PV Module Safety and Performance Standard Requirements in Extreme Environments

NIST/UL Workshop on Photovoltaic Materials Durability

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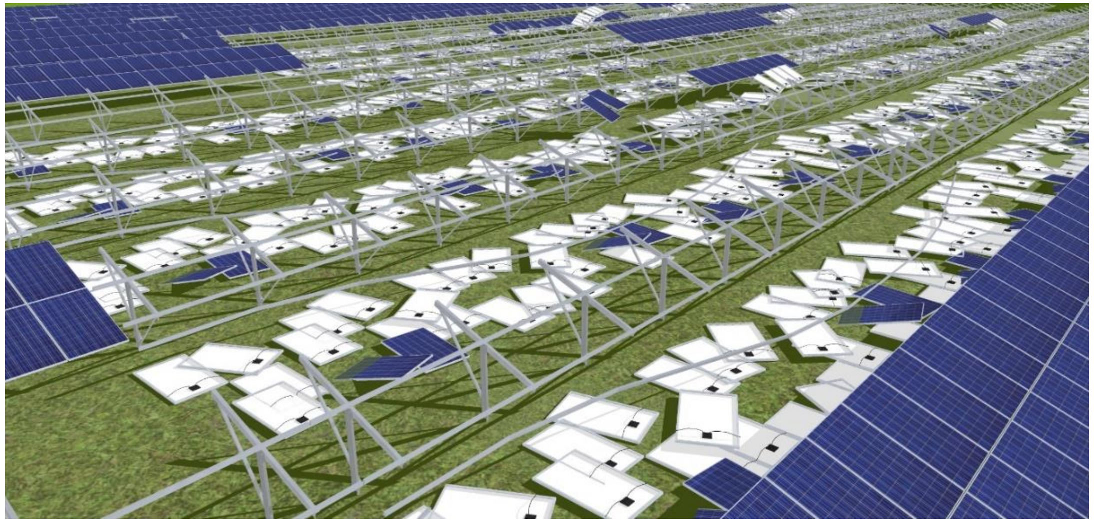
Manifestations of material durability…



UL Standards Development Addressing PV Market Needs

North American Leader

1986 – UL1703 PV Modules and Panels
1999 – UL1741 Inverters and Converters
1999 – SU 1279 Solar Collectors

2005 – UL 4703 PV Wire
2007 – SU 2579 Low Voltage Fuse Holders
2007 – SU 5703 Max Operating Temp
2008 – SU 8703 Concentrator PV Modules
2010 – UL 2703 Mounting Systems
2010 – SU 4248-18 Fuse Holders
2010 – UL 489B Circuit Breakers
2010 – UL 6703/A Connectors
2010 – SU 98B Dead-Front Switches

2011 – SU 1699B Arc Fault Protection
2011 – UL 3703 Solar Trackers
2011 – UL 3730 Junction Boxes
2011 – SU 508i Disconnect Switches
2011 – SU 9703 Wiring Harnesses
2012 – UL 4730 Name Plate Rating
2014 – UL 62109-1 Power Converters
2016 – UL 61215 Terrestrial PV Modules – series
2016 – UL 1741SA Advanced Inverter Testing
2016 – UL 9540 Energy Storage Systems and Equipment
2017 – UL 61730 PV Module Safety (harmonized)
2018 – UL 9540a Thermal Runaway Fire in BESS
2018 – SU 3741 PV Hazard Control

2000 > 2010 > 2020

International Collaborator

IEC 61215	Module Type Qualification - Series
IEC 61724	System performance monitoring
IEC 61730-1/2	Module safety
IEC 61853-1/2	Module performance
IEC 62093	BOS design Qualification
IEC 62109-1/2/3/4	Safety of Power Converters
IEC 62446	System commissioning and Inspection
IEC 62509	Battery charge controller performance
IEC 62548	PV array design requirements
IEC 62738	PV plant guidelines
IEC 62804	System voltage durability for modules
IEC 62938	Snow load testing
IEC 62947	Energy performance
IEC TS 60904-1-2	Measurement for Bifacial Modules

Safety and Performance Standards For *Typical* Environments

Safety

- Demonstrate non-hazardous failure conditions

Compliance to Standards

- UL1703
- UL/IEC 61730
- IEC 62788-2 Back/front sheet
- New BiPV: UL 7103

Performance

- Achieve standard test conditions

Compliance to Standards

- IEC 61215 series
- LeTID
- IEC 62782 DML
- IEC 62790 – Component, Jbox
- IEC 62852 – Component, Connector
- IEC 62788-1-7 Encapsulant

Durability

- Performs under stress conditions

Standards Based

- Acc Life Test (ALT):
- ✓ Temperature Cycle (TC)
- ✓ Humidity-Freeze (HF)
- ✓ Damp Heat (DH)
- ✓ Dynamic Mech Load (DML)
- ✓ Ultra-Violet (UV)

