IEC TS 63209-2 AND EXTENDED TESTING OF PV POLYMERIC COMPONENTS

Nancy Phillips

IEC TS 63209-2 brings together work from several IEC Project Teams:

- Component standards:
  - IEC 62788-1, encapsulants (Project Leader: Dave Miller)
  - IEC TS 62788-2, frontsheets/backsheets (Project Leader: Peter Pasman)
  - IEC TS 62788-6-3, single cantilever beam adhesion testing (Project Leader: Nancy Phillips)
- Extended test standards:
  - IEC TS 63209-1 extended module testing (Project Leader: Sarah Kurtz)
  - IEC TS 63209-2 extended component testing (Project Leader: Nancy Phillips)

And many project team members

Topics:

- Field examples of degradation of PV backsheets
- IEC standards and component durability
- Stress test plans in:
  - IEC TS 62788-2 (Frontsheets / Backsheets Characterizations) ed. 1
  - IEC TS 62788-2 ed. 2 – new test methods
    - Single point thermal endurance test
    - Sequential coupon test / Solder wire test
  - **IEC TS 63209-2 (Extended testing of PV polymeric components)**

Peter Pasman will cover this in more detail in his presentation

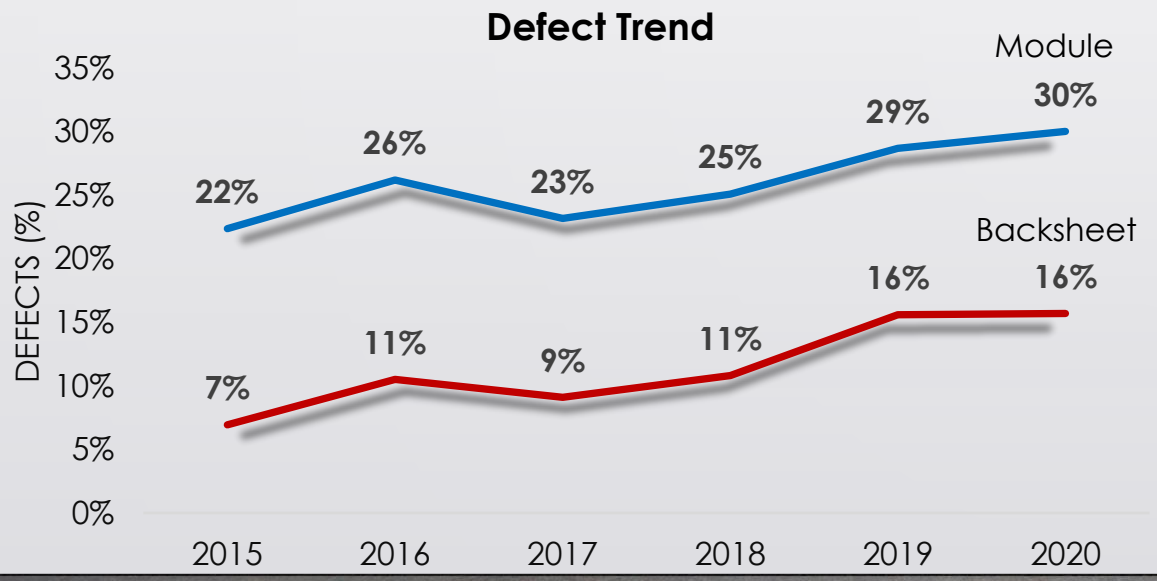
DuPont 2020 Global field data analysis summary

