UL 2703

STANDARD FOR SAFETY

Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels

UL Standard for Safety for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels, UL 2703

First Edition, Dated January 28, 2015

Summary of Topics

This revision of ANSI/UL 2703 dated June 11, 2025 includes the following changes in requirements:

– Clarifications to the Clamp Load Calculation Method, Including Added definitions, Examples, References and the Addition of a Table Showing K-Factor Used in the Clamp Load Calculation; 2.13A, 2.13B, 2.22A, 6.2A, 6.5 – 6.6D, Table 6.1, 26.1, 26.2, Appendix C – Appendix F

– Additional Fire Types to Exception in 11.1(a);

– Clarification on Current and Time to be Selected for the Optional Short-Time Current Test Referenced in 22.1 (note)

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.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated April 4, 2025.

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UL 2703

Standard for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels

First Edition

January 28, 2015

This ANSI/UL Standard for Safety consists of the First Edition including revisions through June 11, 2025.

The most recent designation of ANSI/UL 2703 as an American National Standard (ANSI) occurred on June 11, 2025. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

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 rack mounting systems, mounting grounding/bonding devices, and clamping/retention devices for specific (manufacturer/model designation) flat-plate photovoltaic modules and panels that comply with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, or 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, intended for installation on or integral with buildings, or to be freestanding (i.e., not attached to buildings), in accordance with the National Electrical Code, ANSI/NFPA 70 and Model Building Codes. Systems, components and/or devices evaluated under this standard may be used to ground and/or mount a PV module complying with UL 1703 or UL 61730-1 and UL 61730-2 when the specific module or frame has been evaluated for bonding/grounding or the module has been evaluated for mounting with the evaluated system, component or device.

1.2 These requirements cover rack mounting systems and clamping devices intended for use with photovoltaic module systems with a maximum system voltage of 1500 V.

1.3 These requirements cover rack mounting systems, clamping, retention devices pertaining to ground/bonding paths, mechanical strength, and suitability of materials only.

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) Solar trackers or tracker mechanisms (except as specifically directed as to be utilized by the Standard for Solar Trackers, UL 3703 and in combination with UL 3703).

c) Cell assemblies intended to operate under concentrated sunlight.

d) Optical concentrators.

e) Combination photovoltaic-thermal modules or panels.

f) Equipment intended to carry current as a normal function of that component, such as combiner boxes, connection boxes (other than connection box for grounding), wireways and enclosures housing live parts. See the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703 or the Standard for Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements For Construction, UL 61730-1, or the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741.

g) Ground rods and ground rod accessories.

h) The mechanical and structural requirements of the international building code. See (i).

Note: The IBC and other model codes may have additional requirements. As an example, compliance with the IBC will require development load combinations which include dead, snow, wind and seismic forces using ASCE 7. These loads will need to be applied in three orthogonal directions and the load resisting elements of the system will be required to adequately support the applied loads.

i) Roof attachments for above roof mounting.

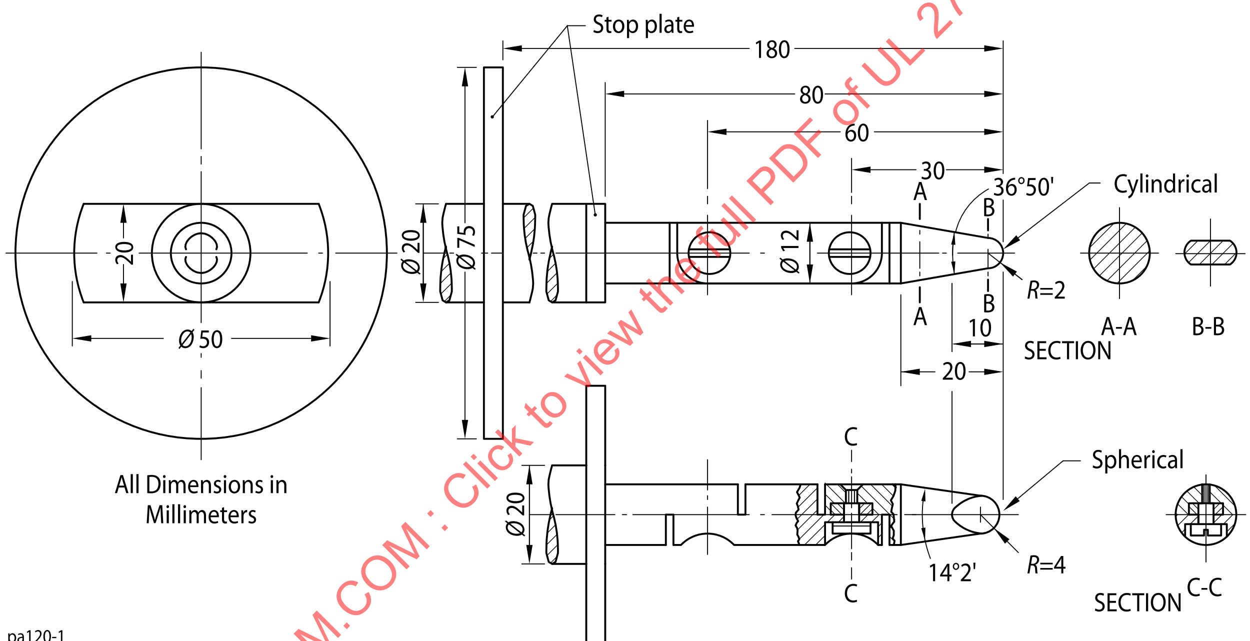
2 Glossary

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

2.2 ACCESSIBLE – A part is considered accessible if, in a fully assembled rack mounting system (that is, with all covers in place) the part may be touched by the probe illustrated in Figure 2.1. 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. The probe illustrated in Figure 2.1 shall be applied to up to any depth that the opening will permit, up to a maximum of 35 inches; 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.

Figure 2.1

Probe for determining accessibility of live parts



2.3 AC MODULE – The smallest complete unit that includes solar cells, optics, inverters, and other components, excluding tracking devices, intended to generate ac power from sunlight.

2.4 ABOVE ROOF MOUNTING (including rack-mounted style installations) – Installations that are spaced away from the building's roof member.

2.5 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 power-producing unit.

2.6 BOLT – A type of fastener. For the purposes of this document the requirements for "cap screws" will apply to bolts as well. See cap screw, 2.11.

2.7 BONDING – Electrically connecting all metal components to the point of the equipment ground conductor.

2.8 BONDING DEVICE – A device for bonding and may include a function to pierce non-conductive coatings such as but not limited to; anodization, paint, vitreous enamel, and may be a separate piercing device or integral to the component to perform the bonding function.

a) SINGLE USE BONDING DEVICES – Bonding device intended for use one time only.

b) MULTIPLE USE BONDING DEVICE – Bonding device intended for multiple use according to the device's installation instructions.

2.9 BONDING STRAP – A solid, multi-strand or braided copper, copper-clad aluminum or aluminum conductor (and may be tin or zinc plated) with factory crimped terminations to allow bonding of components.

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

2.11 CAP SCREW – A threaded fastener which is utilized with a threaded nut or internal threads in a material, to provide a clamp load on the mechanical joint being fastened. Cap screws are most typically hex head, but include socket head, button head, and other types. See ASTM F593, ASTM F837, and for illustrations of these and other types of cap screws, see ANSI/ASME B18.2.1 and ANSI/ASME B18.3.

2.12 CLAMP LOAD – The force exerted on a fastened joint by a fastener, such as a cap screw. To minimize fatigue failures, the clamp load of a fastener, such as a cap screw and hex nut, must exceed the force exerted on the fastener by the fastened joint.

2.13 CLAMPING DEVICE(S) – A mechanical means to secure a PV module to the rack mounting system which does not rely upon the mounting holes in the PV module's frame. These clamping devices are typically, but not limited to, top-down clamps. The clamping device may also function as a bonding device where specified. Top down end-clamps are assumed to be cantilever design, where the fastener securement is approximately at the mid-point between the PV module and the clamps' contact with the supporting structure. Also see Retention Device.

2.13A CRITICAL BONDING FASTENER – A fastener (e.g., lock bolt, bolt, screw, nut, and washer) relied upon as part of the electrical bonding path and a required part of the assembly tested during the bonding and grounding tests.

2.13B CRITICAL STRUCTURAL FASTENER – A fastener (e.g., lock bolt, bolt, screw, nut, and washer) relied upon as part of the structural load path and a required part of the assembly tested during mechanical loading tests.

2.14 CYCLIC LOADING – The non-static (changing) forces that act upon a body; for the purposes of this standard, the changing loads that act upon the fastened joint (i.e., changing wind loads that will force a PV module to act against the clamping device which is securing the PV module in place).

2.15 DIRECT ROOF MOUNTING – PV modules which are direct-mounted; placed upon the building's waterproof membrane/shingles or the like.

2.16 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 the following table:

Surface or part from which measurement is made	Maximum current (dc)
Accessible conductive frame, pan, or the like	10 μA

2.17 FACTORY INSTALLED – The connection of a device under controlled factory conditions at the manufacturer's location(s).

2.18 FASTENER (threaded fastener) – A mechanical device designed specifically to hold, join, couple, or assemble two or more components together. Examples of fastener types include cap screws, machine screws, and bolts.

2.19 FIELD INSTALLED – The connection of a device, which is made in the field by an installer.

2.20 GROUNDING LUG – A device used to provide a ground path between an object (e.g., PV module frame or racking system) and a grounding electrode conductor or equipment grounding conductor; the device provides an equipotential-bonded connection.

2.20A GUARDED PERIMETER – A perimeter that is protected with wire screen or other similar means including sheet metal.

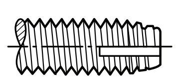
2.21 INTERCONNECT – A conductor within a module that provides a mechanism for conducting electricity between cells.

2.22 LIKELY TO BE ENERGIZED – Any conductive component that may come into contact with a live part under normal operating or single fault conditions. Conductive components of rack mounting systems that enclose electrical circuits or otherwise act as an electrical enclosure, conductive components that are not physically separated from potentially live insulated or non-insulated wires or conductors, conductive components not electrically isolated from other conductive components that are likely to be energized.

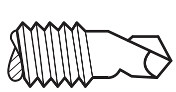
2.22A LOCKBOLT – A two-piece fastener consisting of a metal pin and collar that swages into the grooves of the pin using automated tooling, resulting in a known clamp load and permanent connection. A lockbolt cannot typically be removed without damaging the pin or collar.

2.23 MACHINE SCREW – A machine screw is a fastener defined by ASME B18.6.3 meeting UN or UNR requirements such as UNC, UNF, and UNS thread types defined by ASME B1.1 as well as the M series metric screws defined by ASME B1.13M. There are thread cutting and self-drilling tapping machine screws. Examples of thread cutting screws include Types, D, F, G, T, 1, 23 as defined by ASME B18.6.3. Examples of self-drilling tapping machine screws include CSD screws as defined by SAE J78. These screws have UN style threads with a drill point for creating the pilot hole for the screw.

Thread-Cutting Machine Screw



Self-Drilling Tapping Machine Screw



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

2.25 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 at 1000W/m^2, AM 1.5 spectrum and corrected for the lowest expected ambient temperature.

2.26 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 non-concentrated 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.

2.26.1 MODULE LEVEL POWER ELECTRONIC (MLPE) DEVICE – Device that performs module level electrical control and/or monitoring, which could be connected to PV module frame or racking system.

2.27 MODULE MOUNTING MEANS – A device or combination of devices used to mechanically secure a PV module to a rack. Part of the module mounting means may be integrated into the module frame and/or rack.

2.28 NON-SEPARATELY DERIVED – Photovoltaic systems that have direct electrical connection to another source, such as PV systems that connect to the grid via a grid interactive inverter.

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

2.30 PANEL MOUNTING CLIP (framed modules) – A mechanical means to secure a PV module to the rack mounting system which does not necessarily rely upon the mounting holes in the PV modules frame (but may use such for alignment) and may not be secured with a threaded fastener and may include a bonding function.

2.31 PANEL MOUNTING CLIP (un-framed modules) – A mechanical means to secure a PV module to the rack mounting system and may not be secured with a threaded fastener, and may include a bonding function.

2.32 PROOF LOAD – A tensile load that the fastener must support without evidence of permanent deformation.

2.33 RACK – A structure used to support the PV modules.

2.34 RACK MOUNTING MEANS – Device or combination of devices used to mechanically secure a rack to a building structure or ground.

2.35 RACK MOUNTING SYSTEM – A complete system used to mechanically secure and support one or more PV modules and that is affixed to a structure or ground and includes module mounting means, rack mounting means, and racks.

2.36 RACK MOUNTING SYSTEM ACCESSORIES – Devices that do not act as nor supplement support for the PV module or mechanical securement of the PV module to the rack or mechanical securement of the rack to a structure or ground.

2.37 RATED OPERATING VOLTAGE – The voltage, ±10 percent, at which maximum power is available from the module or panel under standard test conditions (STC).

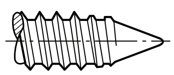
2.38 RETENTION DEVICE – A device which retains a PV module, such as, but not limited to a U-channel rail and where applicable the requirements pertaining to clamping devices may also apply to the retention devices.

2.38A ROOF ATTACHMENT – The mechanical connection (e.g., fasteners, U-bolts, adhesives, etc.) between the mounting system or mounting device and the roof system.

2.39 SHEAR LOADING – A load applied parallel to the cross-section of the material.

2.39.1 SHEET METAL SCREW – A thread forming or thread cutting screw with spaced threads which allow for material displacement during threading. The threads per inch for sheet metal screws are less than those for machine screws (UNC, UNF, or M as defined by ASME B1.1 and ASME B1.13M). Examples of sheet metal screws include Type A, AB, ABR, B, BP, BF, BT and 25 as defined by ASME B18.6.3.

Sheet Metal Screw with Spaced Threads



2.39.2 SINGLE FAULT CONDITION – Condition in which one means for protection against a hazard is defective or one fault is present which could cause a hazard. If a single fault condition results in other subsequent failures, the set of failures is considered as one single fault condition.

2.40 STAINLESS STEEL (300 SERIES) – Stainless steel in the AISI 300 series.

2.41 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.

2.42 TERMINAL CONNECTOR – Establishes a connection between one or more conductors to a terminal plate or stud, or to any similar device, by means of mechanical pressure.

2.43 TORQUE – The tendency of a force to rotate an object; the cross product of the lever arm and force. For the purposes of this standard, refers to the rotational force applied to a threaded fastener to obtain a desired clamp load.

2.44 ULTIMATE TENSILE STRENGTH – The maximum engineering stress a material can withstand while being stretched or pulled before failing or breaking. Ultimate tensile strength is sometimes referred to simply as tensile strength.

2.45 UNCONDITIONED MODULES OR SAMPLES – Modules or samples that have not been previously subjected to tests or environmental exposures.

2.46 *Deleted*

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 this clause, a component of a product covered by this standard shall comply with the requirements for that component. See the Standards for Components appendix for a list of standards covering components generally used in the products covered by this standard.