Possible updates based on:

- IEC 63209-2 Extended-stress testing
- IEC 62982 extended TC
- C-AST

“Typical Environments” Assumed in PV Standards

Factor	Standards Assumption
Air temperature	-40ºC to +40ºC
Module temperature	-40ºC to +90ºC
Wind load	2400 Pa (minimum test load) 1000 cycles x 1000 Pa dynamic mechanical load
Snow load	2400 Pa (minimum test load)
Corrosivity	Mild to moderate
Abrasion resistance	Not typically addressed
Hail	25-75 mm hail, 7.53-39.5 m/s
Mounting	Fixed roof-mount, fixed or tracking ground-mount

Extreme Environments: High PV Temperatures

Hot climates or configurations that limit cooling

Basic Form of Equation

$$T_{module} = Irradiance \times e^{(a + b \times WindSpeed)} + T_{ambient}$$

Empirically determined

Module to Cell Temperature

$$T_{cell} = T_{Module} + \frac{G}{1000\,W/m^2}\Delta T$$

Module Type	Mount	a	b	ΔT (°C)
Glass/cell/glass	Open rack	-3.47	-.0594	3
Glass/cell/glass	Close roof mount	-2.98	-.0471	1
Glass/cell/polymer sheet	Open rack	-3.56	-.0750	3
Glass/cell/polymer sheet	Insulated back	-2.81	-.0455	0
Polymer/thin-film/steel	Open rack	-3.58	-.113	3

→ Tgg open
→ Tgg roof
→ Tgp open
→ Tgp insulated
→ Tps open

SAND2004-3535
Unlimited Release
Printed August 2004

Extreme Environments: High PV Temperatures

Good model/experiment agreement

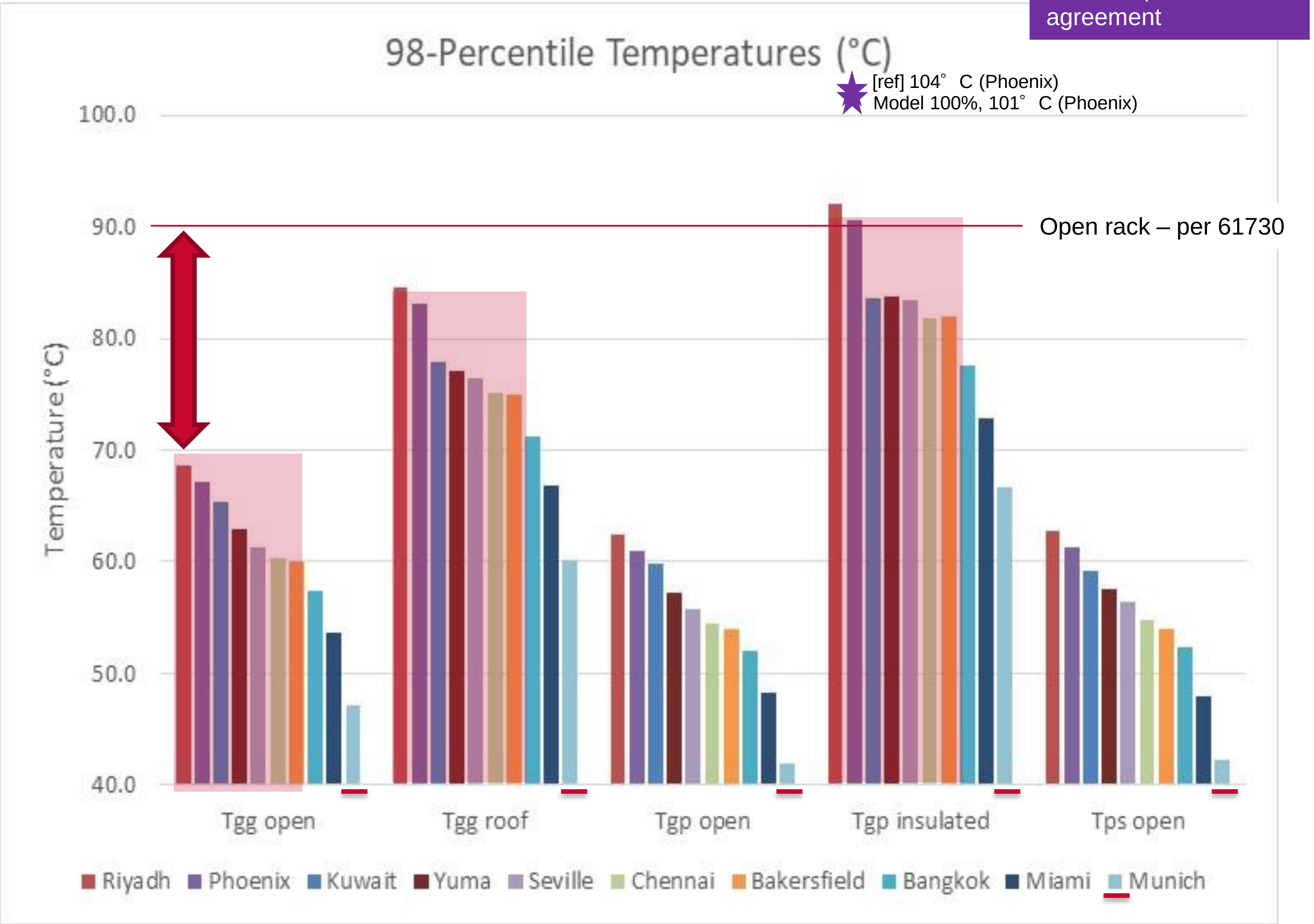
Model indicates open-rack modules in field at
~ 70ºC