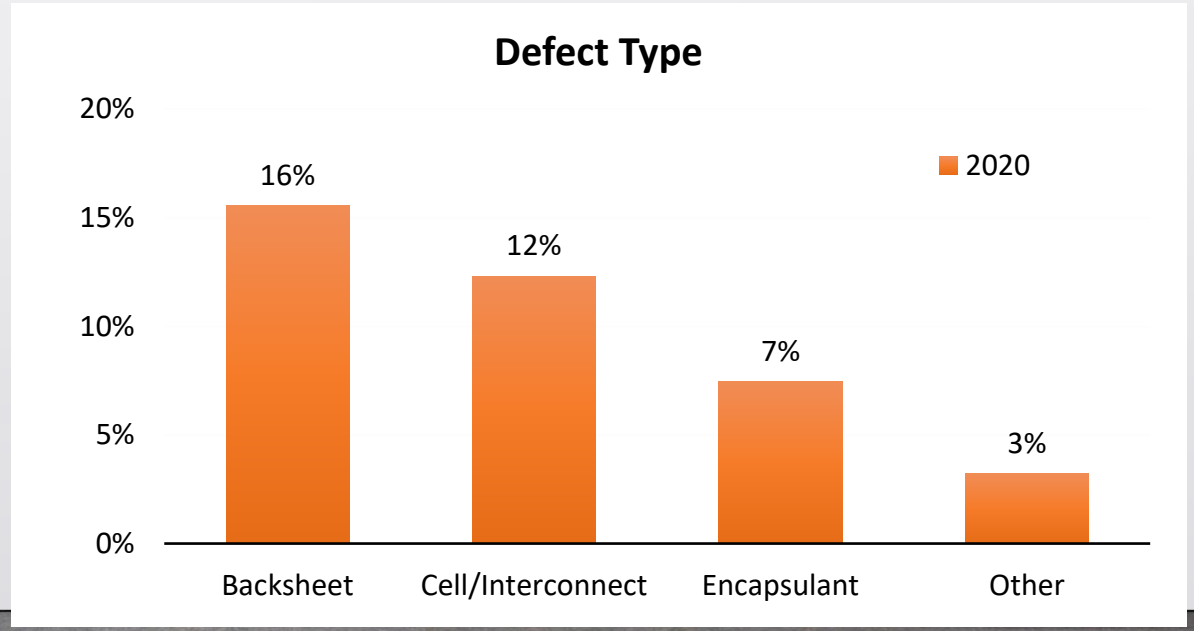
Module Defect Trends

- **Total module defects observed: 30%**
- **Total backsheet defects observed: 16%**
- **Total cell/interconnect defects observed: 12%**
- **Total encapsulant defects observed: 7%**

Module Defect Types

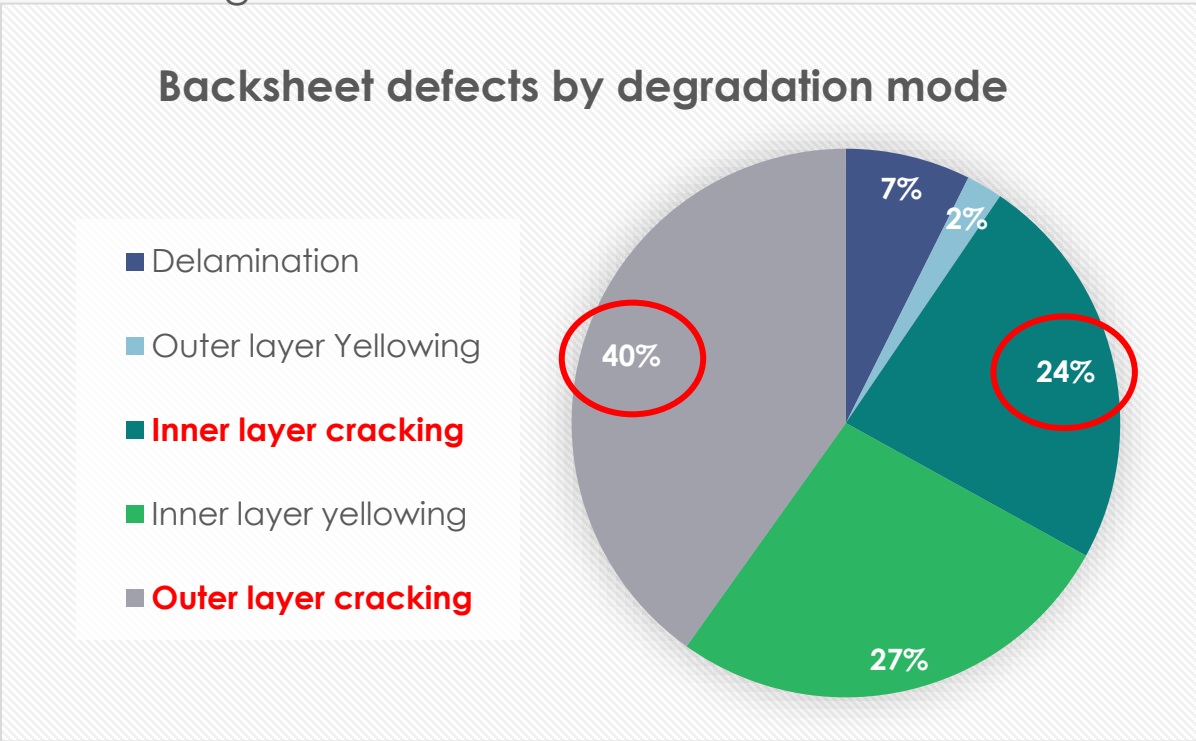
- **Backsheet:** outer layer (air side) and inner layer (cell side) cracking, delamination, yellowing
- **Cell / Interconnect:** corrosion, hot spot, snail trails, broken interconnect, cracks, burn marks
- **Encapsulant:** discoloration, browning, delamination
- **Other:** glass defects, loss of AR coating, junction box