4.2 A component is not required to comply with a specific requirement that:

a) Involves a feature or characteristic not required in the application of the component in the product 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 Undated 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 Rack mounting system and all components shall be designed with suitable materials and at sufficient material thickness for structural integrity for the loads the rack system will be subject. Materials shall also have suitable corrosion resistance (see Section 10). Any dissimilar metals that significantly contribute to galvanic corrosion shall not be utilized. The electrochemical potentials table of Figure 6.1 shows various common metal combinations. Combinations below the table cutoff line, 0.6 V or less, are considered to be acceptable. Inherently, corrosion resistant metals that are not dissimilar, for example an austenitic stainless steel fastener used on an austenitic stainless steel clamp, are not subject this requirement.

Exception No. 1: For the combination of austenitic stainless steel (i.e. 300-series stainless steel) and zinc galvanized material; if the immediate adjacent area of materials zinc galvanized to austenitic stainless steel is greater than 2:1, the galvanic potential may be considered as 0.6 V.

Exception No. 2: 5000 and 6000 series aluminum alloys are considered Al/Mg alloy (although some in these series of alloys may contain additional alloying elements). For example, an austenitic stainless steel fastener used with 5000 series aluminum rail would be 0.55 V in Figure 6.1.

Figure 6.1

Electrochemical potentials

Magnesium, magnesium alloys	Zinc, zinc alloys	80 tin/20 Zn on steel, Zn on iron or steel	Aluminium	Cd on steel	Al/Mg alloy	Mild steel	Duralumin	Lead	Cr on steel, soft solder	Cr on Ni on steel, tin on steel, 12% Cr stainless steel	High Cr stainless steel	Copper, copper alloys	Silver solder, austenitic stainless steel	Ni on steel	Silver	Rh on Ag on Cu, silver/gold alloy	Carbon	Gold, platinum	
0	0.05	0.55	0.7	0.8	0.85	0.9	1.0	1.05	1.1	1.15	1.25	1.35	1.4	1.45	1.6	1.65	1.7	1.75	Magnesium, magnesium alloys
	0	0.05	0.2	0.3	0.35	0.4	0.5	0.55	0.6	0.65	0.75	0.85	0.9	0.95	1.1	1.15	1.2	1.25	Zinc, zinc alloys
		0	0.15	0.25	0.3	0.35	0.45	0.5	0.55	0.6	0.7	0.8	0.85	0.9	1.05	1.1	1.15	1.2	80 tin/20 Zn on steel, Zn on iron or steel
			0	0.1	0.15	0.2	0.3	0.35	0.4	0.45	0.55	0.65	0.7	0.75	0.9	0.95	1.0	1.05	Aluminium
				0	0.05	0.1	0.2	0.25	0.3	0.35	0.45	0.55	0.6	0.65	0.8	0.85	0.9	0.95	Cd on steel
					0	0.05	0.15	0.2	0.25	0.3	0.4	0.5	0.55	0.6	0.75	0.8	0.85	0.9	Al/Mg alloy
						0	0.1	0.15	0.2	0.25	0.35	0.45	0.5	0.55	0.7	0.75	0.8	0.85	Mild steel
							0	0.05	0.1	0.15	0.25	0.35	0.4	0.45	0.6	0.65	0.7	0.75	Duralumin
								0	0.05	0.1	0.2	0.3	0.35	0.4	0.55	0.6	0.66	0.7	Lead
									0	0.05	0.15	0.25	0.3	0.35	0.5	0.55	0.6	0.65	Cr on steel, soft solder
										0	0.1	0.2	0.25	0.3	0.45	0.5	0.55	0.6	Cr on Ni on steel, tin on steel, 12% Cr stainless steel
											0	0.1	0.15	0.2	0.35	0.4	0.45	0.5	High Cr stainless steel
												0	0.05	0.1	0.25	0.3	0.35	0.4	Copper, copper alloys
													0	0.05	0.2	0.25	0.3	0.35	Silver solder, austenitic stainless steel
														0	0.15	0.2	0.25	0.3	Ni on steel
															0	0.05	0.1	0.15	Silver
																0	0.05	0.1	Rh on Ag on Cu, silver/gold alloy
																	0	0.05	Carbon
																		0	Gold, platinum

Ag = Silver
Al = Aluminium
Cr = Chromium
Cd = Cadmium
Cu = Copper
Mg = Magnesium
Ni = Nickel
Rh = Rhodium
Zn = Zinc

NOTE. – Corrosion due to electrochemical action between dissimilar metals which are in contact is minimized if the combined electro–chemical potential is below about 0.6V. In the following table the combined electrochemical potentials are listed for a number of pairs of metals in common use; combinations above the dividing line should be avoided.

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6.2 The rack mounting system shall be designed with suitable corrosion resistant materials (see Section 10) to ensure structural integrity and that the rack system, through all connection points, is a suitable bond/ground path. Note that for constructions that comply with the Exception to 9.1 for non-separately derived systems, not all the connection points will be bond/ground paths.

6.2A The manufacturer shall specify the critical properties of the critical structural fasteners and critical bonding fasteners. Such properties shall include but not be limited to, geometry, tolerances, surface coating/plating type and thickness, metal alloy, minimum yield, minimum tensile strength, and/or proof strength. The requirements shall be included in the installation manual in accordance with 26.1(c).

Note: The fastener properties may be controlled through compliance with consensus standards developed by Standards Organizations such as the American Society for Testing and Materials (ASTM), American Society of Mechanical Engineers (ASME), Society of Automotive Engineers (SAE), International Organization for Standardization (ISO), Deutsch Industrie Norm (DIN), Japanese Industrial Standard (JIS) or Industrial Fasteners Institute (IFI). Informative Appendix D summarizes common imperial and metric fastener standards and specifications. A manufacturer's quality management system is an alternate path to control the critical properties of fasteners.

6.3 Clamping devices shall be evaluated with their mounting hardware designed with suitable corrosion resistant materials (see Section 10) to ensure structural integrity to suitably retain the PV modules for loading, cyclic loading and, where applicable, to maintain a bond/ground path. The clamping devices for bonding, where intended to be utilized with aluminum framed PV modules, must have a means to pierce the PV module's frame anodization, paint or other non-conductive coatings.

6.4 Threaded fasteners without suitable clamp load are subject to loosening and/or fatigue failure, therefore, threaded fasteners used to secure clamping devices and other components shall be utilized at their recommended clamp load. For grounding and bonding connections, screws shall not be sheet metal thread forming type screws. For structural/mechanical connections, screws shall be as allowed in the relevant sections of the locally adopted Building and/or Residential Codes. Threaded fasteners are to be of suitable tensile strength and corrosion resistance and are to be tightened to the recommended torque for the fastener type and size as stated by the mounting system manufacturer.

6.5 For fastened joints in tension, a fastener is at a high risk of yield, fatigue, or tensile fracture if the separating load applied to the fastened joint exceeds the clamp load in that joint. Depending on the specific design, an upward, downward or downslope load may apply a tension load to fastened joint. Therefore, the clamp load developed in a joint through the assembly process must exceed the separating load. The separating load shall be based on the minimum design load rating defined in 21.4 or the manufacturer's product load rating, whichever is greater.

6.5A The estimated separating load applied to each fastened joint within the system at the minimum design load rating or manufacturer's product rating can be estimated using free body diagrams or finite element analysis. For threaded fasteners, the clamp load developed in a joint when the associated fastener is tightened in the field shall be determined through one of two methods defined in 6.5B and 6.5D. For lock bolts, the clamp load developed in the joint when tightened shall be determined in accordance with 6.5D.

Note: For fastened joints that carry shear loads, see 6.6.

6.5B For the Calculation-Based Method, the estimated average clamp load can be calculated based on the manufacturer's recommended torque and a torque coefficient (K) from a cited reference, (see Appendix E).

$$W = T / (Kd)\ [\text{lbf} = \text{in} - \text{lbs} / \text{in}]\ \text{or}\ [\text{N} = \text{N} - \text{mm} / \text{mm}]$$

$$W = 12T / (Kd)\ [\text{lbf} = 12\,\text{ft} - \text{lbs} / \text{in}]$$

where:

W = Estimated Average Clamp Load (lbf or N)

T = Torque (in-lbf or N-mm)

K = Torque Coefficient (See Appendix E)

d = Nominal diameter of the threaded fastener (in or mm)

See Appendix C.1, Example.

6.5C A safety factor of 3:1 or greater (Estimated Average Clamp Load / Estimated Separating Load) shall be applied when the 6.5B Calculation-Based Method is used to estimate the Average Clamp Load.

Note: This safety factor does not apply to critical bonding fasteners.

6.5D For the Experimentally Based Method, the minimum expected clamp load (W_{min}) in a joint shall be determined statistically, based on experimental work using a representative joint, tightened using the manufacturer's specified assembly method (defined in the assembly instructions according to 26.1). Experimental data shall provide a 95% confidence level that 99% of the population exceeds W_{min} based on the following equation.

$$W_{min} = W_{mean} - SC * \sigma_x$$

where:

W_{min} = Minimum Expected Clamp Load

W_{mean} = Mean clamp load from all tests

SC = Statistical coefficient based on the number of tests n. (See Table 6.0)

σ_x = Standard deviation of all tests

Table 6.0
Statistical Coefficient (SC) vs. Sample Size

n	SC	n	SC
3	10.550	18	3.370
4	7.042	19	3.331
5	5.741	20	3.295
6	5.062	21	3.295
7	4.641	22	3.233
8	4.353	23	3.206
9	4.143	24	3.181
10	3.981	25	3.158
11	3.852	30	3.064
12	3.747	35	2.994
13	3.659	40	2.941

Table 6.0 Continued on Next Page

Table 6.0 Continued

n	SC	n	SC
14	3.585	45	2.897
15	3.520	50	2.863
16	3.463	100	2.684
17	3.415		

Note: This Table was developed based on the document titled “SCR-607 Factors for one-sided tolerance limits and variable sampling Plans”, which defines single-sample variable sampling plans and one-sided tolerance limits for a normal distribution. SC is the one-sided factor where 99% of the population, exceed W_{min} with a confidence of 95%.

6.5E The testing laboratory shall determine if it is acceptable for the manufacturer to perform and document this testing. A detailed description of the representative joint test sample, the test procedure, test data and statistical analysis shall be documented in a test report by either the test laboratory or the manufacturer. The results shall validate the defined minimum expected clamp load. An example of this method is provided in Appendix F.

6.5F A safety factor of 1.5:1 or greater (Minimum Expected Clamp Load / Estimated Separating Load) shall be used when 6.5D Experimentally Based Method is used to estimate the minimum expected clamp load.

Note: This safety factor does not apply to critical bonding fasteners.

6.6 For fastened joints in shear, a fastener is at a high risk of loosening, yield, or fatigue fracture if the shear load applied to that joint exceeds the slip resistance in that joint. Depending on the specific design, an upward, downward or downslope load may apply a shear load to fastened joint. Therefore, the slip resistance developed in a joint through the assembly process shall exceed the shear load. The shear load shall be based on the minimum design load rating defined in 21.4 or the manufacturer’s product load rating, whichever is greater.

6.6A The estimated shear load applied to each fastened joint within the system at the minimum design load rating or manufacturer’s product rating can be estimated using free body diagrams or finite element analysis.

Note: For fastened joints subjected to tension, see 6.5.

6.6B For threaded fasteners, the estimated average slip resistance can be determined using the estimated average clamp load defined in 6.5B and the static coefficient of friction between the joint mating surfaces in accordance with the following equation. For lock bolts, the estimated average slip resistance can be determined using the mean clamp load ($W_{mean\ tested}$) determined in accordance with 6.5D and the static coefficient of friction between the joint mating surfaces in accordance with the following equation:

$$\text{Estimated Average Slip Resistance} = W \times \text{Static Coefficient of Friction}$$

where:

W = Estimated Average Clamp load

See Appendix C.2, Example.

6.6C The static coefficient of friction shall be taken from Table 6.1 for from a well-established, properly cited engineering reference.

6.6D A slip safety factor of 3:1 or greater (Estimated Average Slip Resistance / Estimated Shear Load) shall be applied when the 6.6 Calculation Based Method is used to estimate the average slip resistance.

Note: This safety factor does not apply to critical bonding fasteners.

Table 6.1
Static Coefficients of Friction
(Informative)

Material combination	Static coefficient of friction [a]	Source
Mild Steel on Mild Steel (clean & dry)	0.74	Hardy & Hardy, Phil Magazine, 1919
Steel on mill aluminum (clean & dry)	0.61	Tomlison, Phil Magazine, 1929
Steel on anodized aluminum	0.30	SIS Handbook, Aluminium, ed. 3, June 2003
Mill aluminum on mill aluminum (clean & dry)	1.00	Ernst and Mechant, Conference on Friction and Surface
Mill Aluminum on anodized Aluminum	0.50	This value is widely cited but the original source of this could not be found
Anodized aluminum on anodized aluminum	0.30	This value is widely cited but the original source of this could not be found
As received galvanized on galvanized	0.30	Donahue, Helwig, Yura, Final Report for Galvanized Surfaces

[a] Static coefficients of friction obtained during testing may be used in place of the values in the table. Where a combination of materials is not shown in the table, coefficient of friction may be established through testing or other well established, and properly cited engineering references.

6.7 Where a threaded rod is utilized, such as but not limited to a leveling device, and as such a clamp load is not possible, then the stress of the component needs to be analyzed to show a factor of safety of at least 6:1 using the design load acting on that component applied to the area tributary to the component being analyzed. This is calculated using the tensile strength of the material multiplied by the stress area of the threads as follows:

$$A_s = 0.7854[D-0.9743/n]^2$$

where:

A_s = Stress Area

D = Major Diameter

n = number of threads

The result, A_s, is then multiplied by the tensile strength of the threaded rod, then comparison is made to the load the threaded rod would be subject to, using the cross-sectional area of the PV modules and the design loads.

The following tensile strengths may be used for the given alloys if a specific value is not provided by the material standard. Other suitable materials may also be used:

301	110,000 psi
302/303	90,000 psi
304/308	85,000 psi
316	80,000 psi

6.8 Unless specifically defined within a module's installation instructions, the rack mounting system and clamping device(s) shall not be designed such that a module or panel assembly bolt, screw, or other part integral to the construction of the module or panel is used for securing the PV module or panel to the rack mounting system.

6.9 The rack mounting system and clamping device(s) shall not be designed such that a PV module or panel requires any alteration 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.

6.10 The construction of a rack mounting system and clamping device 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.

6.11 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.

6.12 With the exception of the items below, friction between surfaces is not acceptable as the sole means to inhibit the turning, loosening, or movement of a part.

Exception No. 1: Threaded fasteners that comply with 6.5 or 6.6.

Exception No. 2: Threaded fasteners utilized in shear loading, with 2 or more fasteners utilized at a joint whereby the pair (or more) of fasteners would prevent rotation at that joint, and that comply with 6.6.

