclination of the module or panel with respect to the roof is to be the minimum module or panel inclination specified in the installation instructions. The slope of the simulated roof deck shall be 0.5 in/ft (41.6 mm/m).

31.2.1.7 A module or panel is not required to be usable after any of the tests of this Section.

31.2.2 Spread-of-flame tests

31.2.2.1 The spread-of-flame tests are to be conducted on PV modules or panels. Tests are to be conducted using the apparatus as described in the Standard Test Methods for Fire Tests of Roof Coverings,UL 790, and the tests modified as described in the following subsections. For the tests described in (a) and (b), the modules or panels shall be evaluated in combination with the intended mounting systems as described in the accompanying manufacturer's installation instructions.

a) Spread of Flame at Roof and Module or Panel Interface Over Representative Steep Sloped Roof. With the module or panel installed on a steep slope roof as an assembly and oriented such that the fire growth from the roof covering materials advances to the interstitial space below the module or panel and above the roof. Mounting equipment that prevents flame in the interstitial space is permitted to meet this requirement. The module or panel installation shall be installed with a minimum of 36 inches (910 mm) between the edge of the flame test apparatus and the edge of the PV mounting system, as defined by the PV module or a deflector in the direct flame path upon the test deck, whichever is closer to the leading edge of the test deck. The module or panel installation for steep sloped roofs shall be the measured baseline in accordance with 31.2.1.2 minus 12 inches (303 mm). Figure 31.2 illustrates how the baseline roof tests are used to establish the location of PV mounting system relative to the test flame. Figure 31.3 and Figure 31.4 illustrate where the test sample is to be located relative to the test flame, including application of deflector. The rating obtained for a 5-inch (127 mm) gap between the bottom of the module frame and the roof covering surface can be used for any other gaps allowed by the mounting instructions. This test is not required if the Installation Instructions require that the module or panel only be installed for slopes less than 2 inches/foot (167 mm/m).

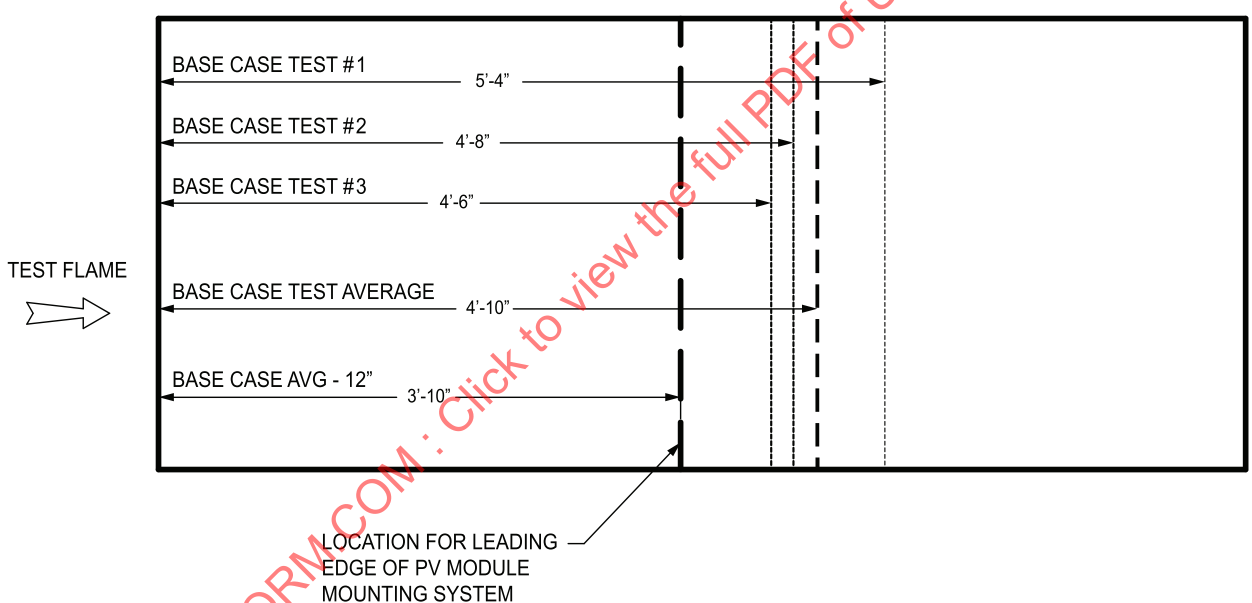
b) Spread of Flame at Roof and Module or Panel Interface Over Representative Low Sloped Roof. With the module or panel installed on a low slope roof as an assembly and oriented such that the fire growth from the roof covering materials advances to the interstitial space below the module or panel and above the roof. Mounting equipment that prevents flame in the interstitial space is permitted to meet this requirement. For low sloped roofs, the module or panel installation shall be installed with a minimum of 36 inches (910 mm) between the edge of the flame test apparatus and the edge of the PV mounting system, as defined by the PV module or a deflector in the direct flame path upon the test deck, whichever is closer to the leading edge of the test deck. The module or panel installation for low sloped roofs shall be the measured baseline in accordance with 31.2.1.2 minus 12 inches (303 mm). For products with asymmetrical edge configurations, these dimensions apply to each of the 3 tests described in 31.2.1.3. Figure 31.5 – Figure 31.12 illustrate where the test sample is to be located relative to the test flame, including application of deflector. If no gap height is specified in the manufacturer's instructions, a 5-inch (127 mm) gap between the bottom of the module frame and the roof covering surface shall be used with the module or panel parallel to the roof surface. The rating obtained for a 5-inch (127 mm) gap can be used for any other gaps allowed by the mounting instructions. This test is not required if the Installation Instructions require that the module or panel only be installed for slopes greater than 2 inches/foot (167 mm/m).

A deflector is defined as a continuous flame mitigation device which has a significant impact on the flame path and/or air flow direction. Breaks are permitted if no change in the impact on the flame path and/or air flow direction can be expected. The deflector cannot be used to adjust the offset distance by more than 6 inches (152.4 mm). If the deflector is greater than 6 inches away from the module edge, then the edge of the PV mounting system is considered to be 6 inches away from the module frame. For the purposes of defining test configurations, the deflector shall be installed as described by the installation manual on the leading edge only.

Note: Testing during the development of fire testing procedures suggest that 5 inches (127 mm) is a worst case condition.

Figure 31.2

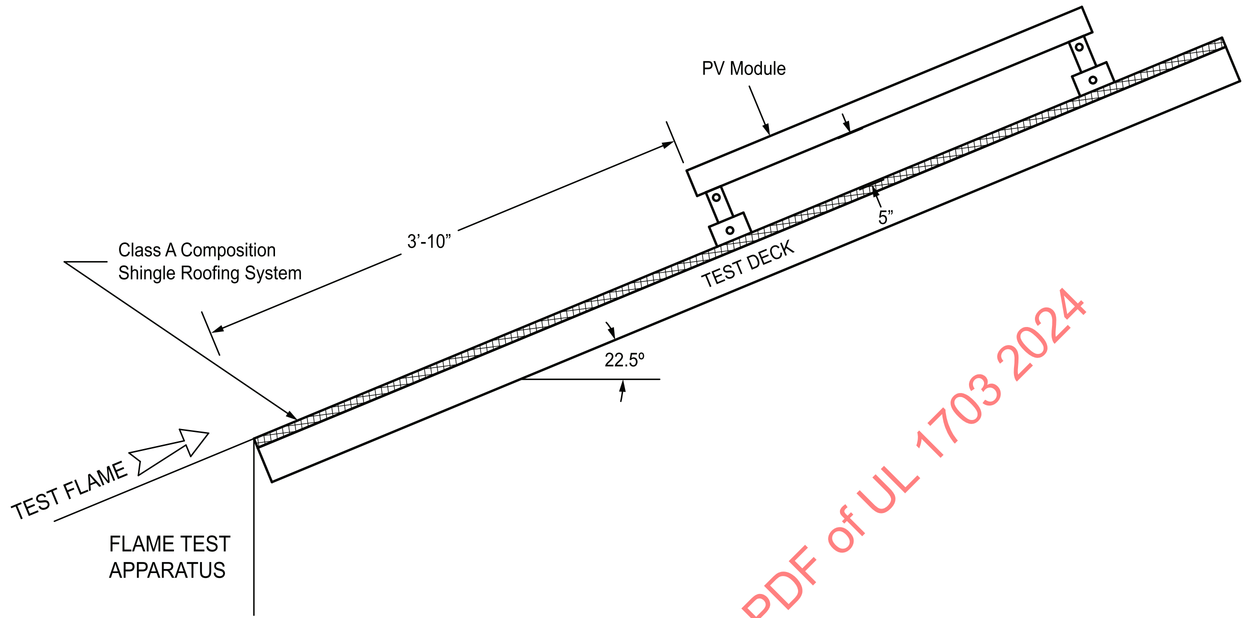
Method to determine location of PV module mounting system for steep-sloped and low-sloped flame spread test



su1526

Figure 31.3

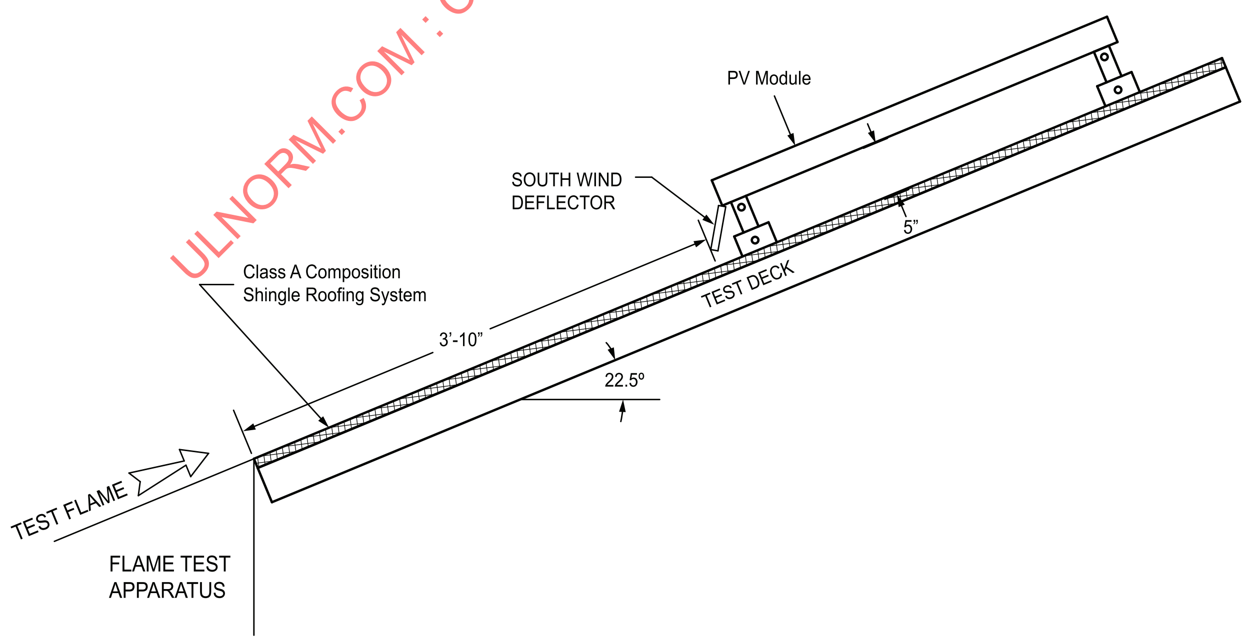
Steep-sloped flame spread test deck-south edge