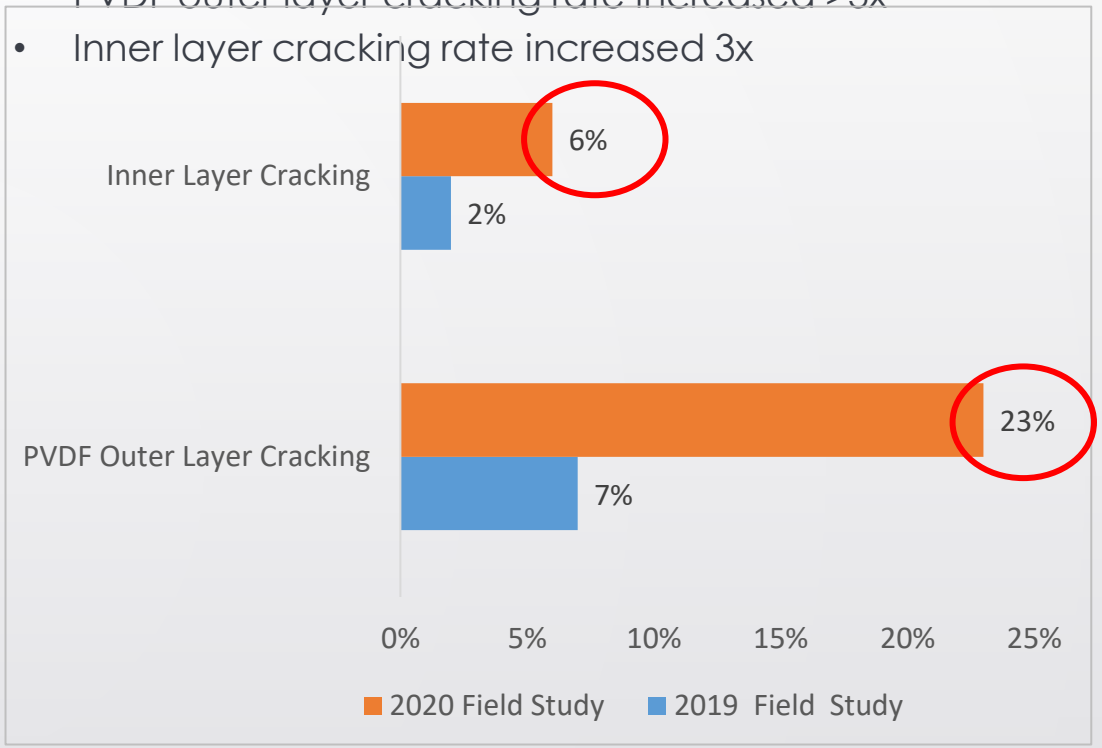


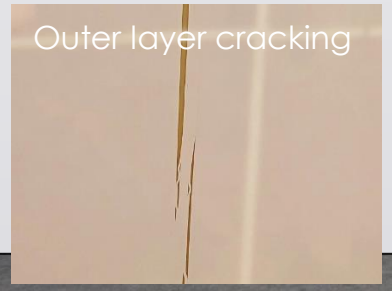
Backsheet defect trends

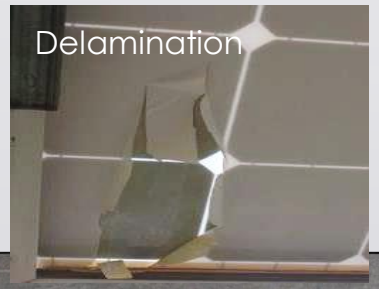
Cracking constitutes 64% of all backsheet defects

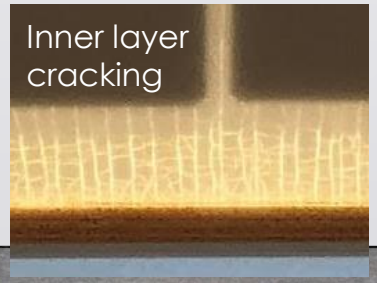


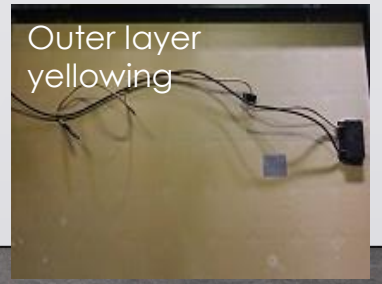
- PVDF outer layer cracking rate increased >3x