Exception No. 3: A construction that utilizes set-screws for retention shall demonstrate surface deformation of the material to which they are secured and shall be separately mechanical load tested to verify a minimum 3:1 safety factor when compared to the manufacturers product design load rating and also with consideration for the additional loading where PV Modules or supports are on either side of the set screw construction (2 times 3:1).

Exception No. 4: For bonding only devices that rely on spring force and piercing function to penetrate anodization or other nonconductive coatings and into the base material, see 9.10.

Exception No. 5: Ballasted systems at the interface between the ballasted system and the roof or ground.

6.13 Screw threads that are intended to clamp two or more materials together shall be installed such that the clamping load is obtained after assembly.

6.14 An adjustable or movable structural part shall be provided with a positive locking device to reduce the likelihood of unintentional shifting, such as but not limited to a cap screw or machine screw with a definite clamp load, retaining pin or the like, if any such shifting may result in a risk of fire, electric shock, or injury to persons.

6.15 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.

6.16 Accessible edges, projections, and corners of rack mounting system and clamping devices shall be such as to reduce the risk of injury to persons.

Exception: Devices being used for clamping or bonding that have no exposed sharp edges when installed are not required to meet this requirement.

6.17 Whenever a referee measurement is necessary to determine that a part as referenced in 6.16 is not sufficiently sharp to constitute a risk of injury to persons, the method described 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 utilized in a rack mounting system and/or clamping device, which is not relied upon for electrical isolation or insulation, shall comply with the applicable requirements in the Standard for Polymeric Materials Polymeric Materials – Long Term Property Evaluations Use in Electrical Equipment Evaluations, UL 746C, concerning:

a) Ultraviolet light exposure,

b) Water exposure and immersion, and

c) Relative Thermal Index (mechanical) (RTI).

7.2 A polymeric material serving as the mechanical support and/or clamping device which is relied upon for electrical isolation or insulation involving a risk of fire or electric shock 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, in addition to meeting the flammability requirements in the Standard for Polymeric Materials Polymeric Materials – Long Term Property Evaluations Use in Electrical Equipment Evaluations, UL 746C;

b) Meet the hot-wire ignition (HWI) requirements from UL 746C;

c) 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

d) Have a Comparative Tracking Index performance level category (PLC) of 2 or better, when the system voltage rating is 600 V or less, as determined in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A;

e) Have an Inclined Plane Tracking (ASTM D2303) rating of 1 h using the time to track method at 2.5 kV when the system voltage rating is in the range 601 – 1000 V; and

f) 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.

7.3 A polymeric material that serves as mechanical or electrical support and 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 complies with 11.1 meets the intent of this requirement.

7.4 A polymeric material that serves as mechanical mounting support shall have a minimum Relative Temperature Index (RTI) Mechanical without Impact value in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, as noted below:

a) 105° C for components that are in direct contact with a module's polymeric substrate or superstrate and where:

1) The RTI of the module's substrate is no greater than 105°C, and

2) There is no standoff requirement in the module's installation requirements or the module's compliance with UL 1703 (Section 19) or UL 61730-2.

b) 90° C for components that are not in direct contact with a module's polymeric substrate or superstrate,

c) 70° C for components that are not in direct contact with a module's polymeric substrate or superstrate and where:

1) The product installation instructions or physical constraints ensures the bottom of a module is nominally on average 3 in or more off the roof surface,

2) There is a minimum of 1/4 in gap between modules, and

3) A minimum of 75% of the vertical area around the array is open for sloped roof racking systems (i.e. a skirt on only one side) and a minimum of 75% of the vertical area around a row of modules is open for flat roof racking systems (i.e. only side deflectors).

Exception: A lower RTI minimum requirement for a polymer may be derived from the measured temperature of the polymer within a representative PV system including the manufacturer's rack mounting system that is subjected to the UL 1703 or UL 61730-2 Temperature Test. The test shall be conducted with the irradiance measured in the plane of the module and also in any other position relative to the sun that is allowed in the manufacturer's installation instructions where the polymer would likely experience maximum temperature.

8 Grounding and Grounding Devices

8.1 The requirements in Section 9, Bonding, also apply to Grounding.

8.2 Mounting systems shall have a means for grounding/bonding all accessible potentially conductive parts. Grounding devices shall comply with the Grounding and Bonding Equipment, UL 467, and also to the requirements of this Standard. The grounding means shall be bonded to each conductive part of the rack mounting systems and clamping devices. The grounding means shall be described in detail in the installation manual. See Installation, Assembly and Maintenance/Inspection Instructions, Section 26.

8.3 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, 300-series stainless steel, or suitably corrosion protected for the application, see Section 10, 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 or 300-series stainless steel,

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.

8.4 If a terminal connection is employed as part of a rack mounting system or clamping device (a wire-binding screw, a pressure wire connector, or a stud) for an equipment grounding conductor, it shall be identified by being marked "G," "GR," "GROUND," "GROUNDING," or the like, or shall have a green-colored part. None other than grounding terminals shall be so identified.

8.5 If a marking is used to identify an equipment grounding terminal, it shall be located on or adjacent to the terminal.

8.6 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.

9 Bonding

9.1 Mounting system and clamping/retention device(s) shall have a means for bonding all accessible potentially conductive parts to ground. The grounding means shall comply with the applicable requirements in Grounding and Grounding Devices, Section 8. The grounding means shall be bonded to each conductive part of the rack mounting systems and clamping devices. The grounding means shall be described in detail in the installation manual. See Installation, Assembly and Maintenance/Inspection Instructions, Section 26. Mounting system and clamping/retention device(s) that create a bonding path by connecting to and bonding multiple PV frames together is permitted, provided that the device(s) comply with all of the following:

a) Comply with Sections 8, 9 and 22,

b) The device(s) are used with framed PV modules that comply with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, or with the Standard for Photovoltaic (PV) Module

Safety Qualification – Part 1: Requirements For Construction, and Part 2: Requirements for Testing, UL 61730-2, and

c) The specific PV modules used with the mounting system are evaluated with the device(s) in accordance with applicable sections in this standard.

Exception: Accessible conductive components that are not a part of the fault current ground path such as flashings, roof attachments, L-feet, tile hooks, skirts, ballast trays and wind deflectors, and metal roofing panels are not required to be electrically bonded when the following are all true:

a) The installation instructions clearly identify the system's fault current ground path components and their methods of assembly.

b) The accessible conductive component is not likely to be energized other than through direct or indirect contact with other accessible conductive components that are likely to be energized under normal operations or single fault conditions.

In addition, a suitable wire positioning device that complies with the Standard for Positioning Devices, UL 1565, or the Standard for Cable Management Systems – Cable Ties for Electrical Installations, UL 62275, is not required to be electrically bonded.

9.2 Routine maintenance of a PV module or mounting system, e.g. inspection or cleaning, shall not involve breaking or disturbing the bonding path of the system. If the removal of a module may break or disrupt the bonding path of the system, the installation manual shall comply with 26.10.

9.2.1 A dedicated/identified grounding or bonding hole of a PV module, shall not also be used for securing a module.

9.2.2 Unless specifically defined within a module's installation instructions, the rack mounting system and clamping device shall not be designed such that a module assembly bolt, screw, or other part integral to the construction of the module is used for bonding the PV module to the mounting system.

9.3 The securement of bonding devices or achieving bonding shall be by positive mechanical means, such as clamping, riveting, bolted or screwed connections (see 6.5 and 6.6), or welding, soldering (see 9.5) or brazing. The bonding connection/device shall penetrate nonconductive coatings, such as but not limited to anodization, paint or vitreous enamel. Machine screws of all types are considered to be a positive mechanical means. Sheet metal screws are not considered a positive mechanical means.

9.4 A bolted, screwed or riveted connection that incorporates a star washer under the head of the fastener, a serrated screwhead, or a bonding device between surfaces may be acceptable for penetrating nonconductive coatings. If the bonding means depends upon threaded fasteners, two or more screws each with at least a full thread, or two full threads of a single screw shall engage the metal.

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

9.6 A separate bonding conductor or bonding strap shall comply with the following:

a) Be of copper and its alloys, aluminum and its alloys, 300 series stainless steel, or other material acceptable for use as an electrical conductor;

b) Where there is risk of mechanical damage, a minimum 6 AWG strap shall be used or the strap shall be protected from mechanical damage by using methods such as but not limited to a protective raceway or routing straps along structural elements;

c) Be secured via a positive mechanical means (see 9.3). If secured by a removable fastener, the fastener shall be used only to secure the bonding conductor or strap if it is likely that the bonding conductor or strap would not be reinstalled after removal and replacement of the fastener;

d) If terminations are included, be factory crimped terminations, not field crimped;

e) Comply with the sizing requirement in Table 9.1. A separate bonding conductor or bonding strap shall have a minimum size or be rated to carry the required current in accordance with the following:

1) For a dc input from a photovoltaic source or output circuit, 1.25 times the rated short-circuit input current for that input.

2) For any ac input or output circuit or dc (non-PV) input or output circuit, Column 2 of Table 9.1 based on the size of the overcurrent device protecting that circuit.

Exception: A smaller conductor or strap is usable when it complies with Bonding Conductor Test, Section 22.

f) Bonding straps with non-flat terminations/crimps are subject to the Bonding Path Resistance Test, Section 13; Humidity Test, Section 18; Bonding Conductor Test, 135%, 200% and Limited Short Circuit, Section 22 and evaluated in accordance with the Standard for Grounding and Bonding Equipment, UL 467; or

g) Flat bonding straps with flat end terminations/crimps, are subject to the Bonding Path Resistance Test, Section 13; Humidity Test, Section 18; Bonding Conductor Test, 135%, 200% and Limited Short Circuit, Section 22, and the Bonding Strap Pull Test, Section 23.

Table 9.1
Size of equipment-grounding conductors

Column 1	Column 2			
	Minimum size of equipment-grounding or bonding conductor			
	AWG or kcmil (mm^2)			
Maximum circuit current rating, amperes	Copper		Aluminum or copper-clad aluminum	
15	14	(2.1)	12	(3.3)
20	12	(3.3)	10	(5.3)
30	10	(5.3)	8	(8.4)
40	10	(5.3)	8	(8.4)
60	10	(5.3)	8	(8.4)
90	8	(8.4)	6	(13.3)
100	8	(8.4)	6	(13.3)
150	6	(13.3)	4	(21.2)
200	6	(13.3)	4	(21.2)
300	4	(21.2)	2	(33.6)
400	3	(26.7)	1	(42.4)
500	2	(33.6)	1/0	(53.5)
600	1	(42.4)	2/0	(67.4)
800	1/0	(53.5)	3/0	(85.0)
1000	2/0	(67.4)	4/0	(107.2)
1200	3/0	(85.0)	250	(127)
1600	4/0	(107.2)	350	(127)
2000	250	(127)	400	(203)
2500	350	(177)	600	(304)
3000	400	(203)	600	(304)
4000	500	(253)	800	(405)
5000	700	(355)	1200	(608)
6000	800	(405)	1200	(608)

9.7 A bonding device that pierces non-conductive coatings such as, but not limited to; anodization, paint, vitreous enamel may be a separate piercing device such as, but not limited to; a piercing washer, star washer, serrated fasteners, or integral to the component. It shall have sufficient hardness to pierce the non-conductive coating and as such may be 300-series stainless steel, or a suitably corrosion protected conductive material (see Section 10).

9.8 A ferrous metal part shall be protected against corrosion by metallic or nonmetallic coatings, such as painting, galvanizing, or plating. 300-series stainless steel is acceptable without additional coating. Any corrosion protection shall not interfere with the grounding/bonding path.

9.9 Suitable corrosion resistant (see Section 10) metal-to-metal multiple load bearing pin-type hinge may be an acceptable means for bonding.

9.10 Bonding only devices that rely on spring force and piercing function to penetrate the anodization or other nonconductive coating and thereby secure into the base material, shall also demonstrate that upon removal, base material is also removed or deformed.

9.11 Bonding devices evaluated as multiple use shall be subject to the Multiple Use Bonding Conductor Limited Short Circuit Test portion of 22.4.

9.11.1 Bonding device multiple use location restrictions shall be evaluated and where applicable, so indicated in the installation instructions. For example, where a bonding device re-use case requires specific placement on the module frame, the installation instructions shall reflect and inform Section 22 performance testing.

9.12 A bonding/grounding device evaluated to this standard, that is mounted to a PV module frame (such as a Module Level Power Electronic device or mounting bracket) used in accordance with the bonding/grounding device installation instructions provided, is not required to be evaluated with the rack system or included in the racking installation instructions, unless it is identified as the grounding method for the system.

10 Corrosion Resistance

10.1 Aluminum; cast and wrought aluminum alloys of series 1XX.X,1XXX, 3XX.X, 3XXX, 4XX.X, 4XXX, 5XX.X, 5XXX, 6XX.X, and 6XXX; 300 series stainless steel, copper and its alloys, or polymeric materials may be used without additional corrosion protection.

10.2 Aluminum alloys of series 2XX.X, 2XXX, 7XX.X, 7XXX, 8XX.X, and 8XXX shall not be used, as test methods to assess the corrosion resistance of these alloys have not yet been developed. Steel, iron or other non-inherently corrosion-resistant materials which may be exposed to the weather shall be made corrosion-resistant by one of the following minimum coatings:

a) Hot-dipped mill-galvanized sheet steel conforming with the coating designation G90 (Z275) in the Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot Dip Process, ASTM A653/A653M, or for equivalent ASTM 123, 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).

Exception: For the posts that are to be driven into the ground; the coating designation of G210 (Z600), minimum, according to ASTM A653/A653M or the equivalent in either the Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware, ASTM A153, or the Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products, ASTM A123, shall be utilized.

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 0.61 mils (0.015 mm) on the surface with a minimum thickness of 0.54 mils (0.014 mm). The thickness of the coating shall be established by the Metallic Coating Thickness Test, Section 20. An annealed coating shall also comply with 10.5 and 10.6.

c) A cadmium coating not less than 1.0 mils (0.025 mm) thick on both surfaces. The thickness of the coating shall be established by the Metallic Coating Thickness Test, Section 20.

d) A zinc coating conforming with 10.2(a) or 10.2(b) with one or more coats of outdoor paint. The coating system shall comply with 10.3.

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 than 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 20, and the coating system shall comply with 10.3.

f) An organic or inorganic protective coating systemproviding protection at least equivalent to that provided by the zinc coating described in 10.2(a). See Corrosive Atmosphere Tests, Section 19.

10.3 With reference to 10.2(d) and 10.2(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 10.2(a). See Corrosive Atmosphere Tests, Section 19.

10.4 With reference to 10.1 and 10.2, 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 10.1(a) or 10.2 as applicable, indicate they provide equivalent protection. See Corrosive Atmosphere Tests, Section 19.

10.5 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.

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

10.7 Iron or steel serving as a necessary part of the product but not exposed to the weather shall have a protective coating, such as plating, paint, or enamel for protection against corrosion.