su1527

Figure 31.4

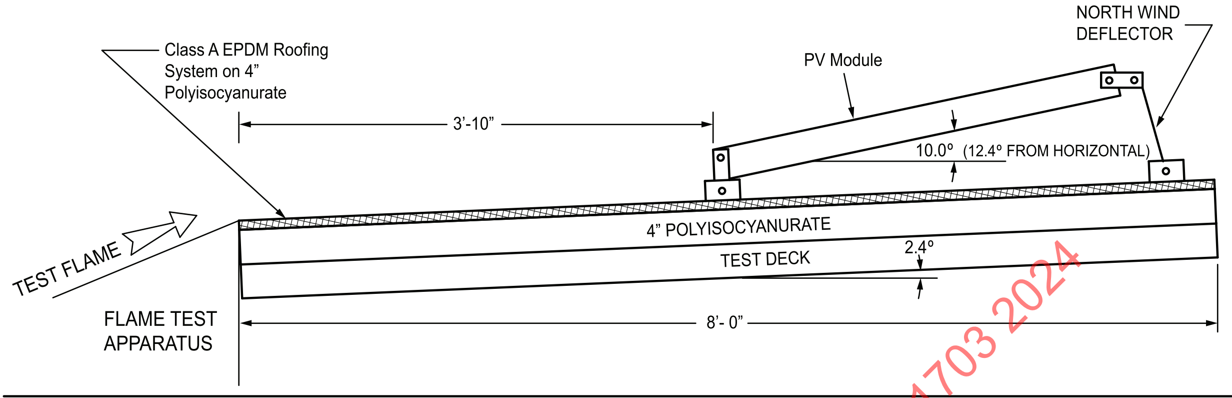
Steep-sloped flame spread test deck-south edge with deflector



su1528

Figure 31.5

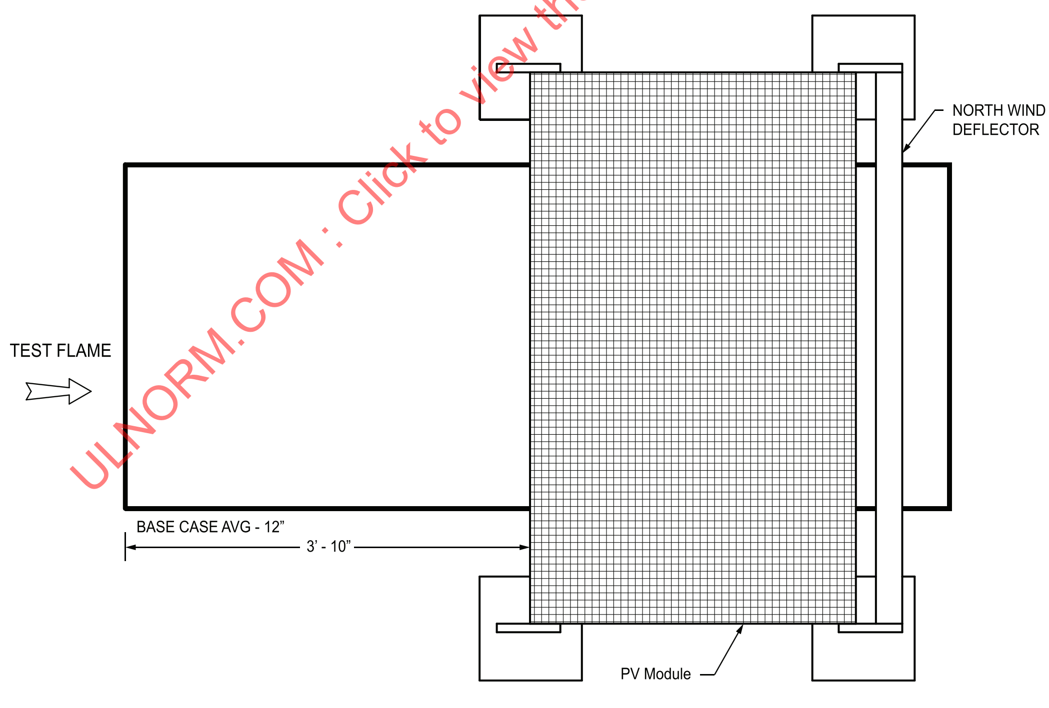
Low-sloped flame spread test deck-south edge (asymmetrical cross section)



su1529

Figure 31.6

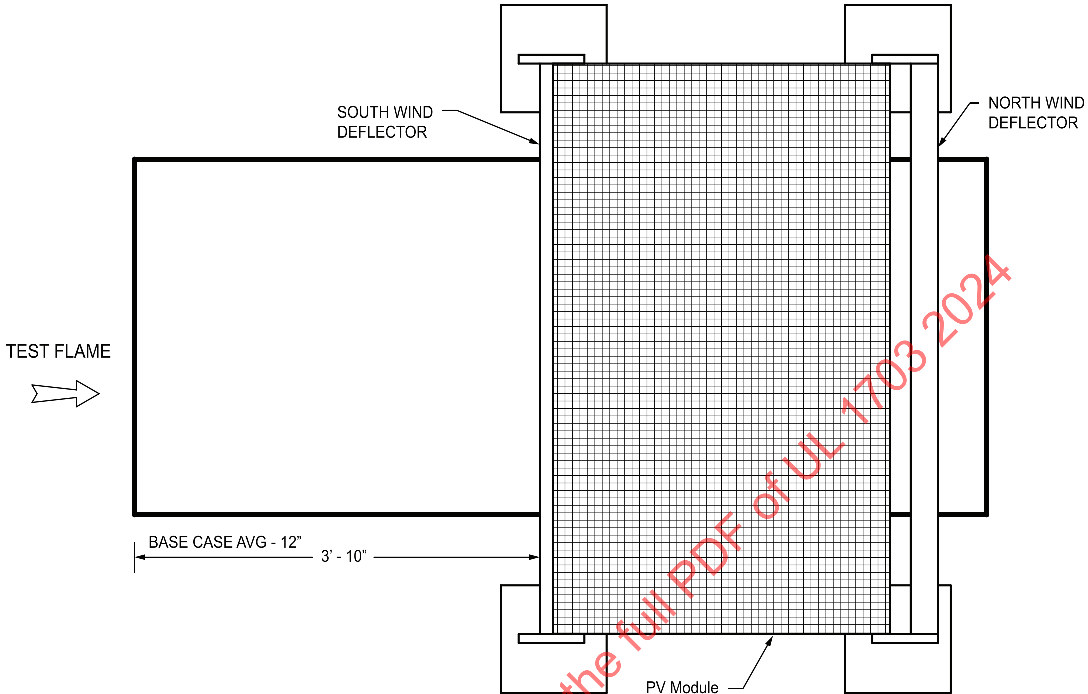
Placement of PV mounting system relative to test flame for flame spread test deck-south edge (no south deflector-asymmetrical cross-section)



su1530

Figure 31.7

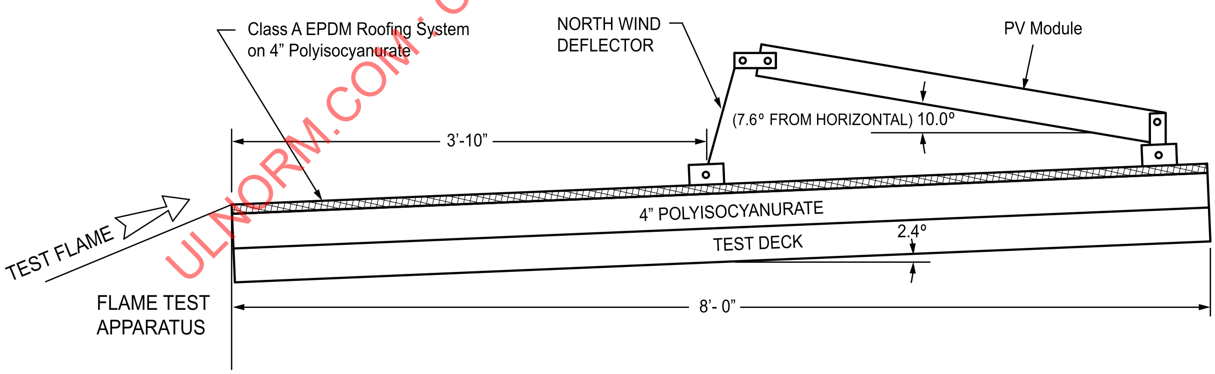
Placement of PV mounting system relative to test flame for low-sloped flame spread test deck-south edge (south deflector – asymmetrical cross-section)



su1531

Figure 31.8

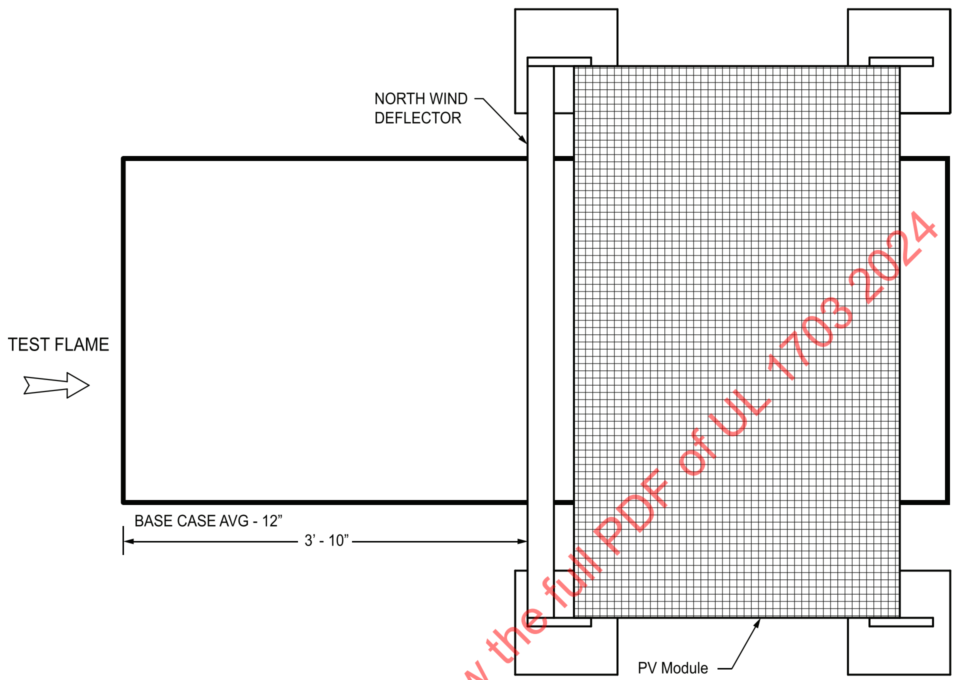
Low-sloped flame spread test deck-north edge (asymmetrical cross-section)



su1532

Figure 31.9

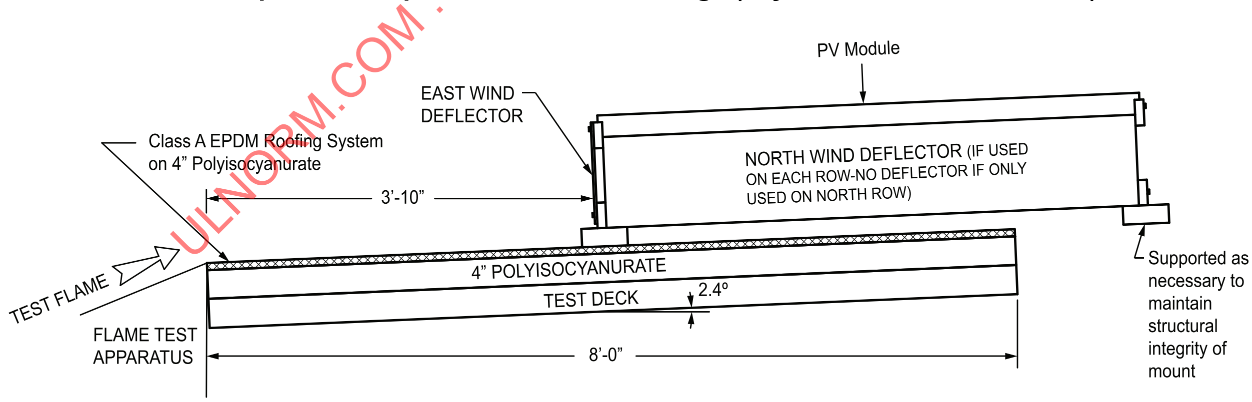
Placement of PV mounting system relative to test flame for flame spread test deck-north edge (asymmetrical cross-section)



su1533

Figure 31.10

Low-sloped flame spread test deck-east edge (asymmetrical cross section)



su1534

Figure 31.11

Placement of PV mounting system relative to test flame for flame spread test deck-east edge (asymmetrical cross-section)