- Inner layer cracking rate increased 3x











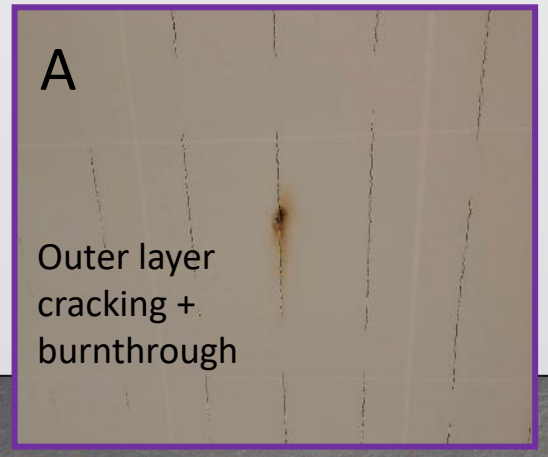
Note: 2019 field study report is based on field data up to April 2019. 2020 field study report is based on field data up to April 2020.

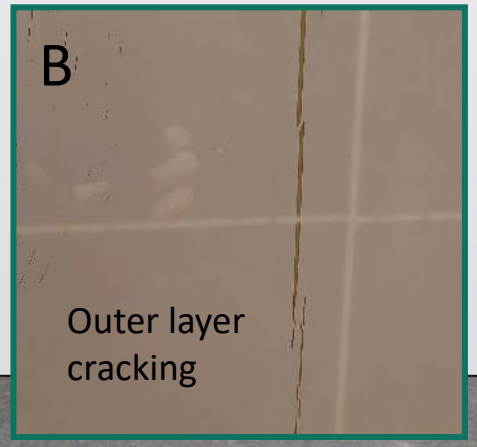
Variability between different Bills of Materials (BOM)