10.8 Materials not specifically mentioned in this section shall be evaluated on an individual basis. The Corrosive Atmosphere Tests, Section 19, may be used for the evaluation.

10.9 The corrosion resistant material shall not interfere with the grounding/bonding path.

10.10 Steel parts which have either a through or surface hardness equivalent to Rc35 or greater, and are electroplated, shall be additionally treated following the electroplating process to relieve hydrogen embrittlement.

11 Fire Resistance

11.1 A mounting system intended for stand-off, rack mounting, or direct mounting in combination with a specified roof, or intended for integral mounting in combination with the specified PV module(s) that are not BIPVs, shall comply with the fire resistance requirements for a Class A, B, or C PV System Rating in Section 15 and marked as being fire rated as specified in 25.4. The PV mounting system with its module or panel 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. 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. PV rack mounting systems may be tested with specific ″types″ of modules as characterized in accordance with paragraph 16.4.1 of the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, or with paragraphs 10.17DV.4.2 – 10.17DV.4.2 of the Standard for Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements for Testing, UL 61730-2.

Exception: The fire tests outlined in this section are not required for systems that meet all the following requirements:

a) Modules or panels with a defined Type classification and a spread of flame result that meet Class A requirements, which is <1,82 m (6 feet) or less in 10 minutes, in accordance with UL 1703 or UL 61730-2 (for example, Types 1, 2, 3, 10, 13, 16, etc.);

b) Rack mounting systems, that comply with this standard, constructed of minimum 98% (by weight) noncombustible materials, as defined by ASTM E136; and *c) Installed over Class A roof assemblies with the following noncombustible roof coverings:*

1) Clay tile,

2) Concrete tile,

3) Metal panels made from steel, minimum 28 Ga ferrous panels or shingles.

These systems shall be identified as having a Class A fire rating.

11.2 Rack or direct mounting systems with 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.

PERFORMANCE

12 General

12.1 Samples of the rack mounting system and clamping device(s) with associated hardware and with the PV Modules intended to be utilized with the rack mounting system and clamping devices shall be subjected to the tests indicated in Table 12.1. The order of the tests in Table 12.1 is not required. It is not intended that any one sample be subjected to the complete sequence or a partial sequence of tests, except for the Bonding Path Resistance Test, which is conducted before and after the Humidity Test.

Table 12.1
Rack Mounting System and Clamping Devices Performance

Section	Test	Number of samples
13	Bonding Path Resistance Test	1, also see Humidity Cycling and Bonding Conductor Tests
14	Terminal Torque Test	1
15	Fire Tests	1
16	Accelerated Aging Test	a
18	Humidity Test	1 each connection point
19	Corrosive Atmosphere Tests	2 (For larger samples: 1 for each test. For smaller samples such as cap screws, nuts, washers, etc. 3 for each test)
20	Metallic Coating Thickness Test	As needed
21	Mechanical Loading Test	Number to be determined as to be representative of the construction
22	Bonding Conductor Test, 135%, 200% and Limited Short Circuit	2 for the 135% Bonding Conductor Test, 2 for the 200% Bonding Conductor Test, and 2 for the Limited Short Circuit Test, which is 6 for each connection point[b]
23	Bonding Strap Pull Test (Only for flat bonding straps with flat end terminations/crimps)	2 each

[a] Dependent on the physical size of the gasket and seal material.

[b] Samples may be reduced by reusing samples from other tests at the discretion of the manufacturer.

12.2 Tests performed on representative samples are acceptable given that no differences from the representative samples, or any differences in design are within limits outlined in Appendix B, Retest

Guidelines. Samples shall be of sufficient length and width such that a 1.97 in (50 mm) scribe can be made while maintaining a 0.49 in (12.5 mm) distance (clearance) from the scribe to the sample edge. Samples with sizes or geometries that, in full scale, cannot meet this requirement are exempt from scribing.

13 Bonding Path Resistance Test

13.1 The resistance between grounding or bonding junctions shall not be more than 0.1 Ω when measured in accordance with 13.2.

13.2 Direct current equal to twice the fuse ampere rating specified for the PV Module is to be passed between the grounding/bonding connection points (for example; the PV Module frame to the rack mounting system frame, which may be through the bonding clamp device, if applicable, and also through the rack mounting system frame connection points, where applicable). 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.

Exception: A direct current of 25 amperes may be substituted for twice the fuse ampere rating.

13.3 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.

14 Terminal Torque Test

14.1 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 14.1 without

a) Damage to the terminal supporting member, or

b) Loss of continuity.

Table 14.1
Torque requirements

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

14.2 If a machine-screw thread cutting screw, drill point screw or the like is utilized such that material is removed from the part receiving the screw, the Terminal Torque Test shall be conducted to ensure integrity of the mechanical or electrical (including bond/ground) connection. If the screw size differs from that in Table 14.1, then the manufacturer's recommended torque shall be utilized. If the screw size is the same as in Table 14.1, and the manufacturer’s torque specification differs from Table 14.1, then the higher value shall be utilized for the Terminal Torque Test.

15 System Fire Class Rating of Mounting Systems with Modules or Panels in Combination with Roof Coverings

15.1 General

15.1.1 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 15.1. The specimens selected for testing are to be representative of the construction series being investigated with regard to components, configuration, and design.

Table 15.1
Required tests for System Fire Class Rating of PV module or panel with mounting system in combination with roof coverings

	Tests Over Representative Roof Coverings		
Test	**Class A**	**Class B**	**Class C**
Spread of Flame On Top Surface of Module or Panel (UL 1703, Section 31.1.2 or UL 61730-2, Section DVB.2)[a]	Flame Spread less than 6 ft (1.8 m) in 10 minutes	Flame spread less than 8 ft (2.4 m) in 10 minutes	Flame spread less than 13 ft (4.0 m) in 4 minutes
Spread of Flame at Roof and Module or Panel Interface Over Representative Steep Sloped Roof [15.2.1(a)][b]	Pass	Pass	Pass
Spread of Flame at Roof and Module or Panel Interface Over Representative Low Sloped Roof [15.2.1(b)][b]	Pass	Pass	Pass
Burning Brand on Surface Over Representative Steep Sloped Roof [15.3.1(a)][b]	A Brand	B Brand	C Brand
Burning Brand Between Module or Panel and Representative Steep Sloped Roof [15.3.1(b)][b]	Pass	Pass	Pass

[a] Requirement can be met by either with a type tested module (UL 1703, Section 16.4.1, or with paragraphs 10.17DV.4.2 of the Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements for Testing, UL 61730-2) or by performing the test in UL 1703, Section 31.1.2, or UL 61730-2, Section DVB.2, on the top surface of a module or panel in the mounting system being qualified in 15. For non-type tested products, the product must pass two consecutive tests for each required test.

[b] After testing the required directions, the test which had the worst performance (as determined by the greatest burn distance) shall be repeated. Each test must be passed unless not required by the terms of 15.1.3, Section 15.2 or Section 15.3. For the purpose of this standard, Steep and Low Sloped Roof are defined in 15.1.2.

15.1.2 A rack mounting system intended for stand-off, rack, or direct mounting in combination with a specified roof, or intended for integral mounting in combination with the specified PV module(s) that are not BIPVs in combination with roof coverings shall be installed as shown in this section and according to 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 the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, or in the Standard for Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements for Testing, UL 61730-2. 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 rack mounting system intended for stand-off, rack, or direct mounting in combination with a specified roof, or intended for integral mounting in combination with the specified PV module(s) that are not BIPVs 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: 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 rack mounting system intended for stand-off, rack, or direct mounting in combination with a specified roof, or intended for integral mounting in combination with the specified PV module(s) that are not BIPVs 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 rack mounting system intended for stand-off, rack, or direct mounting in combination with a specified roof, or intended for integral mounting in combination with the specified PV module(s) that are not BIPVs 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: Class A 3 tab asphalt shingle, ASTM D3462, ″Standard Specifications for Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules.″

15.1.3 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 15.1.2 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. Multiple edges may be combined in one test providing the geometry is symmetrical, such as east and west edges or north and south edges. 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

15.1A and Figure 15.1B for clarification on the three required flame test locations for the asymmetrical mounting system.

Figure 15.1A

Demonstration of the three test locations

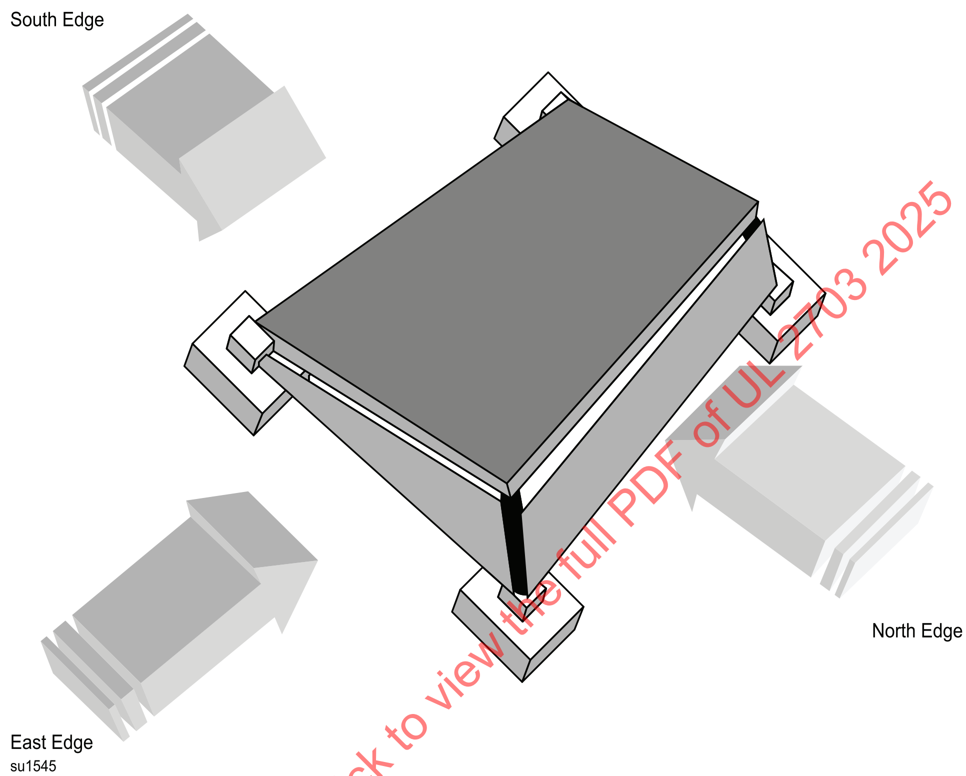
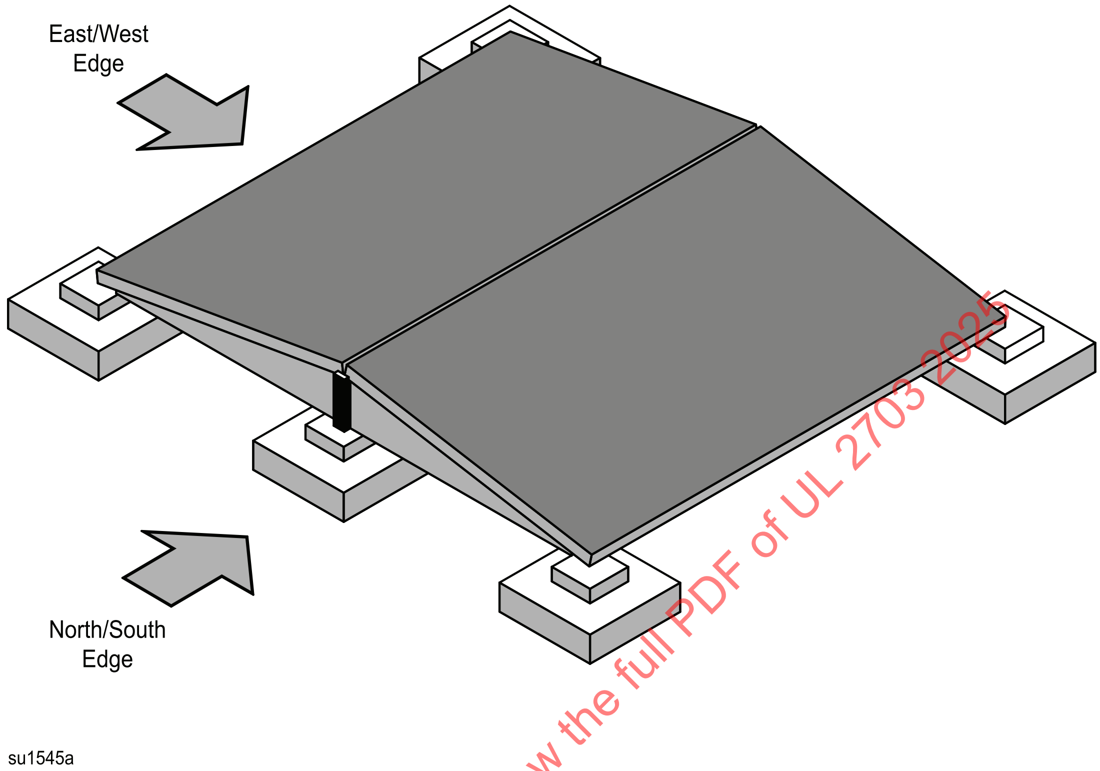


Figure 15.1B

Demonstration of two test locations



15.1.4 For both the Spread-Of-Flame and Burning-Brand Tests, the mounting system and the module or panel are to be installed in accordance with the manufacturer's instructions for both the module and the mounting system, except where described in 15.3.1. 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.

15.1.5 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).

15.1.6 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).

15.1.7 A rack mounting system is not required to be usable after any of the tests in this section.

15.2 Spread-of-flame tests

15.2.1 The spread-of-flame tests are to be conducted on the mounting system assembled with the intended 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. The tested mounting system will be exactly as it is assembled with the PV module according to its evaluation, with alternative designs that affect these test results tested separately according to the Retesting Guidelines in Appendix B. Parameters that are installed with variable settings will be tested with the worst-case condition except as described below.

a) Spread of Flame at Roof and Module or Panel Interface Over Representative Steep Sloped Roof. With the mounting system and 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. The mounting system and 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 mounting system and the module or panel installation for steep sloped roofs shall be the measured baseline in accordance with 15.1.2 minus 12 inches (303 mm). Figure 15.2 illustrates how the baseline roof tests are used to establish the location of PV mounting system relative to the test flame. Figure 15.3 and Figure 15.4 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 mounting system only be installed for slopes less than 2 inches/foot (167 mm/m).