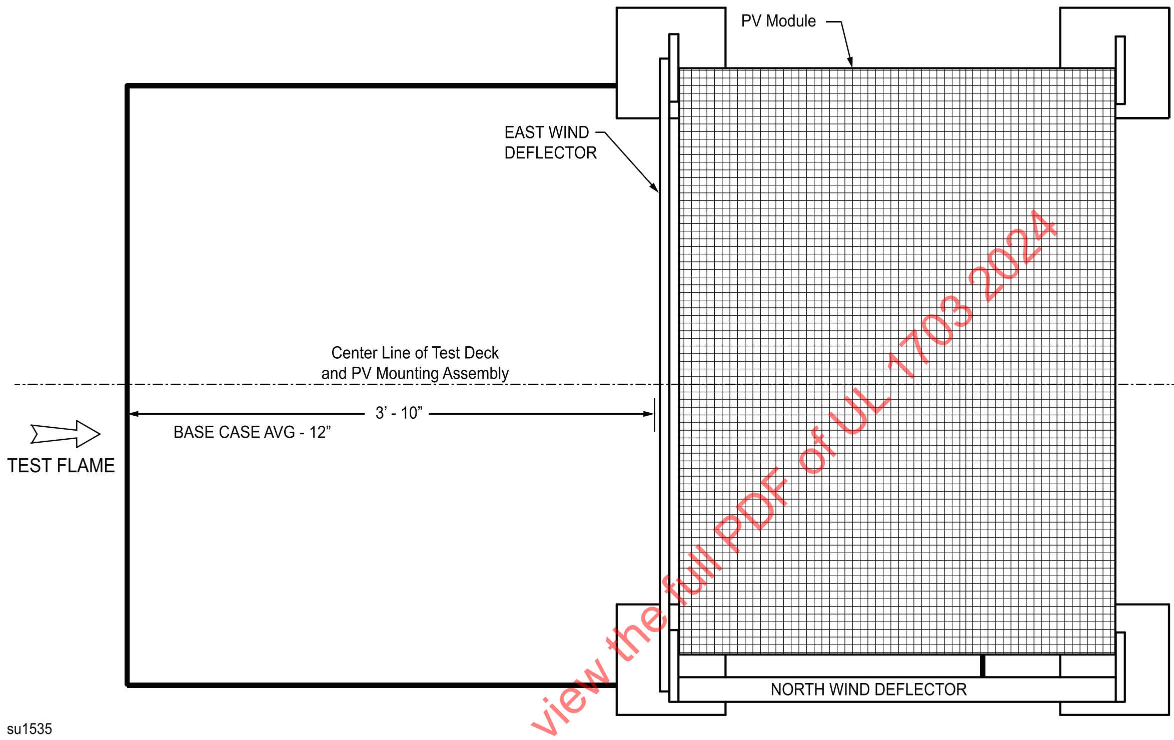
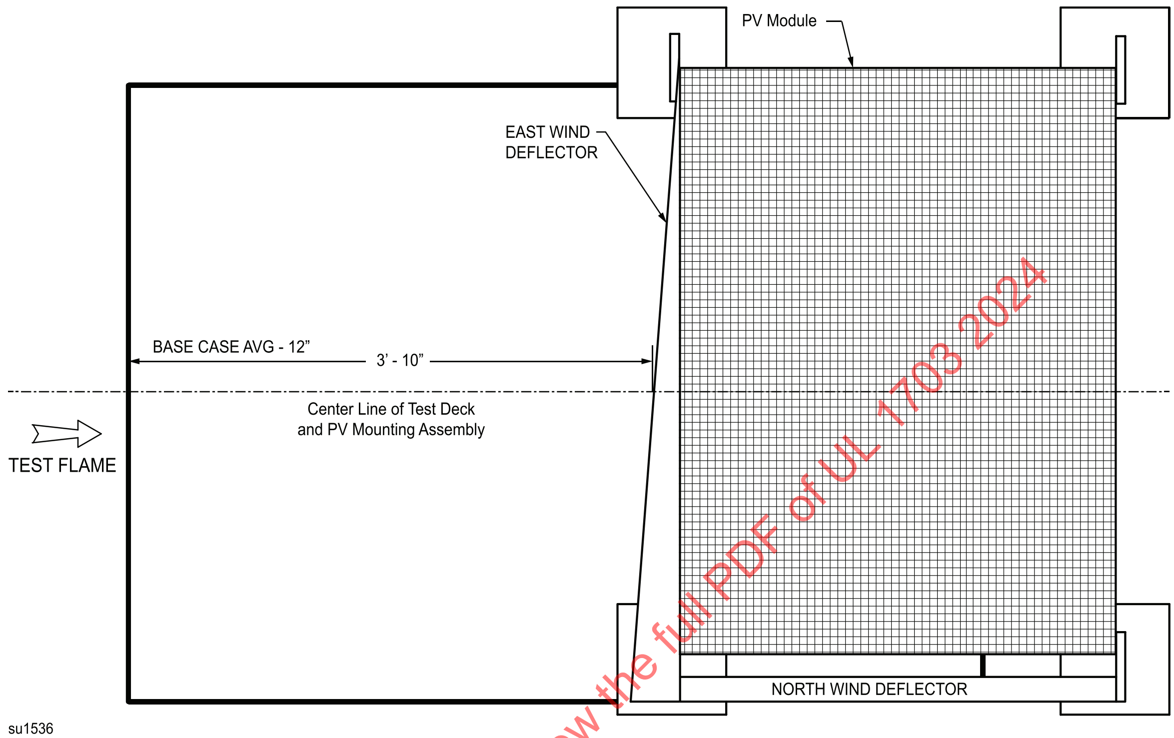


Figure 31.12

Placement of PV mounting system relative to test flame for flame spread test deck-east edge (asymmetrical cross-section, angled deflector)



31.2.2.2 For the Spread-of-Flame Tests, Section 31.2.2, at no time during the tests shall:

a) Any portion of the module or panel be blown off or fall off the test deck in the form of flaming or glowing brands;

b) Portions of the roof deck fall away in the form of glowing particles;

c) The flame spread on the roof surface, or module or panel surfaces beyond 6 ft (1.8 m). The flame spread is to be measured from the leading edge of the test deck. Spread-of-flame includes flaming on both the top and bottom surface of the module or panel; or

d) There be significant lateral spread-of-flame on the module or panel. Significant lateral spread shall be considered to have occurred when surface flaming extends laterally on the mounting system or the module or panel to the full 40-inch (1016 mm) width of the test deck assembly. Lateral flame spread includes flame spread under or along the equipment under test, but not the roof surface.

With respect to (a), any piece of PV module or panel, that continues to glow or flame for 5 seconds or more upon landing on the test room floor is a glowing or flaming brand, respectively. A module or panel is not required to be usable after any of the tests of this Section.

31.2.3 Burning-brand tests for steep sloped mounting systems

31.2.3.1 Burning brand tests are to be conducted on PV modules or panels designed for steep sloped applications. The modules or panels shall be evaluated in combination with the intended mounting systems as described in the accompanying manufacturer’s installation instructions. Tests are to be conducted as described in the Standard Test Methods for Fire Tests of Roof Coverings, UL 790. The tests shall be modified as described in this Section, using the steep sloped roof covering as described in 31.2.1.2, and the Class A burning brand plywood test deck as described in UL 790, Figure 4.5. The module or panel is to be mounted with the longer dimension coinciding with the width of the test deck and with the horizontal and vertical joints on the test deck intersecting the center of the module or panel in both dimensions. For modules or panels with a short dimension in excess of 52 inches (1321 mm), the module or panel leading edge shall match the leading edge of the test deck. For modules or panels, which are only to be installed according to manufacturer's installation instruction with the shorter dimension coinciding with the width of the test deck, the module or panel shall be tested with the shorter dimension coinciding with the width of the test deck and the module or panel leading edge shall match the leading edge of the test deck. The test shall be applied as follows:

a) Burning Brand on Surface Over Representative Steep Sloped Roof. With a Class A , B, or C brand(s) positioned on the top of the module or panel that has a gap of 5 inches (127 mm) above the surface of the test deck. If the installation instructions do not allow a gap of 5 inches (127 mm), then the module shall be installed above the surface of the test deck according the installation instructions. The brand is to be positioned with its upper edge 25.5 inches (648 mm) from the leading edge of the test deck and centered laterally with respect to the vertical joint in the test deck. The brand is to be placed so that the strips in both the upper and lower layers are parallel to the direction of air flow. The brand is to be secured to the module using a No. 18 B&S gage (0.82 mm^2) soft-iron wire secured to the deck.

Exception: For systems using a Type 2 module and installed with a gap of 5 inches (127 mm), the burning brand test for part (a) shall be waived.

b) Burning Brand Between Module or Panel and Steep Sloped Roof. With a Class B brand positioned in the 5 inch (127 mm) interstitial space below the module or panel and on the surface of the roof. If the installation instructions do not allow a gap of 5 inches (127 mm), then the module shall be installed above the surface of the test deck according the installation instructions. The brand is to be positioned with its upper edge 24 inches (610 mm) from the leading edge of the test deck and centered laterally with respect to the vertical joint in the test deck. The brand is to be placed so that the strips in both the upper and lower layers are parallel to the direction of air flow. The brand is to be secured to the deck by a No. 18 B&S gage (0.82 mm^2) soft-iron wire.

Exception No. 1: For mounting systems with a guarded perimeter, the burning brand test for part (b) shall be waived. A guarded perimeter is defined as a perimeter that is protected with wire screen or other similar means including sheet metal. A guarded perimeter with openings shall not allow a 1/4-in (6.4-mm) diameter hemispherical tipped probe applied with a force of 1 lb (4.4 N) to pass through any opening. For mounting systems with a guarded perimeter, the burning brand test for part (b) shall be waived.

Exception No. 2: For systems installed with a fixed height of 2-1/2 inches (64 mm) or less between the system and the test deck as described in the installation instructions, the burning brand test for part (b) shall be waived.

31.2.3.2 At no time during the tests shall:

a) Any portion of the module or panel or be blown off or fall off the test deck in the form of flaming or glowing brands; or

b) There be sustained flaming of the underside of the plywood deck. Sustained flaming is considered any flaming which continues uninterrupted for 5 seconds or more.

With respect to (a), any piece of roof covering, or PV module or panel, that continues to glow or flame for 5 seconds or more upon landing on the test room floor is a glowing or flaming brand, respectively. A module or panel is not required to be usable after any of the tests of this Section.

31.2.4 Recording

31.2.4.1 The fire performance for modules or panels with mounting systems in combination with roof coverings shall be recorded as follows:

a) Observations of the burning characteristics of the PV module or panel with mounting system during and after test exposure;

b) Results of tests in Table 31.2 relative to the corresponding conditions of acceptance in 31.2.2.2 and 31.2.3.2; and

c) The class of PV module or panel mounting system achieved based on test results (Class A, B, or C).

32 General

32.1 *deleted*

32.2 *deleted*

32.3 *deleted*

32.4 *deleted*

33 Water Spray Test

33.1 A module or panel shall be subjected to a water spray test as described in 33.2 – 33.8. The test shall not result in water on uninsulated live parts or the collection of water in a compartment containing live parts. Immediately following the test, the module or panel shall comply with:

a) Dielectric Voltage-Withstand Test, Section 26; and

b) Leakage Current Test, Section 21.

Both the Dielectric Voltage-Withstand Test and the Leakage Current Test are to be conducted without any drying of the samples.

33.2 A module or panel is to be mounted and oriented in a manner representative of its intended use in the focal area of the apparatus described in 33.5. If the mounting or orientation of the module or panel under the water spray may affect the results, the test is to be conducted with the module or panel in those mountings and orientations deemed necessary to represent any application of the product, considering also that the mounting may be on a tracking frame which alters the module orientation.