Add Safety Margin of 20ºC

- 90°C (matches UL 61730)

Add 20ºC to other constructions and mountings styles:

- **Level 1 ~ Group at 90°-100°C**
- **Level 2 ~ Group at 100°-110°C**



How do we apply Level 1 and Level 2?

Extreme Environments: High PV Temperatures

IEC TS 63126

Standard	Test Ref	Test Name	Original Requirement $T_{98\%}$ = 70 °C or less	Proposal - Level 1 $T_{98\%}$ > 70 °C to ≤ 80 °C	Proposal - Level 2 $T_{98\%}$ > 80 °C to ≤ 90 °C
module level tests					
IEC 61215	MQT 09	Hot-spot endurance test	(50 ± 10) °C	+10 °C, (60 ± 10) °C	+20 °C, (70 ± 10) °C
	MQT 10	UV preconditioning	(60 ± 5) °C	+10 °C, (70 ± 5) °C	+20 °C, (80 ± 5) °C
	MQT 11	Thermal cycling test	(85 ± 2) °C	+10 °C, (95 ± 2) °C	+20 °C, (105 ± 2) °C
	MQT 18	Bypass diode testing chamber Part 1 Part 2	(75 ± 2) °C I_{SC} 1.25 * I_{SC}	+15 °C, (90 ± 2) °C 1.15 * I_{SC} for diode T 1.4 * I_{SC} for stress	+25 °C, (100 ± 2) °C 1.15 * I_{SC} for diode T 1.4 * I_{SC} for stress
IEC 61730	5.5.2.3.3	RTI/RTE/TI	min RTI 90 °C	min RTI 100°C	min RTI 110 °C
	MST 22	Hot spot endurance	(50 ± 10) °C	+10 °C, (60 ± 10) °C	+20 °C, (70 ± 10) °C
	MST 37	Material creep test	105 °C	no change	110 °C
	MST 51	Thermal cycle	(85 ± 2) °C	+10 °C, (95 ± 2) °C	+20 °C, (105 ± 2) °C
	MST 54	UV test	(60 ± 5) °C	+10 °C, (70 ± 5) °C	+20 °C, (80 ± 5) °C
	MST 56	Dry heat conditioning	105 °C	no change	110 °C
component level tests					
IEC 62788-1-7 (encapsulant, performance)	8	Optical durability encapsulants	IEC TS 62788-7-2 (A3 cond.)	IEC TS 62788-7-2 (A4 cond.)	IEC TS 62788-7-2 (A5 cond.)
IEC TS 62788-2* (backsheet and frontsheet safety)	BST 9	Weathering (UV) ageing test	IEC TS 62788-7-2 (A3 cond.)	IEC TS 62788-7-2 (A4 cond.)	IEC TS 62788-7-2 (A5 cond.)
IEC 62852	5.2.1 h)	Marking, Upper Limit Temperature (ULT)	no requirement	95 °C	105 °C
IEC 62790	4.2.1 i)	Range of temperature (upper ambient temperature)	no requirement	95 °C	105 °C

* - Following publication of IEC 62788-2-1, pass/fail requirements from this document shall be followed.

Extreme Environments: Wind Load

What governs wind load? Predominantly, three things:

- The site
- The system design
- The mounting system

Typical, flat-plate PV modules with typical frames are not one of the three governing factors.