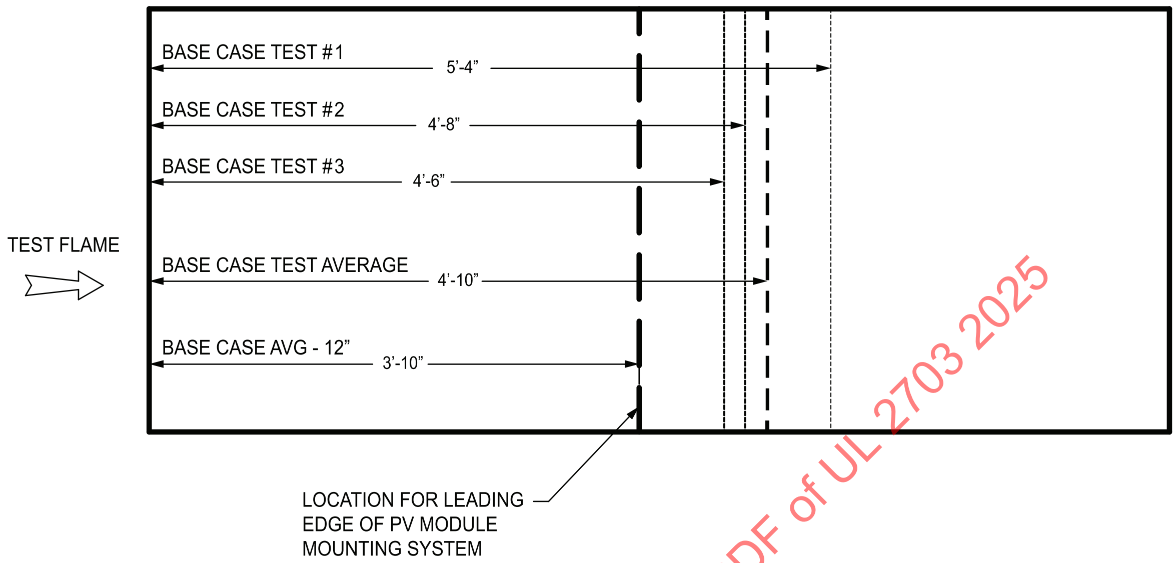
b) Spread of Flame at Roof and Module or Panel Interface Over Representative Low Sloped Roof. With the mounting system and the module or panel installed on a low slope roof as an assembly and oriented such that the fire growth from the roof covering materials advances to the interstitial space below the module or panel and above the roof. For low sloped roofs, the mounting system and 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 mounting system and the module or panel installation for low sloped roofs shall be the measured baseline in accordance with 15.1.2 minus 12 inches (303 mm). For products with asymmetrical edge configurations, these dimensions apply to each of the 3 tests described in 15.1.3. Figure 15.5 – Figure 15.12 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 15.2

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

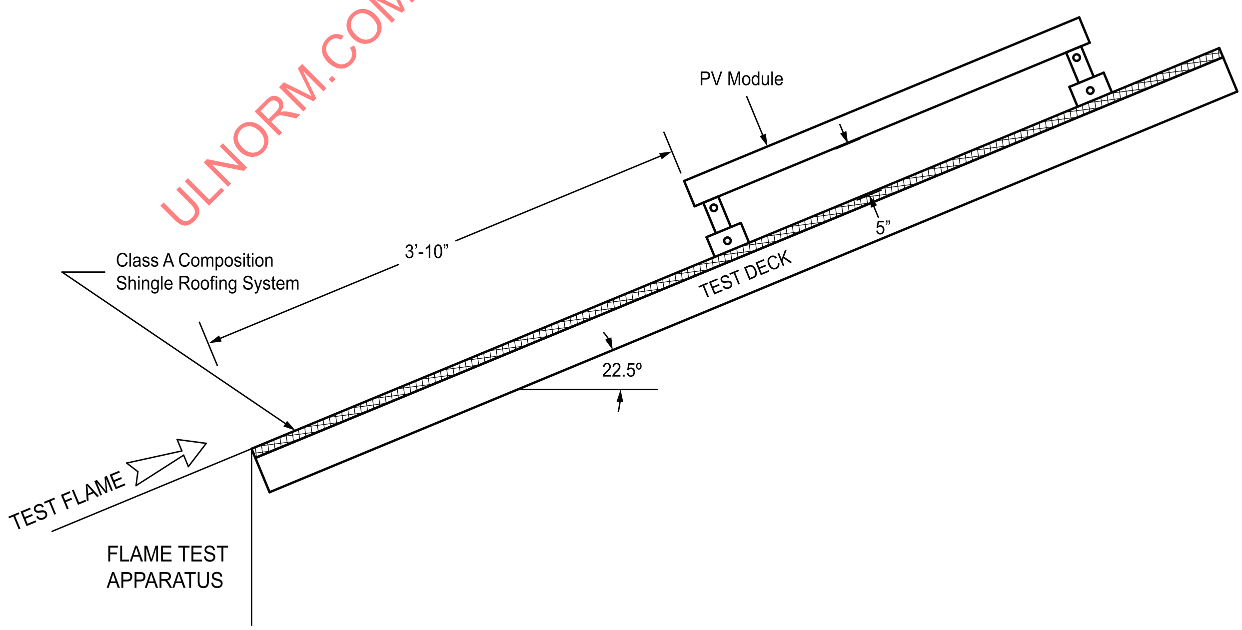


Metric conversion information:

5 ft-4 in (1.6 m)
4 ft-8 in (1.4 m)
4 ft-6 in (1.37 m)
4 ft-10 in (1.5 m)
3 ft-10 in (1.2 m)

Figure 15.3

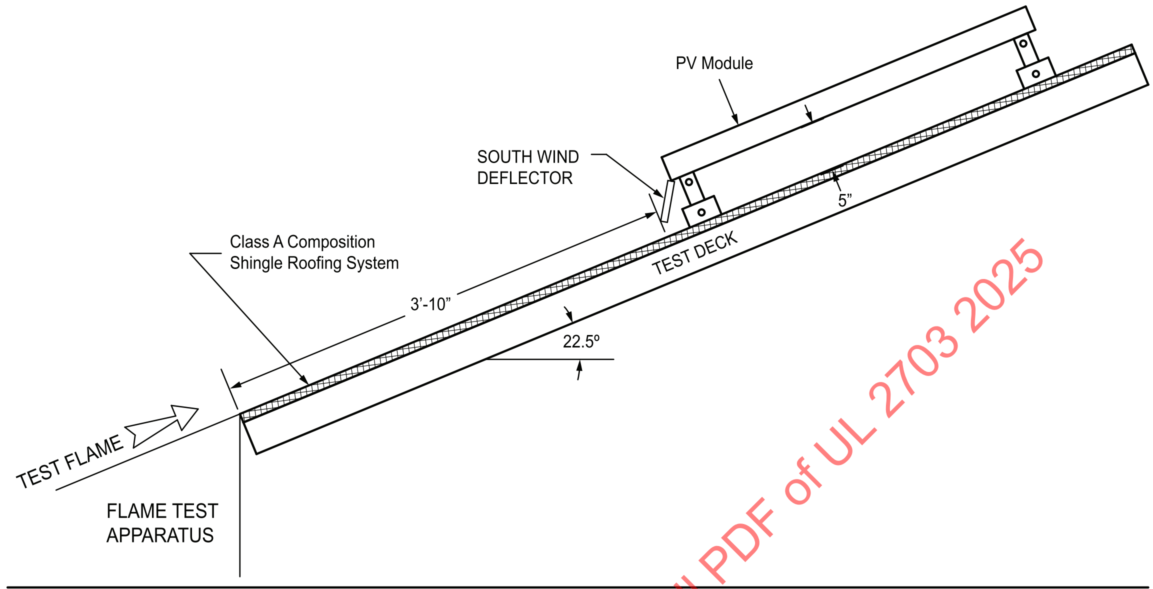
Steep-sloped flame spread test deck-south edge



su1527

Figure 15.4

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



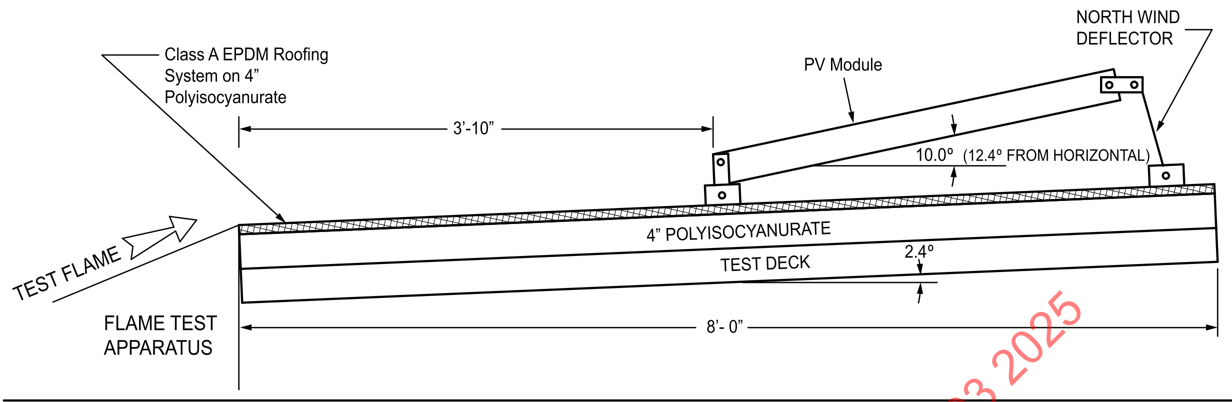
su1528

Metric conversion information:

3 ft-10 in (1.2 m)

Figure 15.5

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



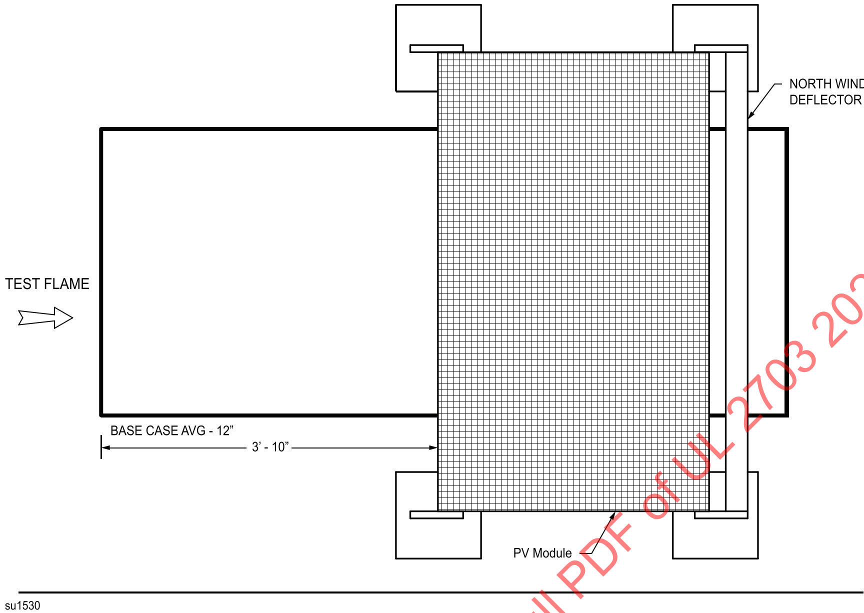
su1529

Metric conversion information:

4 in (10.2 cm)
3 ft-10 in (1.2 m)
8 ft-0 in (2.4 m)

Figure 15.6

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

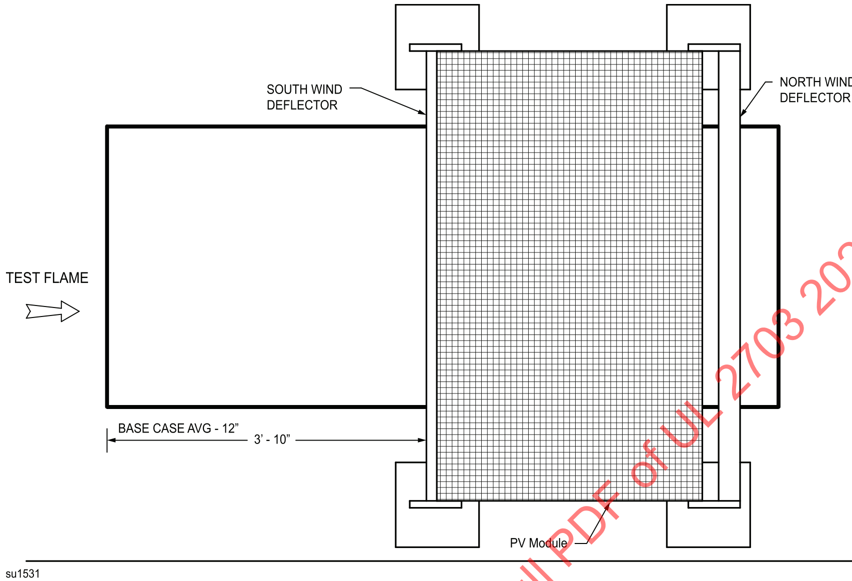


Metric conversion information:

12 in (0.3 m)
3 ft-10 in (1.2 m)

Figure 15.7

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

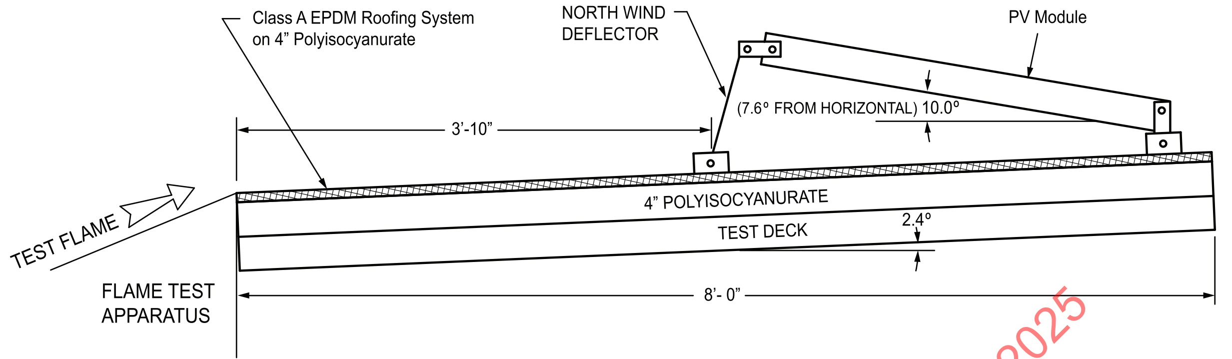


Metric conversion information:

12 in (0.3 m)
3 ft-10 in (1.2 m)