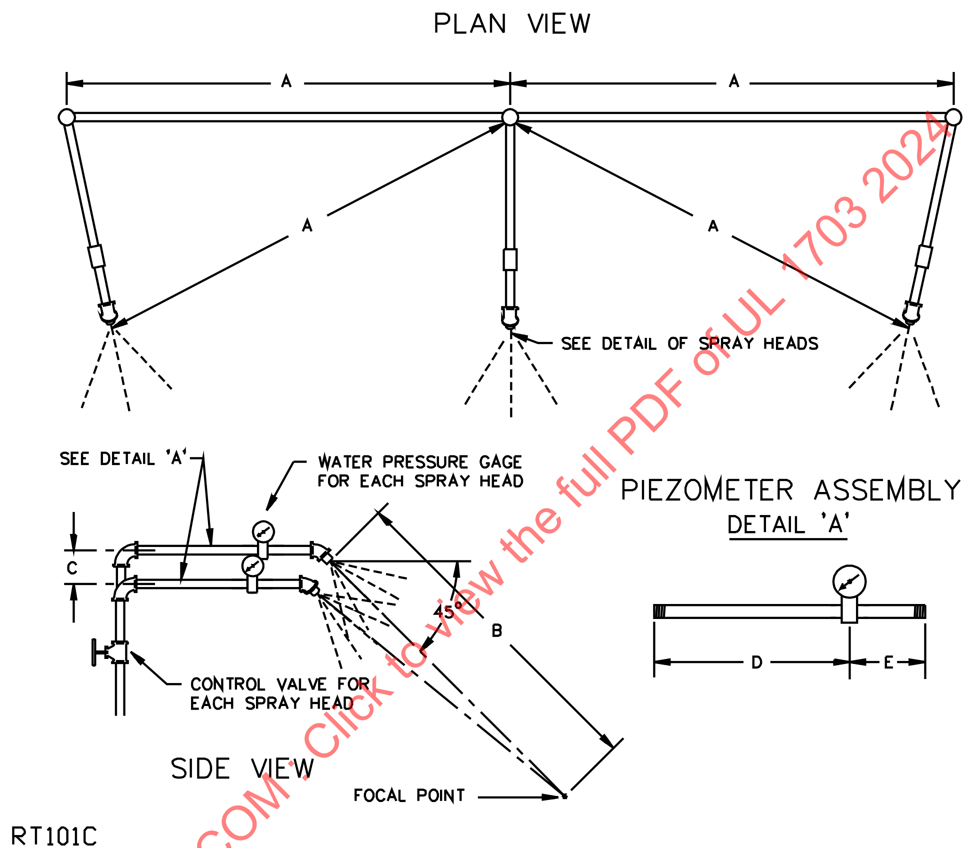
33.3 If a module or panel is intended to be mounted as an integral part of the roof with an adjacent module or panel in an array using factory-designed joining sections, the test is to be conducted using the joining hardware in accordance with the installation instructions.

33.4 Field wiring connections are to be made in accordance with the wiring method specified in the installation instructions. When more than one wiring method is specified, the method least likely to restrict the entrance of water into the field wiring compartment is to be used.

33.5 The rain test apparatus is to consist of three spray heads mounted in a water supply rack as illustrated in Figure 33.1. Spray heads are to be constructed in accordance with Figure 33.2. The water pressure for all tests is to be maintained at 5 psig (34.5 kPa) at each head. The distance between the center nozzle and the product is to be approximately 3 ft (0.9 m). The product is to be brought into the focal area of the three spray heads in such position and under such conditions so as to present the greatest quantity of water to entrances to the product. The spray is to be directed toward the module or panel at an angle of 45 degrees to the vertical.

Figure 33.1

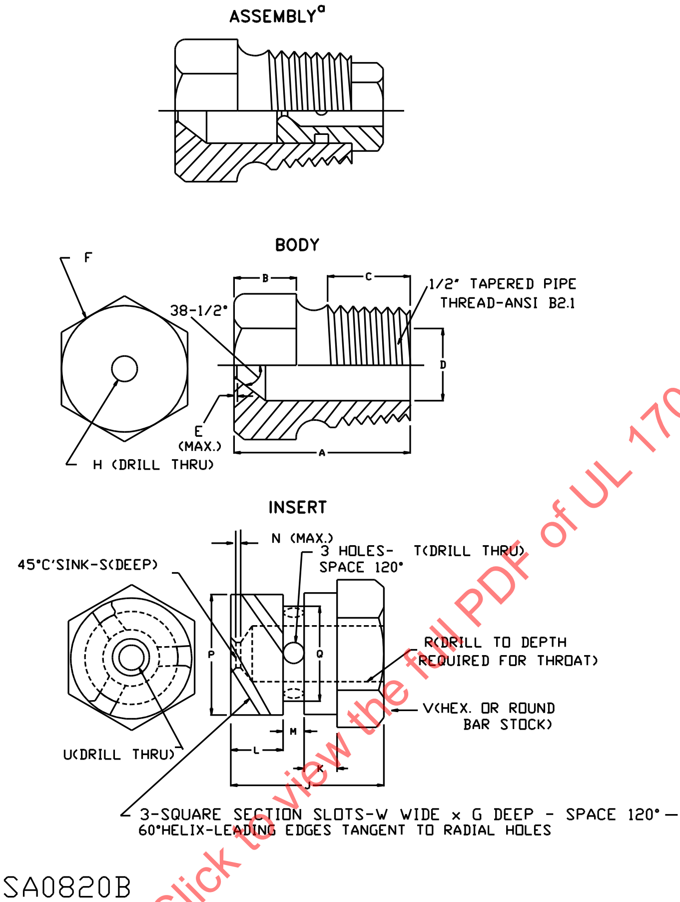
Rain-test spray-head piping



Item	in	mm
A	28	710
B	55	1400
C	2-1/4	55
D	9	230
E	3	75

Figure 33.2

Rain-test spray head



Item	in	mm	Item	in	mm
A	1-7/32	31.0	N	1/32	0.80
B	7/16	11.0	P	.575	14.61
C	9/16	14.0		.576	14.63
D	.578	14.68	Q	.453	11.51
	.580	14.73		.454	11.53
E	1/64	0.40	R	1/4	6.35
F	c	c	S	1/32	0.80
G	.06	1.52	T	(No. 35)[b]	2.79
H	(No. 9)[b]	5.0	U	(No. 40)[b]	2.49
J	23/32	18.3	V	5/8	16.0
K	5/32	3.97	W	0.06	1.52
L	1/4	6.35			
M	3/32	2.38			

[a] Molded nylon Rain-Test Spray Heads are available from Underwriters Laboratories, Inc.

[b] ANSI B94.11 Drill Size.

[c] Optional M To serve as wrench grip.

33.6 *Deleted*

33.7 The exposure time is to be 1 h.

33.8 After exposure, the module or panel is to be examined for evidence of water penetration to and above uninsulated live parts and for evidence of the collection of water in any compartment containing live parts. If drain holes are provided, consideration is to be given to their preventing the water level from reaching uninsulated live parts.

34 Accelerated Aging Test

34.1 Materials used for gaskets, seals, and the like (other than cork, fibrous material, and similar products) shall have the physical properties as specified in Table 34.1, and shall comply with the physical property requirements of Table 34.2. The material shall not deform, melt, or harden to a degree which would affect its sealing properties.

Table 34.1
Physical property requirements

Minimum tensile strength[a]	Minimum ultimate elongation[a]	Compressive set[c], maximum set
Silicone rubber – 500 psi (3.45 MPa)	100 percent	15 percent
Flexible cellular materials (that is such as foam rubber) – 65 psi (0.448 MPa)	100 percent	d
Thermoplastic Elastomer (TPE) – 500 psi (3.45 MPa)	290 percent	55 percent
Other Elastomers – 1500 psi (10.3 MPa)[b]	300 percent[b]	15 percent
Nonelastomers (excluding cork, fiber and similar materials)– 1500 psi (10.3 MPa)[b]	200 percent	15 percent

[a] Tensile strength and ultimate elongation are to be determined using Die C specimens described in the Standard Test Methods for Rubber Properties in Tension, ASTM D 412-98 or Type I specimens described in the Standard Test Method for Tensile Properties of Plastics, ASTM D 638-01.

[b] As an alternate, an ultimate elongation of 200 percent is acceptable providing that the tensile strength is at least 2200 psi (15.1 MPa).

[c] Compressive set is to be determined in accordance with Section 7.4 of the Standard for Gaskets and Seals, UL 157.

[d] Compressive set is not applicable to flexible cellular materials.

Table 34.2
Physical requirements after conditioning

Temperature on material in temperature test		Conditioning Procedure	Minimum percent of the result with unaged specimens		Maximum change (Duro) from unconditioned value[a,b]
°C	(°F)		Tensile strength	Ultimate elongation	
60 or less	(140 or less)	Air oven aging for 70 h at 100 ±2°C (212 ±3.6°F)	60	60	5
61 – 75	(142 – 167)	Air oven aging for 168 h at 100 ±2°C (212 ±3.6°F)	50	50	5
76 – 90	(169 – 194)	Aged in full-draft, air-circulating oven for 168 h at 121 ±2°C (250 ±2°F)	50	50	10

Table 34.2 Continued on Next Page

Table 34.2 Continued

Temperature on material in temperature test		Conditioning Procedure	Minimum percent of the result with unaged specimens		Maximum change (Duro) from unconditioned value[a,b]
°C	(°F)		Tensile strength	Ultimate elongation	
91 – 105	(196 – 221)	Aged in full-draft, air-circulating oven for 168 h at 136 ±2°C (277 ±2°F)	50	50	10
Above 105	(Above 221)	20 ±1°C (36 ±2°F) greater than use temperature in circulating convection oven, 168 h exposure	50	50	10

[a] Determined in accordance with the Standard Method for Rubber Property-Durometer Hardness, ASTM D2240-02.

[b] Not applicable to flexible cellular materials (that is, a material such as foam rubber).

35 Temperature Cycling Test

35.1 A module or panel shall be subjected to 200 cycles of temperature change as described in 35.2 – 35.4; and:

a) The test shall not result in:

1) Loss of circuit continuity;

2) Accessibility of parts that involves a risk of electric shock, such as by delamination or separation of materials;

3) A reduction in the resistance between parts involving a risk of electric shock and an accessible part such that the module or panel is not in compliance with Leakage Current Test, Section 21;

4) Reduction in the thickness of the wall of a nonmetallic wiring compartment below required values;

5) Reduction in the volume of a nonmetallic wiring compartment below required values; or

6) A gap greater than 1/16 in (1.6 mm) or an increase of 1/16 in or more in an existing opening between nonmetallic wiring compartment walls and the cover;

b) After a minimum recovery time of 1 hour after the completion of the last temperature change cycle, the module or panel shall comply with:

1) Dielectric Voltage-Withstand Test, Section 26, at room temperature and then at 50°C (122°F); and

2) Immediately following the 50°C (122°F) Dielectric Voltage-Withstand Test, the Leakage Current Test, Section 21;

3) Following the Leakage Current Test, the Wet Insulation-Resistance Test, Section 27;

4) A module or panel with a wiring compartment as described in 13.1.6 shall comply with Wiring Compartment Securement Test, Section 42, following the Wet Insulation-Resistance Test; and

5) A module or panel with a wiring compartment as described in 13.1.6 shall comply with Wet Insulation-Resistance Test, Section 27, following the Wiring Compartment Securement Test.

35.2 Three samples of a module or panel are to be placed in an air circulating chamber, the temperature and humidity of which can be varied and controlled. The humidity is to be regulated only as required to prevent the accumulation of humidity on the samples. Leads are to be connected to the terminals and the frame of the samples to provide for continuous individual detection of loss of circuit continuity and loss of resistance between the electrical circuit and accessible metal.

35.3 The samples are to be mounted or supported in the chamber, so as to provide for free circulation of the surrounding air. The thermal conduction of the mount or support means is to be low, so that the samples are thermally isolated.