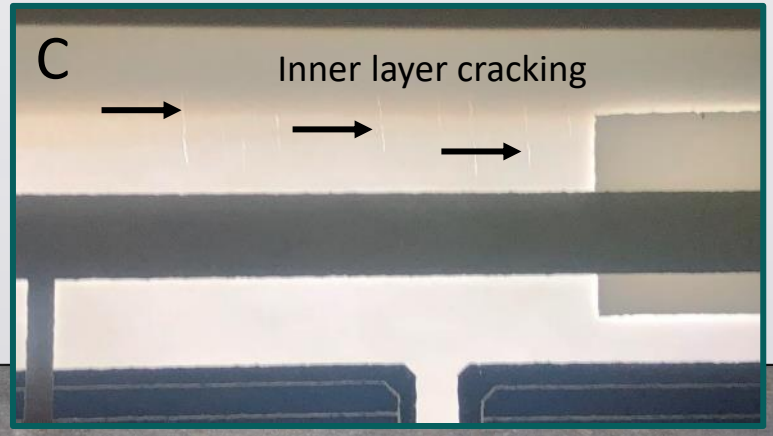
Backsheet Defects in High Desert, SW USA

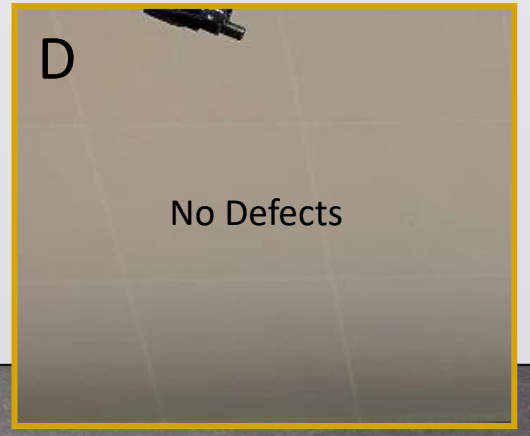
Total installation – single model number

- 100% BS cracking type A
- 100% BS cracking type B
- BS inner layer cracking type C
  - ~5% exhibited severe busbar corrosion
  - instances of electrical fires
- No obvious BS defects type D
- Encapsulant browning all modules





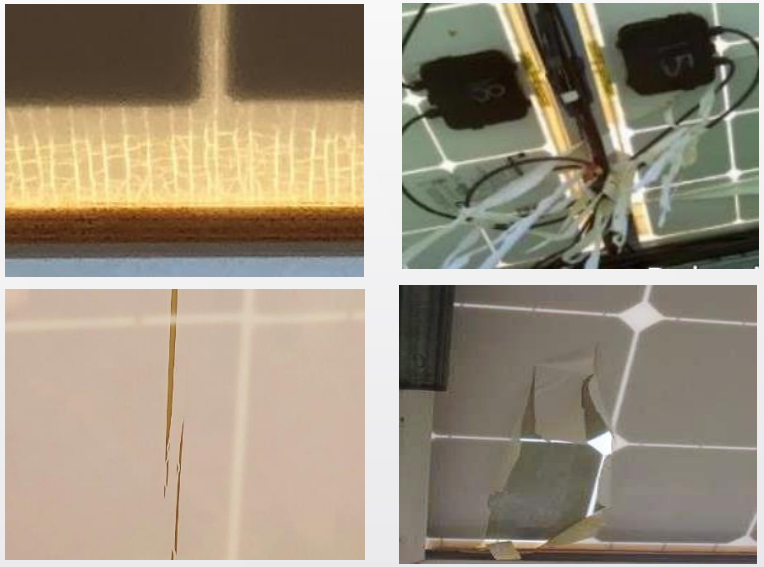




Problem Statement:

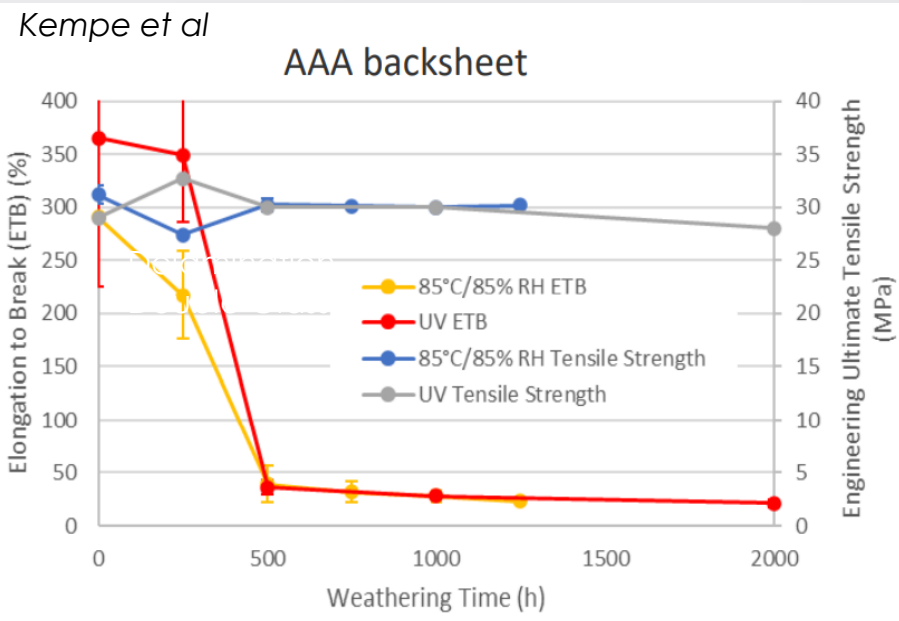
Backsheets which pass Qualification Tests Fail in the Field

- **Root cause analysis**
  - Use of tensile strength as a key metric for RTI/RTE/TI
    - % Elongation is a better indicator of propensity to crack
  - No significant amount of UV exposure on front/back sides
  - Cracking likely to occur with sequential stresses
- **Improvements:**
  - Use % elongation at break instead of tensile strength
  - Add weathering requirements for backsheets
  - Include longer UV exposures for evaluation of extended reliability
  - Improve UV sequential test for modules
  - Develop a sequential test for coupons
  - Develop “BOM-specific” coupon tests



Delamination

Kempe et al



published draft

Backsheet reliability in IEC standards

Module Standards

IEC 61215

IEC 61730

Known gaps :

- degradation of Relied-upon-insulation (RUI) materials
- extended reliability

Extended stress tests

IEC TS 63209-1
Module reliability risk assessment

Known gaps:

- Extended UV stress
  - No front-side UV exposure
  - Backside UV exposure not sufficient
- Use of light source with low fidelity to solar spectrum can reduce accuracy

Polymeric Component Standards

(single component tests)

Qualification Requirements

IEC 62788-2-1
backsheets

Data sheet
(Screening tests)

IEC 62788-1
encapsulants

IEC TS 62788-2
backsheets

IEC TS 62788-5
Edge seals

1) Extend single component stress tests

IEC TS 63209-2
PV component reliability risk assessment

BOM specific testing

Module Qualification – for 1 module model

IEC 61215

IEC 61730

Additional testing for multiple BOMS

IEC 62915

Module retest guidelines

All testing is at the module level

Polymeric Component Standards

(multi component tests ➔ BOM specific testing)

BOM specific coupon testing is a gap

IEC 62788 Component standards have historically addressed evaluation of a single component, w/o specifying BOM partners.

This is changing – parallel development in backsheet and encapsulant standards. Both test methods and stress exposures are being addressed.