Figure 15.8

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



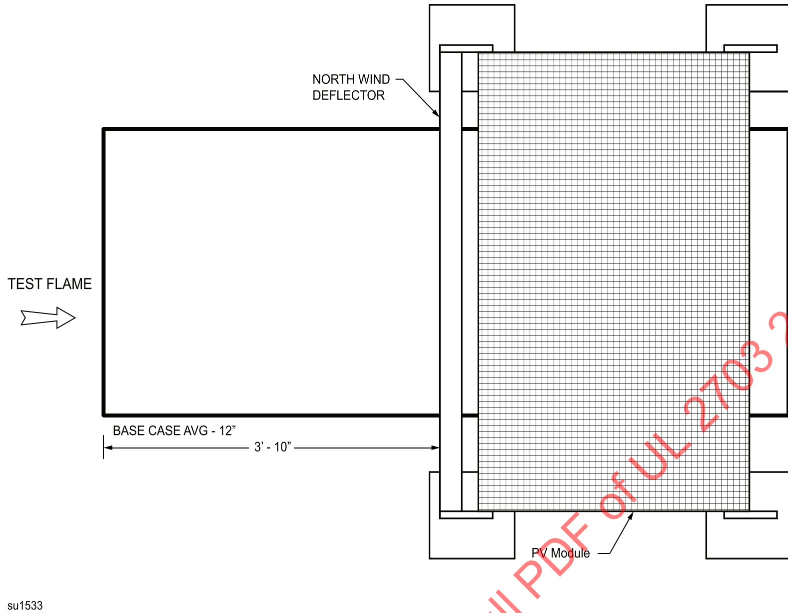
su1532

Metric conversion information:

4 in (10.2 cm)
3 ft-10 in (1.2 m)
8 ft-0 in (2.4 m)

Figure 15.9

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

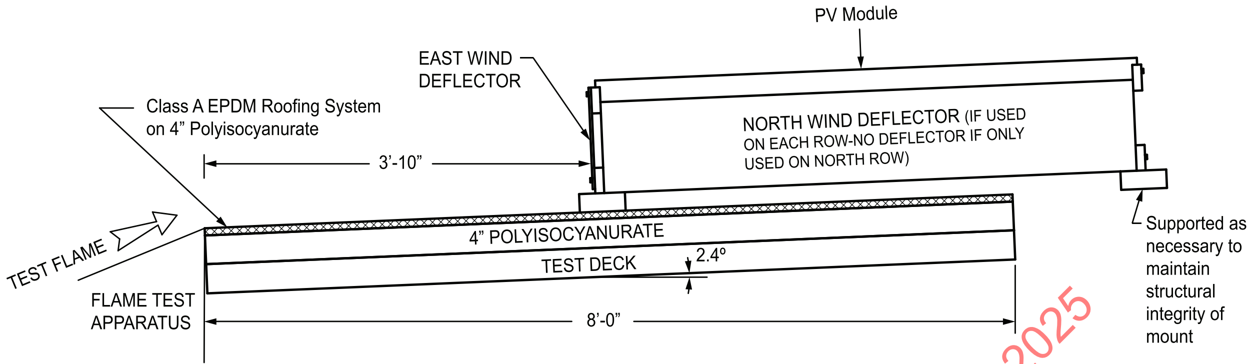


Metric conversion information:

12 in (0.3 m)
3 ft-10 in (1.2 m)

Figure 15.10

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



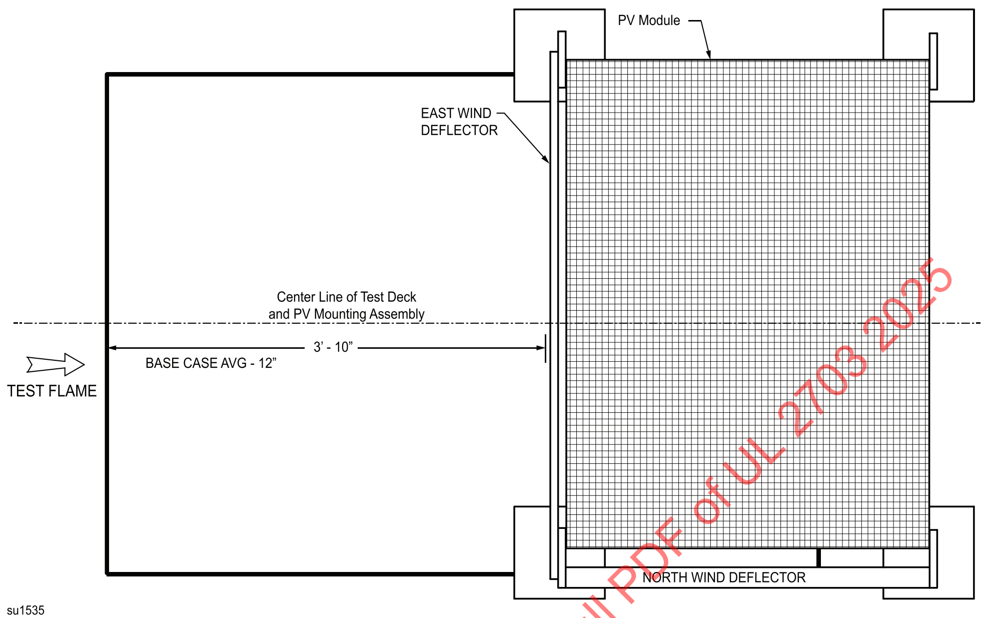
su1534

Metric conversion information:

4 in (10.2 cm)
3 ft-10 in (1.2 m)
8 ft-0 in (2.4 m)

Figure 15.11

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

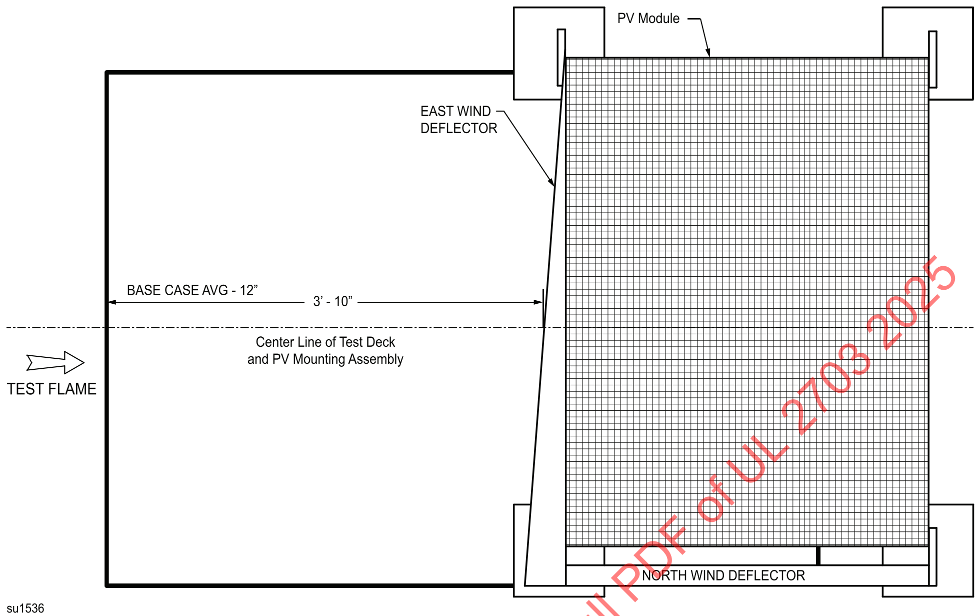


Metric conversion information:

12 in (0.3 m)
3 ft-10 in (1.2 m)

Figure 15.12

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



Metric conversion information:

12 in (0.3 m)
3 ft-10 in (1.2 m)

15.2.2 For the Spread-of-Flame Tests, Section 15.2, 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 in (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.

15.3 Burning-brand tests for steep sloped mounting systems

15.3.1 Burning brand tests are to be conducted on mounting systems with PV modules or panels designed for steep sloped applications. The mounting systems shall be evaluated in combination with the intended modules or panels 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 15.1.2, and the Class A burning brand plywood test deck as described in UL 790, Figure 4.5. The mounting system is to be installed and 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 or the gap to be tested specific to the mounting system. 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 Ga (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 or the gap to be tested specific to the mounting system. 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 Ga (0.82 mm^2) soft-iron wire.

Exception No. 1: For mounting systems with a guarded perimeter (see 2.20A), the burning brand test for part (b) shall be waived. 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.

15.3.2 At no time during the tests shall:

a) Any portion of the module, rack mounting system, mounting grounding/bonding components or clamping/retention devices 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, PV module, rack mounting system, mounting grounding/bonding components or clamping/retention devices, 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.

15.4 Recording

15.4.1 The fire performance for rack mounting system intended for stand-off, rack, or direct mounting in combination with a specified roof, or intended for integral mounting in combination with the specified PV module(s) that are not BIPVs 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 15.1 relative to the corresponding conditions of acceptance in 15.2.2 and 15.3.2; and

c) The class of PV mounting system, in combination with the specific PV modules(s) or module type, achieved based on test results (Class A, B, or C).

16 Accelerated Aging Test

16.1 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 16.1, and shall comply with the physical property requirements of Table 16.2. The material shall not deform, melt, or harden to a degree which would affect its sealing properties.

Table 16.1
Physical property requirements

Minimum tensile strength[a]	Minimum ultimate elongation[b]	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
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 30 min after specimen release using the Standard Test for Rubber Property-Compression Set, ASTM D395-01, Method B.

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

Table 16.2
Physical requirements after conditioning

Maximum operating temperature of material °C	(°F)	Conditioning Procedure	Minimum percent of the result with unaged specimens: Tensile strength	Ultimate elongation	Maximum change (Duro) from unconditioned value[a,b]
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
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).

17 Temperature Cycling Test

17.1 *Deleted*

17.2 *Deleted*

17.3 *Deleted*

17.4 *Deleted*

Figure 17.1

Thermal cycle test

Figure deleted

17.5 *Deleted*

18 Humidity Test

18.1 Representative samples of the PV modules, rack mounting system and clamping device's interconnect points (where one member is connected to another where a bonding path is to be maintained) shall be subjected to 10 cycles of humidity-freezing as described in 18.2 – 18.6; and:

a) The test shall not result in:

1) Loss of ground circuit continuity;

2) Corrosion of metal parts where continued corrosion would negatively impact compliance with this standard;

b) Before and immediately following the Humidity Cycling Test, the bonding path resistance shall be measured using the procedure in the Bonding Path Resistance Test, Section 13.

18.2 Representative samples of the rack mounting system and clamping device's inter-connect points (where one member is connected to another where a bonding path is to be maintained) 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 grounding/bonding continuity.

18.3 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.

18.4 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.

18.5 Each cycle is to consist of:

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

b) A dwell at 85°C for 20 h minimum;

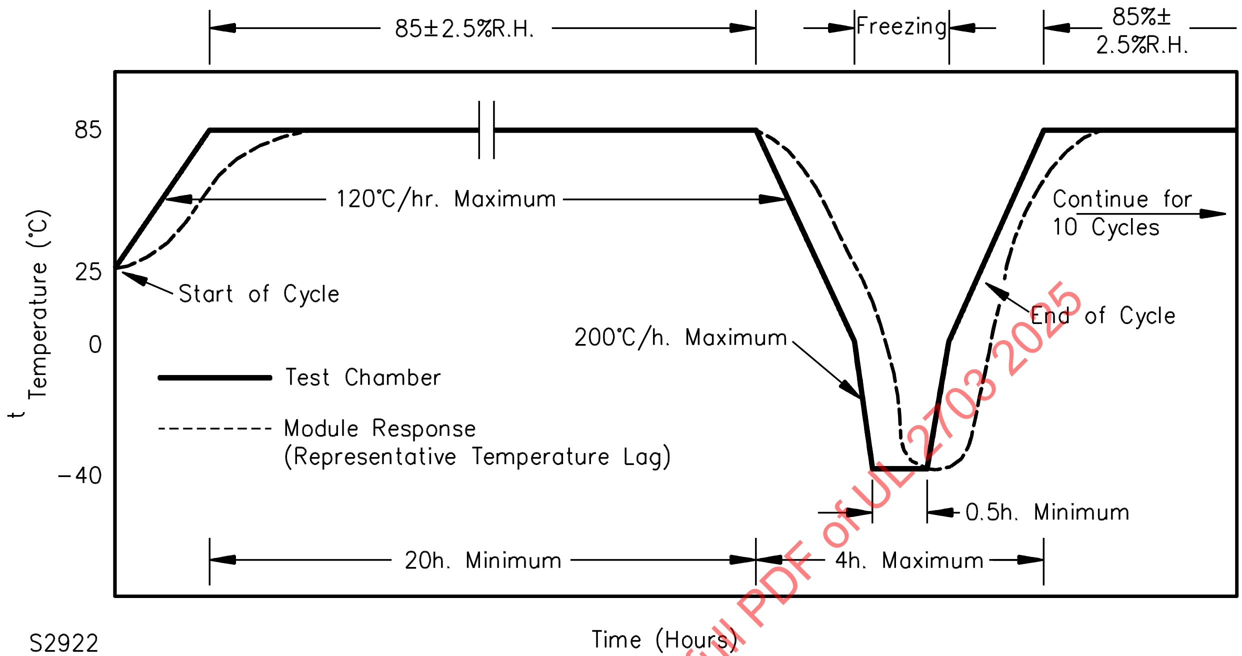
c) A transition from 85°C to minus 40°C (minus 40°F);

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

e) A transition from minus 40°C to 25°C. When the temperature is 0°C (32°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 0°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 to 30°C (59°F to 86°F) may be used. The total cycle time is not to exceed 24 h. See Figure 18.1.

Figure 18.1

Humidity-freezing cycle test



18.6 The humidity of the chamber air when the chamber air temperature is 85°C (185°F) is to be 85 ±2.5 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.

18.7 When an adhesive or polymeric material is being utilized for mechanical securement of a PV module or a portion of the rack mounting system, a sample shall be subjected to the following sequence with the adhesive/polymeric material subject to the stress of the weight of the PV Module(s) and racking components, in the orientation most likely to produce failure while in the chambers:

a) Humidity Cycling Test, followed by;

b) Mechanical Loading Test.

It is also acceptable to conduct this sequence on a separate representative sample (where the weight per surface area is equivalent).

19 Corrosive Atmosphere Tests

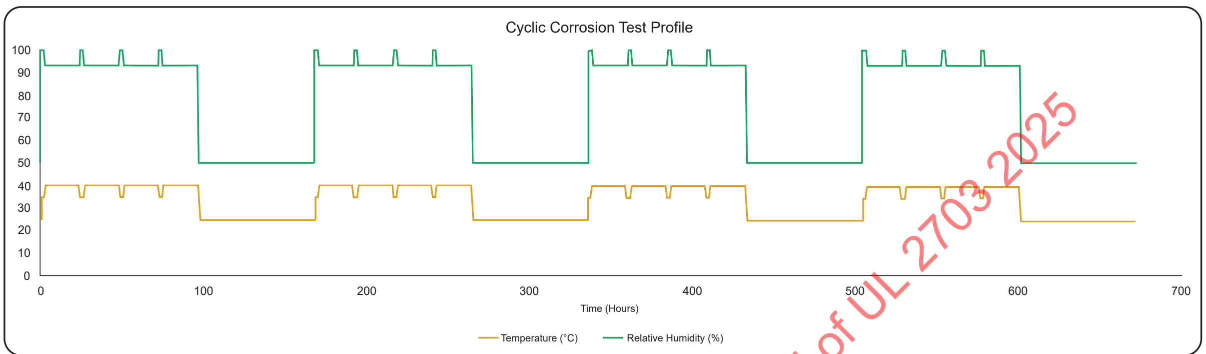
19.1 Salt spray test

19.1.1 The samples shall be subjected to the salt spray test as described in the Standard for Environmental testing – Part 2-52: Tests – Test Kb: Salt mist, cyclic (sodium chloride solution), IEC 60068-2-52, Test method 5. The duration shall be a maximum of 28 days with shorter durations allowed, provided that transitions between test conditions occur within the maximum times specified in Figure 19.1 and Figure 19.2.