35.4 Each test is to consist of:

a) A transition in test chamber temperature from 25°C to minus 40°C (77°F to minus 40°F);

b) A dwell at minus 40°C for 30 min or until the module or panel attains a temperature within 2°C (4°F) of the chamber temperature, whichever is longer, but in no case longer than 1 h, 45 min;

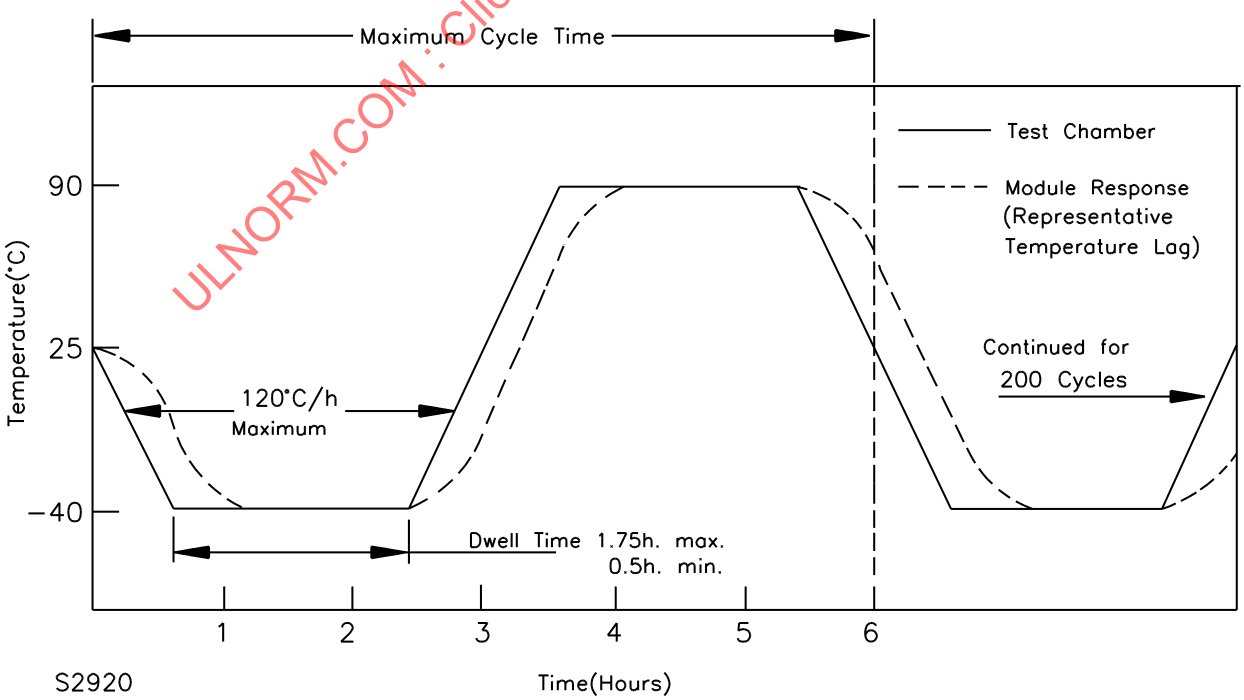
c) A transition in test chamber temperature from minus 40°C to 90°C (194°F);

d) A dwell at 90°C for 30 min or until the module or panel attains a temperature within 2°C of the chamber temperature, whichever is longer, but in no case longer than 1 h, 45 min; and

e) A transition in test chamber temperature from 90°C to 25°C. The total cycle time is not to exceed 6 h. If the 25°C temperature is the start or end of the 200 cycles, any nominal room temperature in the range of 15°C – 35°C (59°F – 95°F) may be used. For all transitions, the instantaneous rate of temperature change of the test chamber with respect to time is not to be greater than 120°C/h (216°F/h). See Figure 35.1.

Figure 35.1

Thermal cycle test



36 Humidity Test

36.1 A module or panel shall be subjected to 10 cycles of humidity-freezing as described in 36.2 – 36.6; and:

a) The test shall not result in:

1) Loss of circuit continuity;

2) Accessibility of parts that involves a risk of electric shock, such as by delamination or separation of materials;

3) A reduction in the resistance between a part involving a risk of electric shock and an accessible part such that the module or panel is not in compliance with the Leakage Current Test, Section 21;

4) Corrosion of metal parts;

5) Reduction in the thickness of the wall of a nonmetallic wiring compartment below required values;

6) Reduction in volume of a nonmetallic wiring compartment below required values; or

7) A gap greater than 1/16 in (1.6 mm) or an increase of 1/16 in or more in an existing opening between nonmetallic wiring compartment walls and the cover.

b) After a recovery time of between 2 and 4 hours after the completion of the last humidity-freezing cycle, the module or panel shall comply with:

1) Dielectric Voltage-Withstand Test, Section 26; and

2) Leakage Current Test, Section 21, immediately following the Dielectric Voltage-Withstand Test; and

3) Following the Leakage Current Test, the Wet Insulation-Resistance Test, Section 27; and

4) A module or panel with a wiring compartment as described in 13.1.6 shall comply with Wiring Compartment Securement Test, Section 42, following the Wet Insulation-Resistance Test; and

5) A module or panel with a wiring compartment as described in 13.1.6 shall comply with Wet Insulation-Resistance Test, Section 27, following the Wiring Compartment Securement Test.

36.2 Three samples of a module or panel are to be placed in a chamber, the humidity and temperature of which can be varied and controlled. Leads are to be connected to the terminals and the frame if necessary, of the samples, to allow for continuous individual detection of loss of circuit continuity and loss of resistance between the electrical circuit and accessible metal.

36.3 The samples are to be mounted or supported in the chamber, so as to provide for free circulation of the surrounding air. The thermal conduction of the mount or support means is to be low, so that the samples are thermally isolated.

36.4 The test apparatus and arrangement of samples is to be such that dripping of condensate on a sample is prevented. Terminations are to be afforded the least degree of protection against condensation of water as they would be in any intended installation of the product.

36.5 Each cycle is to consist of:

a) A transition in the test chamber temperature from 25°C ±2°C to 85°C ±2°C (77°F to 185°F);

b) A dwell at 85°C ±2°C for 20 h minimum;

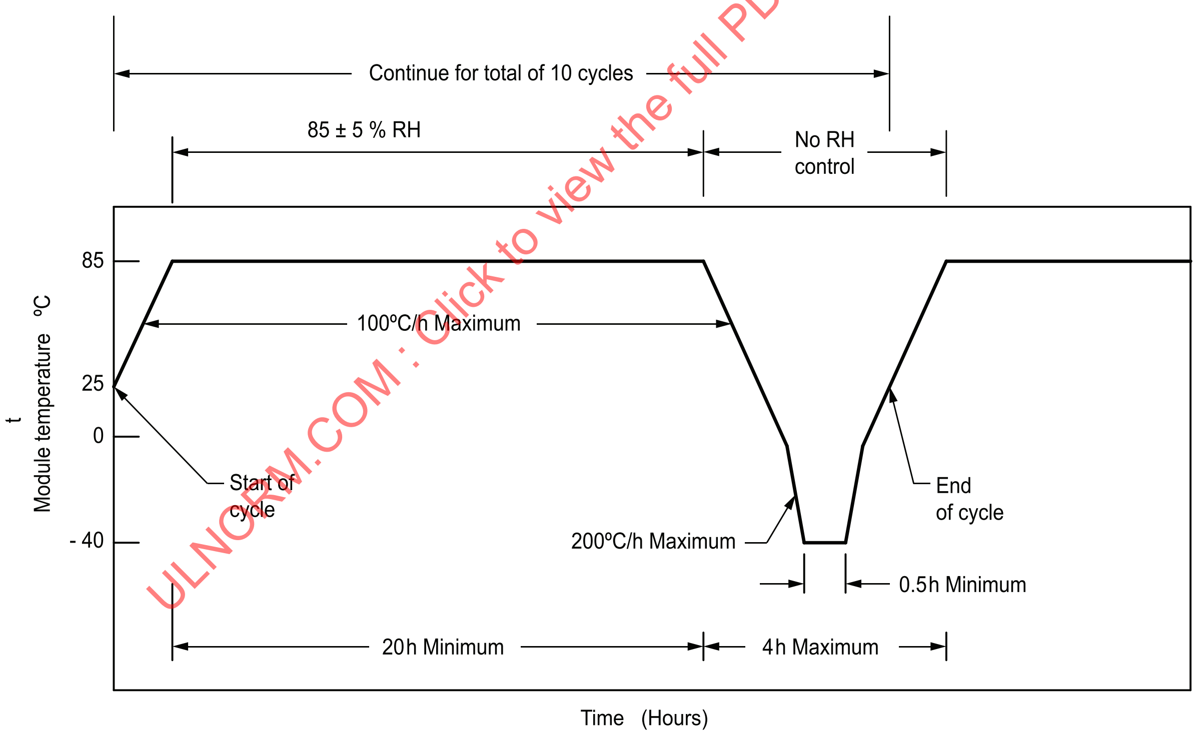
c) A transition from 85°C ±2°C to minus 40°C ±2°C (minus 40°F);

d) A dwell at minus 40°C ±2°C for 30 minutes minimum; and

e) A transition from minus 40°C to 25°C. When the temperature is 5°C (41°F) or above, the temperature transitions of the test chamber with respect to time are not to be greater than 120°C/h (216°F/h). When the temperature is less than 5°C, the temperature transitions of the test chamber with respect to time are not to be greater than 200°C/h (360°F/h). The total time for the transitions and the minus 40°C dwell together is not to exceed 4 h. If the 25°C temperature is the start or end of the 10 cycles, any nominal room temperature in the range 15°C – 30°C (59°F – 86°F) may be used. The total cycle time is not to exceed 24 h. See Figure 36.1. All temperatures are to be within ±2°C measured on the surface of the module.

Figure 36.1

Humidity-freezing cycle test



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36.6 The humidity of the chamber air when the chamber air temperature is 85°C (185°F) is to be 85 ± 5 percent relative humidity. During all temperature transitions the chamber air is to be isolated from the outside air (no make-up air) to allow condensing water vapor to freeze in the module or panel.

37 Corrosive Atmosphere Test

37.1 Salt spray test

37.1.1 One complete sample of the module or specimen samples of materials representative of that used in the module shall be subjected to the salt spray test as described in 37.1.3 – 37.1.11.

Exception: A module constructed of materials such as plastic, stainless steel, or aluminum that are inherently resistant to atmospheric corrosion need not be tested.

37.1.2 With reference to 37.1.1, after the test, the corrosion products formed on the test sample shall not be more than that formed on the reference sample as determined by visual observation. Corrosion in the scribed line area is judged by the spread of corrosion from the scribed line.

37.1.3 The apparatus for salt spray testing is to consist of a chamber with inside measurements of 48 in by 30 in by 36 in (1.22 m by 0.76 m by 0.91 m) or larger if required; a salt solution reservoir; a supply of conditioned compressed air; one dispersion tower constructed in accordance with ASTM designation B117-97, for producing a salt spray; specimen supports; provision for heating the chamber; and necessary means of control.

37.1.4 The dispersion tower for producing the salt spray is to be located in the center of the chamber and is to be supplied with humidified air at a gauge pressure of 17 to 19 lb/in^2 (117 to 131 kPa) so that the solution is aspirated as a fine mist or fog into the interior of the chamber.

37.1.5 The salt solution is to consist of 5 percent by weight of common salt (sodium chloride) in distilled water. The pH value of the collected solution is to be between 6.5 and 7.2 and have a specific gravity between 1.026 and 1.040 at 95°F (35°C). The temperature of the chamber is to be maintained within the range of 92°F to 97°F (33°C to 36°C) throughout the test.

37.1.6 The test sample is to be supported on plastic racks at an angle of 15 degrees from the vertical.

37.1.7 Drops of solution which accumulate on the ceiling or cover of the chamber are to be diverted from dropping on the specimen. Drops of solution which fall from the specimens are not to be recirculated, but are to be removed by a drain located in the bottom of the apparatus.

37.1.8 Reference specimens, 4 in by 12 in (102 mm by 305 mm) of commercial zinc coated sheet steel are to be used for comparison. The selected specimens are to be representative of the minimum acceptable amount of zinc coating under requirements for G90 or G60 coating designation (as applicable, see Accessibility of Uninsulated Parts, Section 15) as determined in accordance with the Standard Test Method for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles, ASTM A90-81(1991) Such zinc coatings are considered as providing acceptable protection against corrosion.

37.1.9 The zinc coated reference specimens are to be cleaned with soap and water, rinsed with ethyl alcohol and ethyl ether, dried, and the cut edges protected with paint, wax, or other effective medium before being placed in the salt spray chamber.

37.1.10 Both the reference specimen and the samples under test are to be scribed with a single groove approximately 6 in (152 mm) long, to expose the underlying steel.

37.1.11 The test is to continue until the coating on the test samples or reference samples are broken down and corrosion products are formed on the underlying steel.

37.2 Moist carbon dioxide/sulphur dioxide

37.2.1 One complete sample of the module or specimen samples of materials representative of that used in the module shall be subjected to the Moist Carbon Dioxide/Sulphur Dioxide Test as described in 37.2.3 – 37.2.9.

Exception: A module constructed of materials such as plastic, stainless steel or aluminum that are inherently resistant to atmospheric corrosion need not be tested.

37.2.2 The corrosion products formed on the test sample shall be no more than that formed on the reference sample as determined by visual observation. Corrosion in the scribed line area is to be judged by the spread of corrosion from the scribed lines.

37.2.3 A chamber measuring 48 in by 30 in by 36 in (1.22 m by 0.76 m by 0.91 m) or larger if required, having a water jacket and a thermostatically controlled heater in order to maintain a temperature of 95 ±3°F (35 ±2°C) is to be used.