Mechanical safety and performance of PV modules would *ideally* be addressed in conjunction with mounting system standards:

- UL 2703 (fixed), 3703 (trackers) – static/uniform mechanical Load tests, bonding tests
- IEC 62782 DML

Extreme Environments: Wind Load

Possible improvements to existing standards:

- IEC WG7 project just initiated, UL will participate
- Updates to 2703/3703

Mounting systems – CB verifies/report manufacturer specs:

- Deflections under maximum rated load / torques
- Static pressure coefficients and/or load ratings
- Dynamic response
    - Natural frequencies for all modes < ~10 Hz
    - Damping ratio for all modes < ~10 Hz
    - Dynamic amplification factors

PV modules

- Add nonuniform wind-load test (under consideration in WG2 and WG7)
- Verify allowable deflections and loads – designers then verify compatibility with mounting system

Extreme Environments: Snow Load

- Use test load of 1.5 x specified rating
- Also consider draft IEC 62938: non-uniform snow loading for PV modules

Extreme Environments: Severe Corrosivity

IEC 61701 Salt mist corrosion testing

Corrosivity Classification of module location	Location Characteristics		One-year Mass loss range (g/m^2) of bare steel coupons	60068-2-52 Test Method achieving similar one-year corrosivity
	Distance from Saltwater (km)	Percentage Time of Wetness (ToW)		
C1 (testing per this document not necessary)	--	--	<10	none
C2 (testing per this document not necessary)	≥ 10	<25%	10-200	2, 3
C3	≥ 10 2 to 10	≥ 25% <25%	200-400	4 (14 days)
C4	2 to 10 < 2	≥ 25% <25%	400-650	1 (28 days) 5 (28 days)
C5	< 2	≥ 25%	650-1500	6 (56 days)
CX	offshore	--	1500-5500	7 (90 days) 8 (70 days)

Percentage time of wetness (ToW) is defined as the number of hours during the year at which the RH is at 80% or higher and the temperature is greater than 0°C, divided by the total hours in a year. This is defined in ISO 9223, but the tool uses a more complex model based on hourly RH measurements in the climate database.

PV Module – Performance (Dust and Abrasion)

Description	Standard	Test Elements	Pass/Fail Criteria
Dust and Abrasion	ASTM D968-17	Standard Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive	Informative Report
	IEC 60068-2-68 :1994	Environmental testing - Part 2: Tests - Test L: Dust and sand Note: more appropriate for sealed enclosures	Informative Report
	DIN EN 1096-2 :2012	Glass in building – Coated glass – Part 2: Requirements and test methods for class A, B and S coatings	Informative Report
	IEC 62788-7-3 under development	• Measurement procedures for materials used in photovoltaic modules • Part 7-3 Materials and coatings for photovoltaic modules or similar solar devices: Abrasion test methods for environment facing surfaces	TBD

Extreme Environments: Hail

- Module manufacturer specifies desired hail test conditions (Table 3, IEC 61215)
- UL verifies compliance
- Designer assess site-specific risk of exceeding test conditions (AHJ, insurance provider, other stakeholders may require specific level of hail resistance
- Testing in excess of standard requirements can be done, if desired

Table 3 – Ice-ball masses and test velocities

Diameter mm	Mass g	Test velocity m/s	Diameter mm	Mass g	Test velocity m/s
25	7,53	23,0	55	80,2	33,9
35	20,7	27,2	65	132,0	36,7
45	43,9	30,7	75	203,0	39,5

Extreme Environments – "New" Applications

New and innovative products - no existing standards:

Custom review needed to assess safety and performance requirements, taking into account safety and performance risks (hazard-based safety engineering, HBSE).

Examples:

Floating PV

- Shock / electric shock drowning
- IP ratings of PV and BOS
- Chronic soiling, heating, shade (IEC TS 63140)
- Site specific cyclic loading, fatigue
- Corrosion
- O&M safety risks
- Reliability of floats and moorings

Extreme Environments – “New” Applications

PV pavers – sidewalk applications

- Immersion risk, impact on reliability, safety
- Slip risk
- Cyclic compressive loads (high heels)
- Maintenance – shoveling, salt/sand

PV thermal hybrid

- Thermal shock
- Thermal cycling
- Extreme temperatures
- PV integration – mechanical securement, chemical compatibility, grounding
- Failsafe design in prolonged leak
- Industry demand for field retrofits based on limited or testing for adding new modules to certifications

Summary - Standards Considerations for Extreme Environments

Factor	Extreme Environment Adjustment
Air temperature	Increase temperature per IEC TS 63126
Module temperature	Increase temperature per IEC TS 63126
Wind load	***Updates needed:*** • Assess impact of mounting system (deflections, dynamic amplification) • Non-uniform load
Snow load	1.5 x load; IEC 62938 (non-uniform)
Corrosivity	IEC 61701
Abrasion	Reference IEC 62788-7-3 (draft); DIN EN 1096-2-2012; ASTM D968-17
Hail	Verify compliance with site requirements or get insurance / modify test
Mounting	Custom hazard based assessment needed to determine requirements.

Thank you