Exception: A specimen constructed of materials such as plastic, 300 series stainless steel, or alloys of aluminum that are known to be resistant to atmospheric corrosion in accordance with 10.1 are not required to be tested.

Figure 19.1

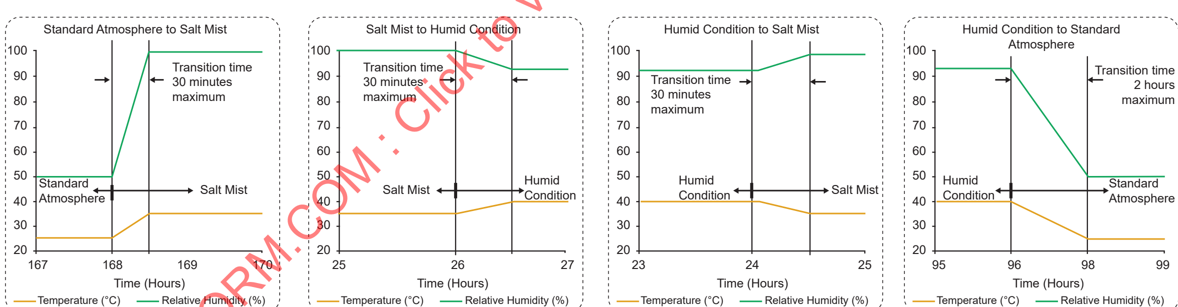
Maximum durations for transitions between test conditions (see additional details in Figure 19.2)



su4590

Figure 19.2

Maximum durations for transitions between test conditions (see also Figure 19.1)



su4591a

Note: The 100% humidity shown on the transition from Salt Mist to Humid Condition (second box) is only for reference and it does not need to be measured (controlled) during the Salt Mist cycle.

19.1.2 *Deleted*

19.1.3 *Deleted*

19.1.4 *Deleted*

19.1.5 *Deleted*

19.1.6 *Deleted*

19.1.7 *Deleted*

19.1.8 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 [reference] specimens are to be sourced from 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.

19.1.9 The zinc coated reference specimens are to be cleaned with soap and water. The specimens are then rinsed with: (1) ethyl alcohol or isopropyl alcohol and (2) ethyl ether or acetone. After the specimens are rinsed, the specimens are dried, and the cut edges protected with paint, wax, or other effective medium before being placed in the salt spray chamber.

19.1.10 Both the reference specimen and the samples under test are to be scribed as described in the Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments, ASTM D1654, with a single groove approximately 1.97 in (50 mm) long, to expose the underlying steel while maintaining a 0.49 in (12.5 mm) distance (clearance) from the scribe to the sample edge. The scribe shall be made using the method described in ASTM D1654 and the scribing tool used is to be either a carbide tipped tool [Style E, with 1/64-in (0.4-mm) nose radius], or a carbide tipped tool ground to a single point having an included angle of 60 ±15 degrees. The scribe shall cut through all layers, including metallic coating layers if under paint. Samples meeting the exemption criteria described in 12.2 need not be scribed, but then comparison is to be made to the un-scribed portion of the reference specimen.

NOTE 1: The intent of scribing a corrosion protective coating is to assess the propagation of corrosion from the scribe area, acknowledging that accidental and foreseeable damage of coatings may occur. This damage may occur due to shipment, installation, operation and maintenance functions, and environmental exposures such as windblown debris, etc.

NOTE 2: The scribe itself may exhibit local corrosion, as does a sheared edge or a drilled hole, so consideration shall only be made on the propagation of corrosion from the scribed edge to the perpendicular distance that base metal corrosion is evident.

NOTE 3: The scribing of the reference specimen is done for qualitative purposes to potentially aid in assessing the results of the test specimen.

19.1.11 The test is to continue for the full test duration specified in 19.1.1 unless it is obvious that a failure has occurred prior to the completion of the test. Upon completion of the test, each specimen shall be prepared as followed: samples shall be rinsed using a gentle stream of water at a temperature up to 45°C (110°F). Scrape each specimen along the scribe vigorously with a rigid spatula, knife or similar instrument with no sharp edges or corners such that all corrosion of the substrate (that is, rust creepage or undercutting) can be observed.

19.1.12 Following the sample preparation described in 19.1.11, the samples shall be assessed relative to the following acceptance criteria. To pass the salt spray test, the corrosion products formed in the field of the test sample shall not be more than that formed on the reference sample as determined by visual observation, and the following:

a) To pass the salt spray test, the corrosion products formed in the field of the test sample shall not be more than that formed on the reference sample as determined by visual observation, and

b) The maximum width of the corrosion zone along the scribe line shall be measured and recorded. The overall width of the corrosion zone along the scribe shall be measured at 6 locations uniformly distributed along the scribe line, ignoring 0.125 in (3 mm) at each end of the scribe. The arithmetic mean of the width of the corrosion zone shall be calculated from these measurements. The rust creepage, *c* is then determined by the following equation:

$$c = (wc - w) / 2$$

where

wc = mean overall width of the corrosion zone and

w = width of the original scribe.

The test sample shall not exhibit a rust creepage, c, greater than Rating No. 5 [1/8 to 3/16 in (3.2 – 4.7 mm)] as designated in the Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments, ASTM D1654, Procedure A; with maximum isolated spot not exceeding 3/8 in (9.5 mm), and

c) The combined results of the test sample as determined in (a) and (b) shall be compared Table 19.1 to determine whether the sample passes or fails the salt spray test.

Table 19.1
Test sample assessment criteria

Test Scenario	Rust Observed			Test Sample Pass / Fail	Note
	Reference Specimen (Rust in Field) [a]	Test Sample			
		Rust in Field	Creepage from Scribe		
1	No	No	Within limit	Pass	Only the test sample has rust in scribe; test sample scribe creep is within limit
2	No	No	Above limit	Fail [b]	Only the test sample has rust in scribe; test sample scribe creep is not within limit
3	Yes	No	Within limit	Pass	Only the reference specimen has rust in scribe; reference specimen scribe creep is within limit
4	Yes	No	Within limit	Pass	Only the reference specimen has rust in scribe; reference specimen scribe creep is not within limit
5	Yes	No	Within limit	Pass	Both reference specimen and test sample have rust in scribe; reference specimen is not within limit, test sample is within limit
6	Yes	No	Above limit	Fail	Both reference specimen and test sample have rust in scribe; reference specimen is within limit, test sample is not within limit
7	No	Yes	Within limit	Fail [b]	Only test sample has rust in field
8	Yes	No	Within limit	Pass	Only reference specimen has rust in field
9	Yes – Worse or same	Yes	Within limit	Pass	Both reference specimen and test sample have rust in field; reference specimen is worse or same
10	Yes	Yes – Worse	Within limit	Fail	Both reference specimen and test sample have rust in field; test sample is worse

Table 19.1 Continued on Next Page

Table 19.1 Continued

Test Scenario	Rust Observed			Test Sample Pass / Fail	Note
	Reference Specimen (Rust in Field) [a]	Test Sample			
		Rust in Field	Creepage from Scribe		
11	No	Yes	Above limit	Fail [b]	Only the test sample has rust in scribe and field; test sample scribe creep is not within limit
12	Yes	No	Within limit	Pass	Only the reference specimen has rust in scribe and field; reference specimen scribe creep is within limit
13	Yes – Worse or same	Yes	Within limit	Pass	Both reference specimen and test sample have rust in scribe and field; reference specimen rust in field is worse or same, test sample scribe creep is within limit
14	Yes – Worse or same	Yes	Above limit	Fail	Both reference specimen and test sample have rust in scribe and field; reference specimen rust in field is worse or same, test sample scribe creep is not within limit
15	Yes	Yes – Worse	Within limit	Fail	Both reference specimen and test sample have rust in scribe and field; test sample rust in field is worse, test sample scribe creep is within limit
16	Yes	Yes – Worse	Above limit	Fail [b]	Both reference specimen and test sample have rust in scribe and field; test sample rust in field is worse, test sample scribe creep is not within limit

[a] The scribing of the reference specimen is done for qualitative purposes to potentially aid in assessing the results of the test specimen.

[b] The test may be terminated early if it is obvious that a failure has occurred prior to the completion of the test. Other scenarios shall complete full cycles (4 cycles, 28 days).

19.2 Moist carbon dioxide/sulphur dioxide test

19.2.1 The samples are not required to be subjected to the Moist Carbon Dioxide/Sulphur Dioxide Test as described in 19.2.3 – 19.2.9, unless requested by the manufacturer.

19.2.2 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.

19.2.3 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.

19.2.4 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.

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

19.2.6 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 coating designation (as applicable, see Corrosion Resistance, Section 10) 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.

19.2.7 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.

19.2.8 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. Smaller samples need not be scribed, but then comparison is made to the unscribed portion of the reference specimen.

19.2.9 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.

20 Metallic Coating Thickness Test

20.1 Zinc or cadmium coating thickness may be measured by following means/methods: X-ray (ASTM B568), eddy-current (ASTM E376), weight of coating (ASTM A90), or the method described in 20.2 – 20.9.

20.2 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.

20.3 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.

20.4 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 21.2°C – 32.0°C (70.0°F – 90.0°F).

20.5 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.

20.6 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.

20.7 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.

20.8 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.)

20.9 To calculate the thickness of the coating being tested, select from Table 20.1 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 20.7.

Table 20.1
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
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

21 Mechanical Loading Test

21.1 The provisions of this section are not intended to imply code compliance. In order to obtain code compliance, a licensed engineer shall incorporate the product rating into engineering that demonstrates code compliance. Among items that shall be addressed are:

a) The appropriateness of the defined factor of safety;

b) Applied loads for a given application. Applied loads shall include dead, snow, ice, wind;

c) Code required load combinations; and

d) Conformance with testing requirements presented within the applicable model code.

21.2 Load tests shall be conducted on the rack mounting system to determine the allowable applied pressures/loads to be presented in the product listing. A minimum of 1 specimen shall be tested for a given pressure/loading direction. Unless otherwise indicated within this standard, the same specimen shall be used for all load cases.

21.3 A rack mounting system shall withstand loading based upon the maximum area of the modules intended to be installed. The test specimen configuration shall be selected such that all critical load combinations are addressed for the elements included within the load rating. Test loads shall be applied in the following three orthogonal directions (also shown in Figure 21.1):

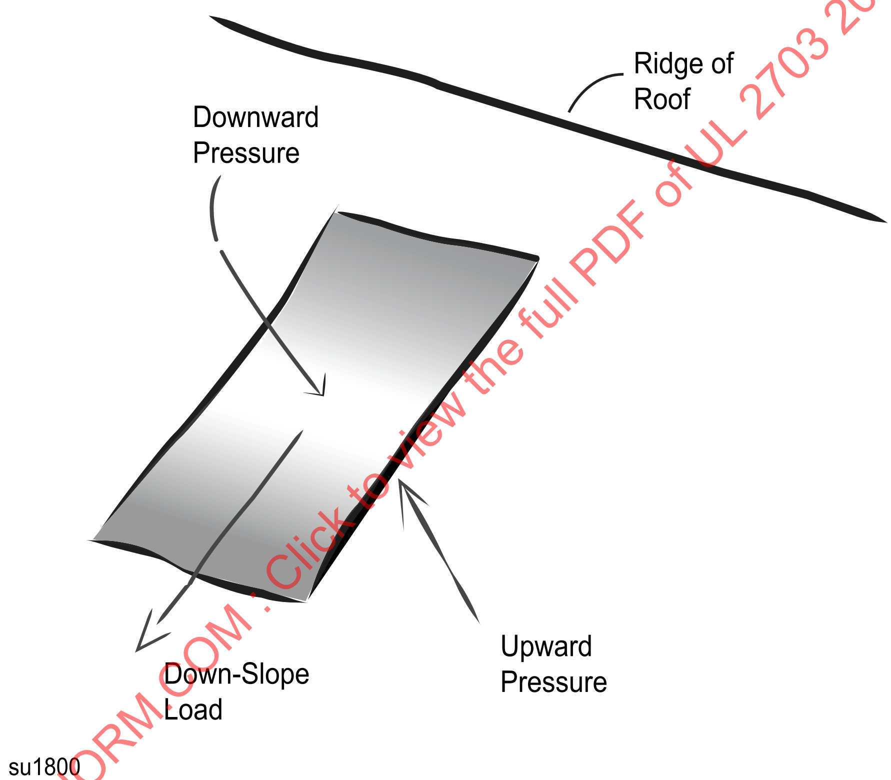
a) Downward Pressure applied to a PV module.

b) Upward Pressure applied to a PV module.

c) Down-Slope Load applied to a PV module (for example, a component of dead load, snow load).

Figure 21.1

Mechanical loading



21.4 The minimum design load rating in each direction shall be:

a) Downward Pressures – 10 psf allowable load.

b) Upward Pressure – 5 psf allowable load.

c) Down-Slope Load – 5.0 psf allowable load.

All design pressures/loads shall be multiplied by a minimum factor of safety of 1.5 to determine the “test” pressure/load to meet the minimum requirement, as shown in 21.5.

21.5 The minimum test load in each direction shall be:

a) Downward Pressures – 15 psf.

b) Upward Pressure – 7.5 psf.

c) Down-Slope Load – 7.5 psf.

Higher test pressures/loads may be used to develop a listing for higher applied loads. Downward and Upward pressures shall not be applied simultaneously. Separate test pressures/loads may be used to develop different listings for each loading direction.

21.6 The rack mounting system shall withstand each of these loads for a period of 30 min, without evidence of structural or mechanical failure, after which the load shall be removed. Once the load is removed, there shall be no visual permanent deformation that may adversely affect system safety or compliance, and for any positive securement means including top-down clamps, there shall not be any shifting/movement relative to the PV module as determined by a visual inspection.

21.7 In addition to the defined “system” testing, the product listing may provide increased design values for the “mounting hardware”. “Mounting hardware” testing shall include the requirements of this Section with the exception that the “mounting hardware” tests shall incorporate support beams with a defined stiffness that results in similar (or greater) beam curvature to that experienced during the system testing.

Exception: When the desired load rating for the mounting hardware is identical to the “system” rating, supplemental “mounting hardware” testing is not required.

21.8 Rack mounting systems 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.

21.9 When an adhesive or polymeric material is being utilized for mechanical securement of a PV module or a portion of the rack mounting system, a sample shall be subjected to the following sequence with the adhesive/polymeric material subject to the stress of the weight of the PV Module(s) and racking components, in the vertical orientation while in the chambers:

a) Humidity Cycling Test, followed by;

b) Mechanical Loading Test.