37.2.4 Sulphur dioxide and carbon dioxide are to be supplied to the test chamber from commercial cylinders containing these gases under pressure. An amount of sulphur dioxide equivalent to 1 percent of the volume of the test chamber and an equal volume of carbon dioxide are to be introduced into the chamber each day. Prior to introducing the new charge of gas each day, the remaining gas from the previous day is to be purged from the chamber. A small amount of water is to be maintained at the bottom of the chamber for humidity.

37.2.5 The samples are to be supported on plastic racks at an angle of 15 degrees from the vertical.

37.2.6 Reference specimens, 4 in by 12 in (102 mm by 305 mm) of commercial zinc coated sheet steel are to be used for comparison. The selected specimens are to be representative of the minimum acceptable amount of zinc coating under requirements for G90 or G60 coating designation (as applicable, see Corrosion Resistance, Section 15) as determined in accordance with the Standard Test Method for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles, ASTM A90-81(1991). Such zinc coatings are considered as providing acceptable corrosion protection.

37.2.7 The zinc coated specimens are to be cleaned with soap and water, rinsed with ethyl alcohol and ethyl ether, dried, and the cut edges protected with paint, wax, or other effective media before being placed in the chamber.

37.2.8 Both the reference specimen and sections of the module being tested are to be scribed with a single groove approximately 6 in (152 mm) long, to expose the underlying steel.

37.2.9 The test is to continue until the coating on the module or reference specimen is broken down and corrosion products are formed on the underlying steel.

38 Metallic Coating Thickness Test

38.1 The method for determining the thickness of a zinc or cadmium coating mentioned in 14.1 and 14.2 is described in 38.2 – 38.9.

38.2 The solution to be used for the metallic coating thickness test is to be made from distilled water and is to contain 200 g/L of reagent (or better) grade chromium trioxide (CrO_3) and 50 g/l of reagent (or better) grade concentrated sulfuric acid (H_2SO_4). The latter is equivalent to 27 ml/l of reagent grade concentrated sulphuric acid, specific gravity 1.84, containing 96 percent of H_2SO_4.

38.3 The test solution is to be contained in a glass vessel such as a separatory funnel with the outlet equipped with a stopcock and a capillary tube of approximately 0.025 in (0.64 mm) inside bore and 5.5 in (150 mm) long. The lower end of the capillary tube is to be tapered to form a tip, the drops from which are about 0.05 milliliter each. To preserve an effectively constant level, a small glass tube is to be inserted in the top of the funnel through a rubber stopper and its position is to be adjusted so that when the stopcock is open, the rate of dropping is 100 ±5 drops/min. If desired, an additional stopcock may be used in place of the glass tube to control the rate of dropping.

38.4 The sample and the test solution are to be kept in the test room long enough to acquire the temperature of the room, which should be noted and recorded. The test is to be conducted at a room temperature of 70.0°F – 90.0°F (21.2°C – 32.0°C).

38.5 The sample is to be thoroughly cleaned before testing. All grease, lacquer, paint, or other nonmetallic coatings, including skin oils, are to be removed completely by means of solvents. The sample is then to be thoroughly rinsed in water and dried with clean cheesecloth.

38.6 The sample to be tested is to be supported from 0.7 in to 1 in (17 mm to 25 mm) below the orifice. The surface to be tested shall be inclined at approximately 45 degrees from the horizontal so that the drops of solution strike the point to be tested and run off quickly.

38.7 The stopcock is to be opened and the time in seconds is to be measured until the dropping solution dissolves the protective metal coating, exposing the base metal. The end point is the first appearance of the base metal recognizable by the change in color at that point.

38.8 The sample of a test lot is to be subjected to the test at three or more points, excluding cut, stenciled, and threaded surfaces, on the inside surface and at an equal number of points on the outside surface, at places where the metal coating may be expected to be the thinnest. (On enclosures made from precoated sheets, the external corners that are subjected to the greatest deformation are likely to have thin coatings.)

38.9 To calculate the thickness of the coating being tested, select from Table 38.1 the thickness factor appropriate for the temperature at which the test was conducted and multiply by the time in seconds required to expose base metal as noted in 38.7.

Table 38.1
Metallic coating thickness factors

Temperature		Thickness factors, 0.00001 in/s (0.00025 mm/s)	
°F	(C)	Cadmium platings	Zinc platings
70	(21.1)	1.331	0.980
71	(21.7)	1.340	0.990
72	(22.2)	1.352	1.000
73	(22.8)	1.362	1.010
74	(23.3)	1.372	1.015
75	(23.9)	1.383	1.025
76	(24.4)	1.395	1.033
77	(25.0)	1.405	1.042
78	(25.6)	1.416	1.050
79	(26.1)	1.427	1.060

Table 38.1 Continued on Next Page

Table 38.1 Continued

Temperature		Thickness factors, 0.00001 in/s (0.00025 mm/s)	
°F	(C)	Cadmium platings	Zinc platings
80	(26.7)	1.438	1.070
81	(27.2)	1.450	1.080
82	(27.8)	1.460	1.085
83	(28.3)	1.470	1.095
84	(28.9)	1.480	1.100
85	(29.4)	1.490	1.110
86	(30.0)	1.501	1.120
87	(30.6)	1.513	1.130
88	(31.1)	1.524	1.141
89	(31.7)	1.534	1.150
90	(32.2)	1.546	1.160

39 Hot-Spot Endurance Test

39.1 General

39.1.1 Each representative cell of a crystalline module or panel shall be subjected to simulated reverse voltage hot-spot heating conditions for 100 h, intermittently, as described in 39.1.2 – 39.9.8. Thin-film modules or panels shall be subjected to the Hot-spot Endurance Test following light soaking in accordance with Section 18A, as defined in Clause 10.9 of the Standard for Thin-Film Terrestrial Photovoltaic (PV) Modules – Design qualification and type approval, IEC 61646. Alternatively, thin-film modules or panels shall be subjected to the Hot-spot Endurance Test as defined in Clause 10.9 of IEC 61646 without light soaking, if the effects of performance degradation are considered. The test shall not result in:

a) The accessibility of parts involving a risk of electric shock;

b) Melting of solder; or

c) Any other indication of a risk of fire or electric shock.

39.1.2 The reverse voltage hot-spot heating condition specified in 39.1.1 occurs when a module is operating at current levels that exceed the reduced short-circuit current capability of an individual cell or group of cells in an array circuit. This reduced short-circuit current capability can be the result of a variety of causes including nonuniform illumination of the module (local shadowing), individual cell degradation due to cracking, or loss of a portion of a series-parallel circuit due to individual interconnect open circuits. A module can operate at current levels exceeding its reduced short-circuit current capability during uncontrolled or deliberate fault conditions such as a short circuit deliberately placed on the module for servicing or to otherwise disable the array. During a reverse voltage hot-spot heating condition, power is dissipated in the overcurrented cell or cells at a level equal to the product of the current and the reverse voltage that develops across the cell or cells. This can heat the cell or cells to elevated temperatures.

39.1.3 The procedure for conducting this test is as follows:

a) Selection and connection of power sources and instruments to appropriate cells for testing,

b) Determination of the hot-spot test levels, and

c) Conduction of the hot-spot endurance test.

39.2 Cell selection and instrumentation

39.2.1 The degree of hot-spot heating within an affected cell is dependent upon, in part, the reverse-voltage current-voltage (I-V) characteristics of the affected cell. The reverse-voltage I-V characteristics may vary considerably from cell-to-cell within a given module. Accordingly, the range of the dark reverse-voltage I-V curves for a representative sample of cells (at least ten) within the test module are to be determined in accordance with 39.2.2 – 39.5.5. This can be done by directly accessing individual cells (intrusive method), or by shadowing technique (nonintrusive method) if the module is a simple series string of cells. The intrusive-nonintrusive option relates to cell selection only. All cells subjected to hot-spot endurance shall be individually accessed.

39.2.2 The dark, reverse-voltage current-to-voltage (I-V) curves for not less than ten cells within the module, modules, or panel, are to be determined using one of the following equations for reverse voltages from 0 (zero) to the maximum voltage limit (V_L) or currents from 0 (zero) to the maximum current limit (I_L), whichever limit is reached first:

$I_L = I_{SC}$, or

$V_L = N \times V_{mp}$.

In which:

I_{SC} is the short-circuit current of an average cell at 100 mW/cm^2, NOCT.

N is the number of series cells per bypass diode:

a) As an integral part of the module or panel, or

b) As is described for use with the module or panel in a marking affixed to the module or panel whichever is less. See 47.9.

V_{mp} is the average maximum power voltage of an average cell at 100 mW/cm^2, NOCT.

When no bypass diode information is provided, N shall be equal to the number of series cells.

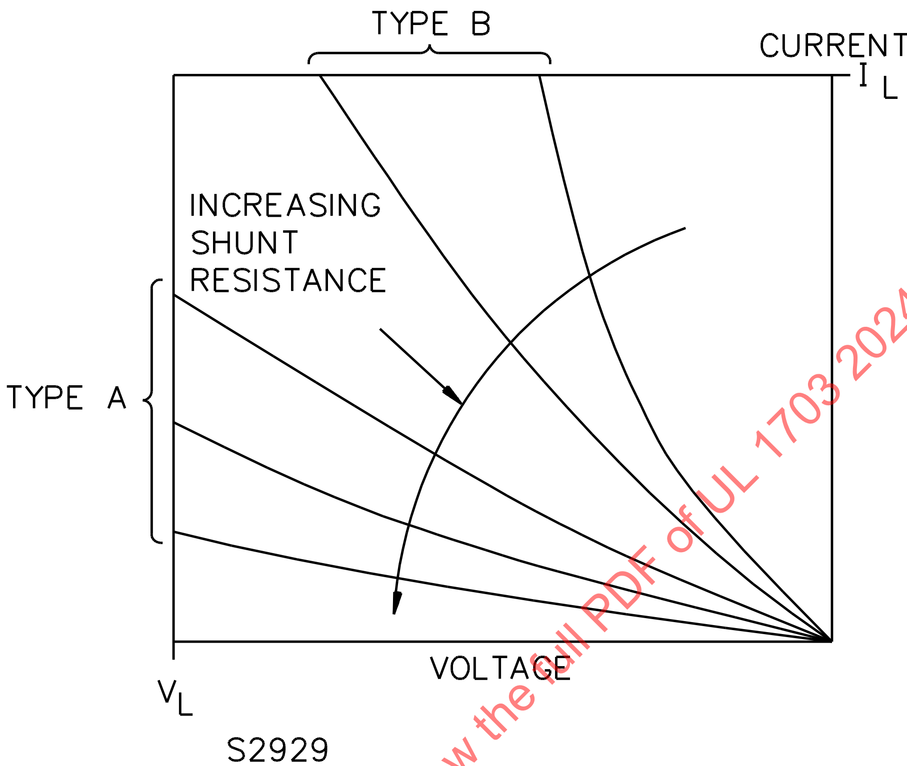
39.3 Intrusive method

39.3.1 With reference to 39.2.2, for the determination of cell I-V characteristics by the intrusive method, each cell tested is to be provided with individual positive and negative electrical leads to allow it to be accessed independently of other cells.

39.3.2 The reverse voltage I-V curves of the tested cells are to be plotted. See 39.3.3. The cells are to be identified as Type A (voltage limited) or Type B (current limited). A graph similar to Figure 39.1 should be obtained.

Figure 39.1

Typical reverse-voltage I-V plot for sample cells



39.3.3 With reference to 39.3.2, the I-V plot will require a power supply to be connected to the cell under test, with the polarity arranged to drive the cell with reverse voltage. The cells are not to be illuminated during this determination.

39.4 Nonintrusive method

39.4.1 The nonintrusive method may be used to determine cell I-V characteristics only if the module consists of a single series string of cells without bypass diodes. This method consists of uniformly illuminating all but one of the cells, while passing a known current (less than the illuminated short-circuit current) through the module. This results in reverse biasing the shadowed cell, while the remaining illuminated cells are in their normal forward-biased condition.

39.5 Theory and method of cell selection

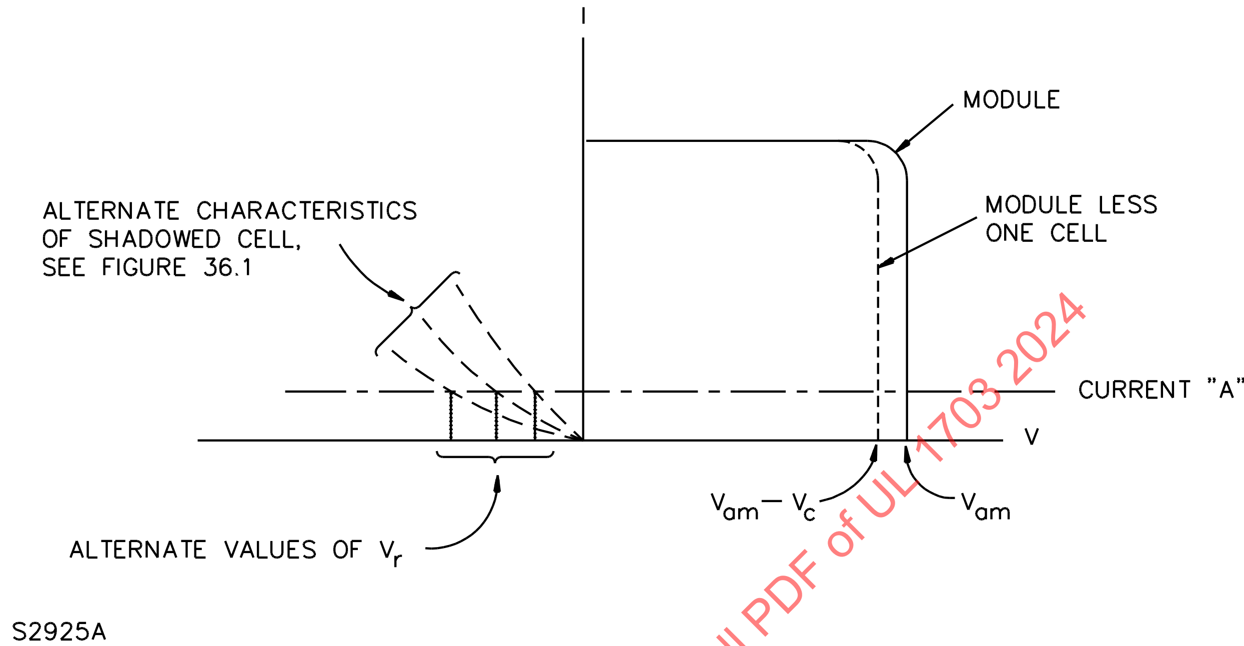
39.5.1 For example, at the particular known current level, A in Figure 39.2, the output voltage at the module terminals (V_o) under the condition of one cell shadowed will be the normal output voltage of the module with all cells illuminated (V_{am}), less the voltage of one cell (V_c), less the reverse voltage of the shadowed cell (V_r), that is:

$$V_o = V_{am} - V_c - V_r$$

The module's normal output voltage and voltage of one cell, both at a particular current level are fixed. The reverse voltage of a cell at a particular current level is variable, cell-to-cell, being higher for higher shunt resistances. Thus, shadowing of the highest shunt resistance cell will result in lowest module output voltage, and shadowing of the lowest shunt resistance cell will result in the highest module voltage.

Figure 39.2

Module and cell characteristics – shadowed cells



39.5.2 To determine the relative cell I-V characteristics by the nonintrusive method, the module is to be connected to a variable resistor so that the output current may be maintained at a fixed level under conditions of shadowing any one cell (same current regardless of which cell is shadowed). The module is to be illuminated under a source which can illuminate all cells at a repeatable and uniform intensity. The module temperature is to be monitored and is to remain constant. Normally these conditions can be achieved by outdoor testing under sunlight.

39.5.3 With the module connected and illuminated as described in 39.5.2, each cell in turn is to be shadowed, the resistor is to be adjusted to maintain the current at the preselected fixed value, and the output voltage of the module measured. The cell that is shadowed when the output voltage is maximum is the cell with minimum shunt resistance, and the cell that is the shadowed when the output voltage is minimum is the cell with maximum shunt resistance. Intermediate shunt resistance cells will have intermediate module voltage outputs.

39.5.4 The nonintrusive method is relative only, and in the manner presented does not provide a numerical value of any of the resistances. The cells of a module may be all voltage limited (high shunt resistance, Type A), all current limited (low shunt resistance, Type B), or a combination of both – see 39.3.2. In general, the cells associated with the highest hot-spot heating levels are those with the highest shunt resistance, although low shunt resistance may be associated with highly localized heating.

39.5.5 Three nonadjacent individual cells within the test module or panel are to be selected: one representative of the highest shunt resistance obtained, one representative of the average, and one representative of the lowest. Each cell to be tested is to be provided with individual positive and negative electrical leads to allow the cells to be connected individually and directly to separate power supplies. Parallel current paths around the cells to be tested are to be eliminated by disrupting cell-to-cell connections as necessary. The lead attachment should minimize disruption of the heat transfer characteristics of the cell or the hot-spot endurance of the encapsulant system.

39.6 Selection of hot-spot test level

39.6.1 The objective of this portion of the test procedure is to select the level of heating and the corresponding test condition that will stress the module or panel in a manner similar to a severe hot-spot field condition. The severity of the field condition will depend on the array circuit configuration, the array I-V operating point, the ambient thermal conditions, the overall irradiance level, and the previously described characteristics of the affected cells. When a module is incorporated into a photovoltaic source circuit, the maximum reverse voltage imposed on an individual cell can approach the system voltage unless bypass diodes are properly used. V_L is set to yield the maximum reverse voltage that can be applied across a single cell when the module is applied in a circuit with the minimum number of bypass diodes as specified by its marking.

39.6.2 Thermocouples are to be affixed to the cell insulation system. See 19.11 and 19.12.

39.6.3 In 39.7.1 – 39.8.1, the detailed levels are separately specified for Type A and Type B cells.

39.6.4 The test is to be conducted in an ambient air temperature of 20 ±5°C (68 ±9°F) and with a radiant heating source that will result in a uniform background module cell temperature equal to NOCT ±2°C (±4°F).

39.7 Type A cells (high shunt resistance)

39.7.1 The governing parameters concerning reverse voltage heating are:

a) The maximum cell reverse voltage (V_L),

b) The cell irradiance level, and

c) The ambient thermal environment.

39.7.2 V_L is to be set equal to N times the V_{mp} of an individual cell, where N is the number of series cells per specified or integral bypass diode.

39.7.3 The irradiance level directly controls the hot-spot current level, and therefore the power level. As illustrated in Figure 39.3, there is a unique irradiance level that corresponds to worst-case power dissipation for any particular Type A photovoltaic cell. The irradiance level on the test cell is to be adjusted to achieve this worst case power dissipation with the current adjusted to I_{TEST}, where I_{TEST} = the maximum power current of the cell at 100 mW/cm^2, NOCT.

39.8 Type B cells (low shunt resistance)

39.8.1 The cell shunt resistance of a Type B cell is so low that the maximum reverse voltage is set by the I-R drop across the cell. Worst-case heating occurs when the test cell is totally shadowed, and the current level is at a maximum. Accordingly, the irradiance is not to be more than 5 mW/cm^2. This irradiance level allows for room lighting and an IR heating source. The current (I_L) is to be equal to the short-circuit current of an average cell at 100 mW/cm^2, NOCT.

39.9 Test execution

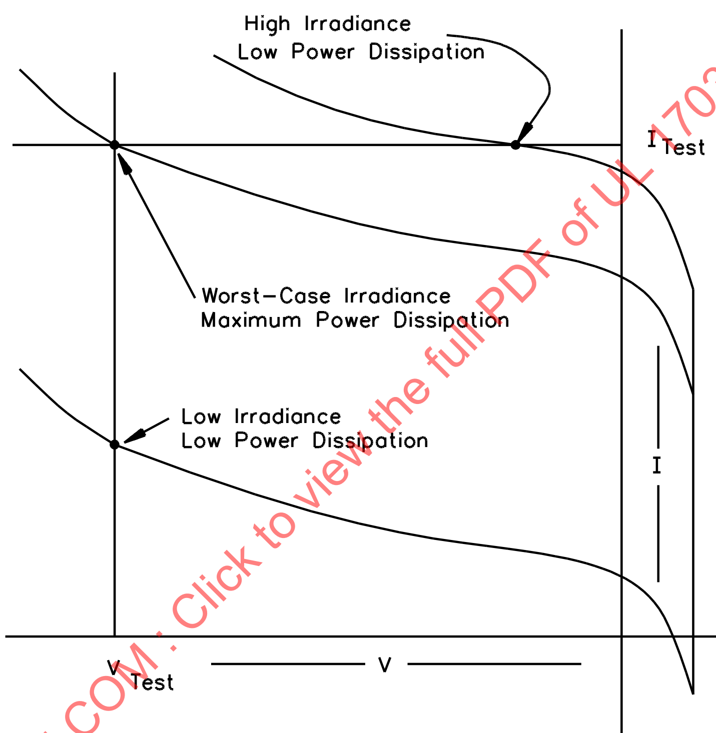
39.9.1 The three selected test cells are to be subjected to cyclic hot-spot heating at the level determined in accordance with 39.7.3 or 39.8.1 for a period of 100 h total on-time as specified in 39.9.2 – 39.9.6.

39.9.2 A constant voltage power supply (for Type A cells) and a constant current power supply (for Type B cells) is to be connected to the cell under test, with the polarity arranged to drive the cells with reverse voltage. The voltage is to be adjusted to V_L, and then the current is to be adjusted to I_{TEST} (for Type A cells) or I_L (for Type B cells). See 39.7.2 – 39.8.1.

39.9.3 An infrared radiant heating source with a visible light contribution below 5 mW/cm^2 is to be applied to the module or panel and adjusted to result in a uniform module cell temperature equal to NOCT ±2°C (±4°F). The ambient air is to be still and at a temperature of 20 ±5°C (68 ±9°F).

Figure 39.3

Effect of test-cell illumination level on hot-spot power dissipation



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39.9.4 For a Type A cell, an additional light source is to be used to illuminate each test cell to the level determined in 39.7.3 (Figure 39.3). The illumination is most easily accomplished after the power supply and IR source are turned on by adjusting the irradiance level to achieve the I_{TEST} current after equilibrium test conditions stabilize.

39.9.5 The power supply, IR source, and irradiance source are to be energized for 1 h followed by an off-period sufficient to allow the cells under test to cool to within 10°C (18°F) of the ambient temperature.

39.9.6 The operation is to be repeated until a total of 100 h of on-time have been accumulated.

39.9.7 the test cells and the adjacent areas of the encapsulation system are to be visually inspected at 24-h intervals during the test while the cells are under impressed voltage conditions and also upon completion of the 100 h of on-time operation.

39.9.8 At the conclusion of the test, the module is to be inspected for visible signs of melted solder, openings in the enclosure, delamination, and burn spots on the substrate.