It is also acceptable to conduct this sequence on a separate representative sample (where the weight per surface area is equivalent).

22 Bonding Conductor Test

22.1 Bonding devices and/or components which are utilized with surfaces having non-conductive materials such as anodization or paint, or have insufficient conductively equivalent cross-sectional area/materials in accordance with Table 9.1 shall be subject to the Bonding Conductor Test as specified in (a) and (b). Alternatively, the Short-Time Current Test from the Standard for Grounding and Bonding Equipment, UL 467, on 2 samples, followed by the Bonding Path Resistance Test (as noted in 22.3) may be substituted for the 135%, 200% and Limited Short Circuit Tests noted under 22.1(a) and 22.1(b).

Note 1: Test current values and times are shown in Table 5, Short-Time Test Currents, of UL 467. To derive test current values for electrode materials other than the ones listed above, see Annex C of IEEE 837-2002. The cross-sectional values shall meet the size requirements of UL 2703, Table 9.1, for the minimum size of the equipment-grounding or bonding conductor.

Note 2: For bonding devices and/or components utilizing non-uniform surfaces where the cross-sectional area cannot be determined, use the series fuse or circuit breaker rating to determine cross-sectional value in Table 9.1, using column 2, Copper, in UL 2703, then use this value in UL 467, Table 5, Short-Time Test Currents, Copper column, to derive test current and duration values to be used.

$$I = A\sqrt{\frac{In\left(\frac{K_o + T_m}{K_o + T_a}\right)}{\beta t_c}}$$

T_m = 1083°C (1981.4°F) for melting point for copper and 657°C (1214.6°F) for melting point for aluminum and 1510°C (2750°F) for melting point for steel

T_a = 40°C (104°F), ambient temperature

I = short time current (rms) in kA

A = conductor cross section in mm^2

t_c = time (s)

K_o = reciprocal of thermal coefficient of resistivity at 0°C (32°F), which is 234 for copper and 228 for aluminum and the appropriate K_o (reciprocal of thermal coefficient of resistivity) for any other specific mating materials used

β = material constant, which is 19.8 for copper and 45.1 for aluminum and the appropriate β (material constant) for any other specific mating materials used

a) Two specimens each are to carry currents equal to 135 and 200 percent of the rating or setting of the intended branch-circuit overcurrent-protective device for the times specified in Table 22.1, and

b) Two specimens are to be subjected to a limited-short-circuit test using a power supply capable of supplying at least 5000 amperes short circuit current for the duration of the test. Each terminal of the device is to be connected to the supply mentioned in 22.1(b) using less than two times 4 ft (1.2 m) of insulated wire, sized for the rating of the overcurrent protection device. A nonrenewable fuse or circuit breaker that is in compliance with UL 248-1, Low-Voltage Fuses – Part 1: General Requirements, or UL 489B, Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures For Use With Photovoltaic (PV) Systems, rated for the maximum ampacity of the circuit in which the bonding device is to be installed, shall be connected in series with the conductor. The bonding device is to be in any position considered to be normal in service. The aforementioned nonrenewable fuse or circuit breaker is to be connected between the supply terminal and the device.

Exception: When a fuse smaller than that indicated in (a) and (b) is employed in the unit for protection of the circuit to which the bonding conductor is connected, the magnitude of the test current and size of fuse used during the test is to be based on the rating of the smaller fuse.

Table 22.1
Duration of overcurrent test

Rating or setting of branch-circuit overcurrent protective device, amperes	Test time, minutes	
	135 percent of current	200 percent of current
0 – 30	60	2
31 – 60	60	4
61 – 100	120	6
101 – 200	120	8

22.2 The test circuit described in 22.1(b) is to have an open-circuit voltage of 240 Vac or more. The open circuit voltages measured before and after the test shall not be less than 240 Vac and shall not differ by more than 5%.

22.3 After the bonding circuits are subjected to the tests in 22.1(a) and (b), the circuits shall comply with Bounding Path Resistance Test, Section 13.

22.4 Multiple use bonding devices shall be assembled and completely disassembled four times from the mating device(s) in accordance with the installation instructions, including any use location restrictions where applicable. Following the fourth disassembly, the bonding connection(s) shall be reassembled and subjected to the Bonding Conductor Limited Short Circuit Test portion of Section 22, or the Short Time Current Test of the Standard for Grounding and Bonding Equipment, UL 467, followed by the Bonding Path Resistance Test, Section 13.

23 Bonding Strap Pull Test (Only for flat bonding straps with flat end terminations/crimps)

23.1 This test is for flat bonding straps with flat end terminations/crimps described in 9.6(g).

23.2 The flat bonding strap to flat end terminations/crimps shall be intact after being subjected for 1 min to the pull test described in 23.3. As a result of this test, there shall be no breakage of the conductor or any strand of a stranded conductor, shearing of components, or other damage to the connector. Breaking of the conductor or any strand of a stranded conductor shall be determined by examination of the complete connector assembly while still intact after the pullout test. Breakage has occurred if the conductor or a strand of a stranded conductor becomes visibly detached. However, strand breakage of 5 percent is allowed for flexible and fine stranded conductors.

23.3 The flat bonding strap to flat end terminations/crimps shall be subjected to a direct pull of the applicable value specified in Table 23.1. The pull shall be exerted by means of a tension-testing machine, dead weights, or other equivalent means so that there is no sudden application of force or jerking during the test. The samples shall be secured in the same manner as in the intended installation.

Table 23.1
Pullout force values

Size of conductor		Pullout force, lbs (N)			
AWG or kcmil	(mm^2)	Copper		Aluminum/Copper-clad aluminum	
14	(2.1)	50	(223)	–	–
12	(3.3)	70	(312)	35	(156)
10	(5.3)	80	(356)	40	(178)
8	(8.4)	90	(401)	45	(200)
6	(13.3)	100	(445)	50	(223)
4	(21.2)	140	(623)	70	(312)
3	(26.7)	160	(712)	80	(356)
2	(33.6)	180	(801)	90	(401)
1	(42.4)	200	(890)	100	(445)
1/0	(53.5)	250	(1,113)	125	(556)

RATINGS

24 Details

24.1 The ratings of a rack mounting system shall include the maximum size, orientation and number of PV modules intended to be installed.

24.2 When tested in accordance with Section 15, the rack mounting system shall have a system Fire Class rating of A, B, or C.

24.3 When tested in accordance with Section 21, the system shall have a load rating.

MARKINGS

25 Details

25.1 Each component or subassembly of a rack mounting system shall have a plain, legible, permanent marking that is molded, die-stamped, paint-stenciled, stamped, or etched metal that is permanently secured, or indelibly stamped on a pressure-sensitive label secured by adhesive that complies with the Standard for Marking and Labeling Systems, UL 969. Ordinary usage, handling, storage, and the like of the component or subassembly shall be considered in determining whether a marking is permanent. The marking shall include:

a) The manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product can be identified;

b) The model number or the equivalent;

c) The date or other dating period of manufacture not exceeding any three consecutive months.

d) A factory code indicating its place of manufacture.

Exception No. 1: The manufacturer's identification may be in a traceable code if the product is identified by the brand or trademark owned by a private labeler.

Exception No. 2: The date of manufacture may be abbreviated; or may be in a nationally accepted conventional code or in a code affirmed by the manufacturer, provided that the code

a) Does not repeat in less than 10 years; and

b) Does not require reference to the production records of the manufacturer to determine when the product was manufactured.

Exception No. 3: Alternatively, the markings are permitted to be on the smallest unit packaging.

Exception No. 4: No markings are required on commonly available hardware (such as screws, bolts, or washers).

25.2 *Deleted*

25.3 *Deleted*

25.4 *Deleted*

25.5 *Deleted*

INSTRUCTIONS

26 Installation, Assembly and Maintenance/Inspection Instructions

26.1 Rack mounting systems and clamping devices shall be supplied with installation instructions. They shall include:

a) Scope of evaluation (grounding/bonding, fire classification, and/or mechanical loading) and a list of all PV modules evaluated for each scope of evaluation (grounding/bonding, fire classification, and/or mechanical load rating), and the statement "As specified in UL 61730-1 5.2.3DV, PV modules are considered to be in compliance with the mechanical loading and bonding and grounding requirements of UL 61730-1 when mounted, bonded and grounded in the manner specified by either the PV module mounting instructions, or the mounting system manufacturer's instructions when the mounting, bonding, and grounding means have been evaluated with the PV module to UL 2703" or the statement "To be used only in combination with modules that include this specific rack system in the module manufacturer's installation manual";

b) Direction on allowable spans and cantilevers;

c) Details on fasteners (bolts, screws, nuts, and washers):

1) For critical structural and bonding fasteners not shipped with the unit, the critical fastener properties shall be specified along with an illustration, including but not limited to markings, cleanliness, geometry, tolerances, surface coating/plating type and thickness, metal alloy, and minimum yield and/or minimum tensile strength and/or proof strength; or

2) For critical structural and bonding fasteners provided with the unit, the statement "fasteners shall be clean and free of damage or signs of corrosion during installation", or equivalent.

d) Assembly method details required to achieve the desired clamp load, such as torque, tightening sequence, and/or tooling requirements in critical structural and bonding fasteners;

e) A representative diagram of the rack mounting system; and

f) Description, illustration, and part number to clearly identify each component of the rack mounting system.

Exception: When instructions furnished with a rack mounting system specify hardware that is commonly available commercially, the manufacturer shall not be required to provide the hardware with the unit, nor show an illustration of such hardware.

26.2 The installation instructions shall include a detailed description of the grounding method, where applicable, to be used in accordance with the National Electrical Code, ANSI/NFPA 70. This description shall include:

a) The size, type, and temperature rating of the conductors to be used, and

b) The specific grounding devices and hardware (such as nuts, bolts, star washers, spilt-ring lock washers, flat washers, or bonding devices) that are used to attach a grounding/bonding device that complies with this standard, and

c) A representative diagram to illustrate the minimum ground path, with each point of a grounding or bonding connection clearly identified.

26.3 The installation instructions for rack mounting systems intended for installation on a roof shall include:

a) A statement indicating the method to install the rack mounting system to the roof,

b) A statement that the rack mounting system is to be installed over a fire resistant roof covering rated for the application, and

c) The PV module(s) or type(s) of PV module(s) and PV rack mounting installation configurations necessary to comply with the Fire Class Rating of the PV system evaluated in accordance with Fire Performance, Section 15.

Exception: The installation instructions for PV rack mounting systems that have not been evaluated for a system fire class rating in accordance with Fire Performance, Section 15, shall include the statement "Not Fire Rated."

26.4 The instructions shall include the following direction for continued maintenance by qualified persons:

a) The statement "Any loose components or fasteners shall be re-tightened in accordance with these instructions", or the equivalent.

b) The statement "Any components showing signs of damage that compromise safety shall be replaced immediately," or the equivalent.

26.5 *Deleted*

26.6 *Deleted*

26.7 For devices that are not evaluated for multiple use, such as torque to yield fasteners or single-use bonding/grounding devices, the installation instructions shall include the statement "For single-use only", or the equivalent. For devices that are evaluated as multiple-use in accordance with 9.12, the installation instructions shall provide removal/reinstallation procedure.

26.8 *Deleted*

26.9 The installation instructions shall include a detailed description of all load ratings and the configurations under which the load ratings apply. Rack mounting system intended and evaluated for structural loads greater than the minimum values defined in the Mechanical Loading Test, Section 21, shall include a detailed description in the installation instructions of the load ratings in each direction and the conditions under which the load ratings apply.

26.10 For a system where the removal of a module may break or disrupt the bonding path of the system (see 9.2), the installation manual shall comply with all of the following:

a) Module removal is not presented as a frequently expected occurrence and will not be required as part of routine maintenance.

b) Include the following statement, or equivalent "CAUTION: Module removal may disrupt the bonding path and could introduce the risk of electric shock. Additional steps may be required to maintain the bonding path. Modules should only be removed by qualified persons in compliance with the instructions in this manual."

c) Scenarios that could result in a disruption of the bonding path are described, for example irregularly-shaped arrays, arrays consisting of individual rows, and any other scenario where module removal could disrupt the bonding path.

d) Instructions for maintaining a complete bonding path when modules are removed.

APPENDIX A
Standards for Components

Standards under which components of the products covered by this standard are evaluated include the following:

Title of Standard − UL Standard Designation

Cable Management Systems - Cable Ties for Electrical Installations – UL 62275
Grounding and Bonding Equipment – UL 467
Marking and Labeling Systems – UL 969
Outlet Boxes, Flush-Device Boxes and Covers, Nonmetallic – UL 514C
Outlet Boxes, Metallic – UL 514A
Plastic Materials for Parts in Devices and Appliances, Tests for – UL 94
Photovoltaic (PV) Module Safety Qualification - Part 1: Requirements For Construction – UL 61730-1
Photovoltaic (PV) Module Safety Qualification - Part 2: Requirements For Testing – UL 61730-2
Polymeric Materials - Fabricated Parts – UL 746D
Polymeric Materials – Long Term Property Evaluations – UL 746B
Polymeric Materials – Short Term Property Evaluations – UL 746A
Polymeric Materials – Use in Electrical Equipment Evaluations – UL 746C
Positioning Devices – UL 1565
Roof Coverings, Standard Test Methods for Fire Tests of – UL 790
Sharpness of Edges on Equipment, Tests for – UL 1439
Terminals, Electrical Quick-Connect – UL 310
Wire Connectors – UL 486A-486B

APPENDIX B
Retest Guidelines
(Informative)

B.1 This appendix sets forth a uniform approach to maintain certification of rack mounting systems and clamping devices with associated hardware and with the PV Modules intended to be utilized with the rack mounting system and clamping devices that have or will undergo modification from the articles originally certified as well as to provide guidance on when re-testing is required to allow certification of the rack mounting system or clamping device with solar modules using representative sample testing when possible.

Changes in material selection, components and manufacturing processes can impact grounding and bonding, corrosion resistance, mechanical properties and reliability of the rack mounting system or clamping device as well as the system or device to module interface.

The following is a list of changes to a rack mounting systems and clamping devices with associated hardware and with the PV Modules intended to be utilized with the rack mounting system and clamping devices (or differences from a representative test sample) and the re-test requirements associated with the change/difference. If the change/difference is within the limits below, no re-testing is required.

For modifications such as:

a) Dimensional change more than 10% that would decrease the structural or mechanical strength

Repeat:

– Mechanical loading test

b) Material thickness reduction more than 10%

Repeat:

– Bonding path resistance test

– Humidity test

– Mechanical loading test

– Bonding conductor test, 135%, 200%, and limited short circuit

c) Material change

Repeat:

– Bonding path resistance test

– Accelerated aging test (assuming not evaluated as a gasket)

– Humidity test

– Mechanical loading test

– Bonding conductor test, 135%, 200%, and limited short circuit

d) Material thickness change more than 5% and either (1) Bonding and grounding conductor reduction in contact area by more than 5%; or (2) Bonding and grounding path reduction in cross-sectional area by more than 5%

Repeat:

– Humidity test