40 Arcing Test

40.1 General

40.1.1 *Deleted*

Figure 40.1

Currents and voltages for arc test
Figure deleted

40.1.2 *Deleted*

40.2 Method A

40.2.1 *Deleted*

40.3 Method B

40.3.1 *Deleted*

40.4 Methods A and B

40.4.1 *Deleted*

40.5 Method C

40.5.1 *Deleted*

40.5.2 *Deleted*

40.6 All methods

40.6.1 *Deleted*

40.6.2 *Deleted*

40.6.3 *Deleted*

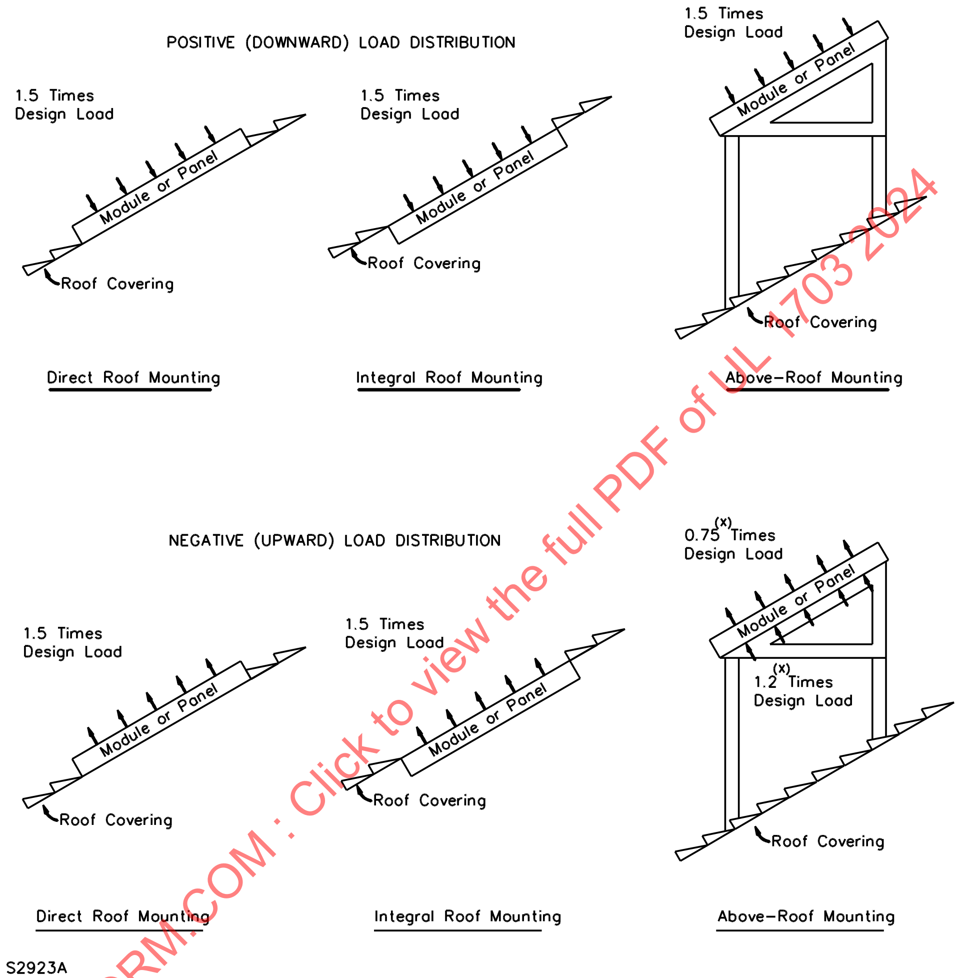
41 Mechanical Loading Test

41.1 A module or panel and any mounting hardware supplied with the module or panel shall withstand a load as shown in Figure 41.1 and specified in 41.2 for a period of 30 min, without evidence of structural or mechanical failure. Modules that are intended to be installed as part of a building wall or roof structure, and serve as primary members of that structure, shall not have a deflection of more than L/240; where "L" is equal to the clear span length in feet of the deflected member. All glazing materials shall be of such strength as to withstand the loads specified in 41.2.

41.2 The design load is to be 30 lb/ft^2 (146.5 kg/m^2) positive (downward) or negative (upward); or a design load designated by the manufacturer, whichever is greater. A load of 1.5 times the design load shall be applied for all tests other than the negative (upward) load on the above-roof mounting configuration, as noted in Figure 41.1. The downward and upward loads shall not be applied simultaneously.

Figure 41.1

Load application



NOTE: (X) The basic load distribution factors for this mounting configuration are 0.5 for the suction load and 0.8 for the uplift load. These factors multiplied by 1.5 result in the indicated factors of 0.75 and 1.2.

42 Wiring Compartment Securement Test

42.1 The tensile force required to separate a wiring compartment or box from a module shall not be less than 35 lbf (155.7 N) or 4 times the wiring compartment or box weight, whichever is greater, when tested as specified in 42.2 and 42.3. For a test in which the superstrate or substrate fails prior to the adhesive, the force required to cause the superstrate or substrate to fail shall be used to determine compliance, and shall not be less than the specified minimum separation force.

42.2 Seven assemblies consisting of a wiring compartment or box secured to a module with adhesive as intended are to be tested. One assembly is to be tested in the as-received condition, three after being conditioned in accordance with Temperature Cycling Test, Section 35, and three after conditioning in accordance with Humidity Test, Section 36.

42.3 The force is to be applied to each assembly so as to separate the wiring compartment or box from the module. The force is to be applied until the wiring compartment or box and the module separates; or the superstrate or substrate fails.

42A Cemented Joints

42A.1 General

42A.1.1 Adhesive joints are considered cemented joints when in compliance with the tests outlined in General, Section 18, and Cemented Joints, Section 42A. Cemented joints are acceptable as equivalent to reinforced solid insulation with no creepage and clearance distance requirements, but minimum through distance instead.

NOTE: Minimum through distance for solid insulation at the perimeter of a module and at other locations with exposed edges must be greater than or equal to the creepage distances defined in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, Table 9.1, using Pollution Degree 1.

42A.1.2 The requirements of 7.2(b), 7.2(c) or 7.2(d) do not apply to materials creating cemented joints.

42A.2 Material tests

42A.2.1 Minimum mechanical performance for cemented joints

42A.2.1.1 The material adhesion characteristics shall be evaluated during RTI testing in a manner that simulates the joint design in an as-deployed state. For glass/glass module configurations, a lap shear sample configuration is required in accordance with ASTM D1002. For glass/polymer and non-glass/polymer based module configurations, a peel sample configuration is required in accordance with ASTM D903. In accordance with the Standard for Polymeric Materials - Long Term Property Evaluations, UL 746B, end of life is defined as 50% property retention for RTI testing.

42A.2.1.2 For cemented joints, the mechanical RTI rating for the electrically insulating adhesive/sealant shall be the higher of:

a) 90°C;

b) The module maximum measured normalized operating temperature as measured along the module edge during the Temperature Test in Section 19.

42A.2.2 Minimum electrical performance for cemented joints

42A.2.2.1 The DC dielectric strength of the material shall be evaluated on a component level during RTI testing with DC dielectric strength measured in accordance with ASTM D3755. In accordance with the Standard for Polymeric Materials - Long Term Property Evaluations, UL 746B, end of life is defined as 50% property retention for RTI testing.

42A.2.2.2 The electrical RTI rating for the electrically insulating adhesive/sealant shall be the higher of:

a) 90°C;

b) The module maximum measured normalized operating temperature as measured during the Temperature Test in Section 19.

42A.2.2.3 The electrically insulating adhesive/sealant shall have a volume resistivity of greater than 50 x 10^6 Ω-cm (dry) and greater than 10 x 10^6 Ω-cm (wet), with volume resistivity as measured in accordance with ASTM D257 and wet/dry conditioning defined in accordance with Section 14 of the Standard for Polymeric Materials - Use in Electrical Equipment Evaluations, UL 746C.

42A.3 UV weathering resistance

42A.3.1 Cemented joints are to be tested for UV exposure utilizing the UV weathering cycle of the Standard for Polymeric Materials - Use in Electrical Equipment Evaluations, UL 746C, Section 25, UV Light Exposure.

42A.3.2 Compliance with 42A.3.1 shall be verified by completing pre/post UV exposure adhesion testing and comparing average force measured before and after exposure. For glass/glass module configurations, a lap shear sample configuration is required in accordance with ASTM D1002. For glass/polymer and non-glass/polymer based module configurations, a peel sample configuration is required in accordance with ASTM D903. Greater than 70% retention of average bond strength is required after UV exposure.

PRODUCTION LINE TESTS

43 Factory Dielectric Voltage-Withstand Test and Factory Wet Insulation-Resistance Test

43.1 General

43.1.1 Each module or panel shall comply with either the Factory Dielectric Voltage-Withstand Test, Section 43.2, or the Factory Wet Insulation-Resistance Test, Section 43.3.

43.2 Factory Dielectric Voltage-Withstand Test

43.2.1 Each module or panel shall withstand for 1 min without electrical breakdown as a routine production line test, the application of a dc test potential as specified in 43.2.2, between parts involving a risk of electric shock and accessible metal parts.

Exception No. 1: The test period may be reduced to 1 s if the test potential is increased to 120 percent of the value specified in 43.2.2.

Exception No. 2: A module or panel with a system voltage rating of 30 V or less need not be tested.

43.2.2 The dc test potential shall be 2V + 1000 V, where "V" is the rated maximum acceptable system voltage.

43.2.3 The test equipment is to include a means of indicating the test voltage that is being applied to the product under test. This may be accomplished by sensing the voltage at the test leads or by an equivalent means. The test equipment is also to include a means of effectively indicating unacceptable performance. The indication is to be:

a) Audible, if it can be readily heard above the background noise level;

b) Visual, if it commands the attention of the operator; or

c) A device that automatically rejects an unacceptable product. If the indication of unacceptable performance is audible or visual, the indication is to remain active and conspicuous until the test equipment is manually reset.

43.2.4 The test potential specified in 43.2.2 may be obtained from any convenient source having a capacity of at least 500 VA.

Exception: The capacity may be lower if the means of indicating the test voltage is located in the output circuit – to maintain the potential indicated in 43.2.2 except in case of breakdown. The voltage of the source is to be continuously adjustable.

43.2.5 The test equipment is to indicate unacceptable performance within 0.5 s if the leakage current at the test voltage exceeds 50 μA.

43.2.6 The test is to be conducted when the module is complete and ready for packing, or when it is complete except for covers or other parts that may interfere with the performance of the test.

43.3 Factory Wet Insulation-Resistance Test

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43.3.1 This test verifies that the insulation properties of outer surfaces of the production PV modules meet the electrical safety requirements of this standard.

43.3.2 Each module or panel shall withstand the requirements of the Wet Insulation-Resistance Test, Section 27.

Exception No. 1: Test voltage, test duration and water temperature of Section 27 shall be changed for Production Line Tests as described in 43.3.3.

Exception No. 2: Terminal boxes and pigtail-leads or other connectors do not need to be wetted.

43.3.3 The test voltage U_{TEST} is calculated by multiplying the maximum system voltage U_{SYS} by a factor *Y*.

$$U_{TEST} = U_{SYS} \times Y$$

43.3.4 With reference to 43.3.3, $Y = 1$ is used for a minimum test duration of 1 min. $Y = 1.2$ is used for a minimum test duration of 5 s. Ramp-up time for test voltage is chosen such that no time induced breakdown will occur. During the test no breakdown of test voltage shall occur.

43.3.5 The temperature range of the water is to be 15 °C to 45 °C. The leakage current shall be corrected to 25 °C using a demonstrated correction factor for the PV module, to be determined for each PV module type.

43.3.6 For PV modules with cemented joints, U_{TEST} shall be increased by a factor of 1.35.

Note: An example for U_{SYS} = 1500 V for cemented joints for test duration of 5 s is U_{TEST} = 1500 V × 1.2 × 1.35 = 2430 V.

44 Factory Voltage, Current, and Power Measurements Test

44.1 The short-circuit current (I_{SC}), maximum power (P_{max}), and open-circuit voltage (V_{OC}) of each production module are to be measured in accordance with the appropriate test procedure (Standard Methods of Testing Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells, ASTM E1036-85, or Photovoltaic Devices, Part 1: Measurement of Photovoltaic Current-Voltage Characteristics, IEC 904-1 or Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices, IEC TS 60904-1-2, under development, use 82/1403/DTS, for bifacial modules) and the results recorded at STC using the appropriate correction procedure. The recorded values of I_{SC}, P_{max}, and V_{OC} for crystalline silicon modules or panels shall be within the marked tolerance. The recorded values of I_{SC}, P_{max}, and V_{OC} for thin-film modules or panels shall be within the marked tolerance of the as-received values determined in accordance with 20.1 – 20.3. See 48.2. The test procedures mentioned in 18.1 and 18.2 shall be applied.

Exception No. 1: See Supplement SA.

Exception No. 2: Front or back only voltage, current, and power measurements production line testing of bifacial modules is allowed provided that the sampling requirements described in Supplement SA are followed.

45 Grounding Continuity Test

45.1 Each module or panel provided with a connection for grounding accessible conductive parts shall be subjected to a routine production line test to demonstrate electrical continuity between the grounding connection and all accessible conductive parts.

45.2 Any appropriate indicating device, such as an ohmmeter, a low-voltage battery and buzzer combination, or the like may be employed for the test described in 45.1.

RATING

46 Details

46.1 The electrical rating of a module or panel shall include the voltage, current and power ratings specified in Table 46.1, as defined in 20.3.

Table 46.1
Electrical ratings

Voltage	Current	Power
Open-circuit voltage	Short-circuit current	Maximum power
Operating voltage	Current at rated operating voltage	
Maximum system voltage		