2) Add BOM-specific tests and relevant stress exposures

IEC TS 63209-2

PV component reliability risk assessment

Test Plans

NOTE:

- testing intended for data analysis and comparative purposes
- No pass/fail requirements

IEC TS 62788-2 Frontsheet / Backsheet Characterization Test Methods

	UCF No.	test name	reference	fresh	1 000 h DH test (4.10.2)	UV (Xenon) test (4.10.3) with exposure of	
						air side[a] (2000h)	sun-facing side[b] (4000 h)
	1	dimensions and tolerances [µm]	4.2.2	✓	–	–	–
	2	area weight and tolerances [g/m²]	4.2.3	✓	–	–	–
Mechanical	3	tensile strength [MPa] (MD and TD)	4.2.4	✓	✓	✓	✓
Mechanical	4	elongation at break [%] (MD and TD)	4.2.4	✓	✓	✓	✓
Adhesion	5	bond strength between layers of composition – or weakest link [N/mm] (for peelable layers)	4.3.6.2	✓	✓	O	O
Adhesion	6	bond strength between coatings or thin layers and film [rating scale](for layers too thin or brittle to peel)	4.3.6.2	✓	✓	O	–
Adhesion	7	bond strength between a specific encapsulant and sheet [N/mm]	4.3.6.3	O	O	O	O
Adhesion	8	bond strength between a specific junction box adhesive and sheet [N/mm]	4.3.6.4	O	see	–	–
Electrical insulation	9	RTE/RTI/TI [°C]	4.4.1	✓	–	–	–
Electrical insulation	10	dimensional stability in MD & TD [%]	4.4.2	✓	–	–	–
Electrical insulation	11	relative thermal expansion [K^{-1}]	4.4.3	O	–	–	–
Electrical insulation	12	dc breakdown voltage [kV]	4.5.1	✓	O	O	O
Electrical insulation	13	distance through insulation [µm]	4.5.2	✓	–	–	–
Electrical insulation	14	comparative tracking index (CTI)	4.5.3	✓	–	–	–
Optical Properties	15	visual inspection	4.6.2	✓	✓	✓	✓
Optical Properties	16	solar transmittance (for transmittive sheets only)	4.6.4	✓	O	O	O
Optical Properties	17	solar reflectance c (for reflective sheets only)	4.6.5	✓ (air side)	O (sun-facing)	–	O (sun-facing)
Optical Properties	18	yellowness index DYI c	4.6.6	O	O	O (air side)	O (sun-facing)
Optical Properties	19	CIE L*a*b* (D65/10°) c	4.6.7	O	O	O (air side)	O (sun-facing)
Optical Properties	20	specular gloss c	4.6.8	O	O	O (air side)	O (sun-facing)
	21	water vapour transmission rate [g/m²d]	4.7.1	O	–	–	–
	22	resistance to recommended cleaning solvent	4.8.1	O	–	–	–

a air-side exposure is directly onto the backsheet

b exposure of sun-facing side of backsheet with choice of UV filter: i) C1A: G/E/E/(trm), ii) C1b: Filter Glass or iii) C2: no UV filter

c for optical characterization of backsheet (UCF nr. 17 – 20) the side of the sheet for optical measurement is indicated: i) air side or ii) sun-facing side.

✓ = required material characterization

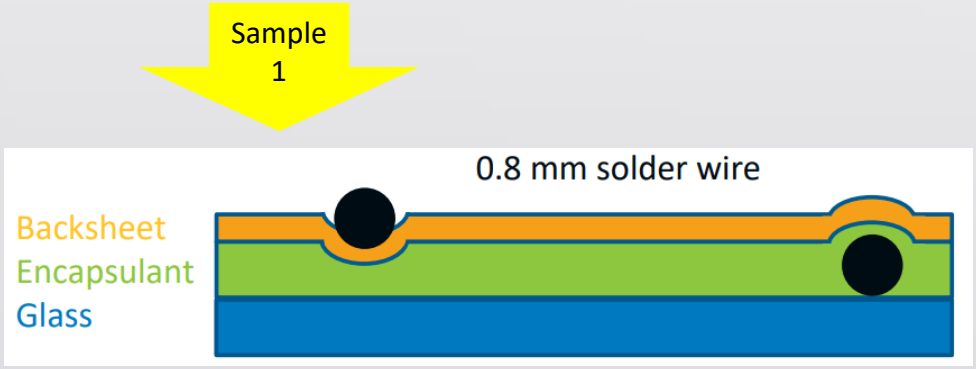
O = optional material characterization

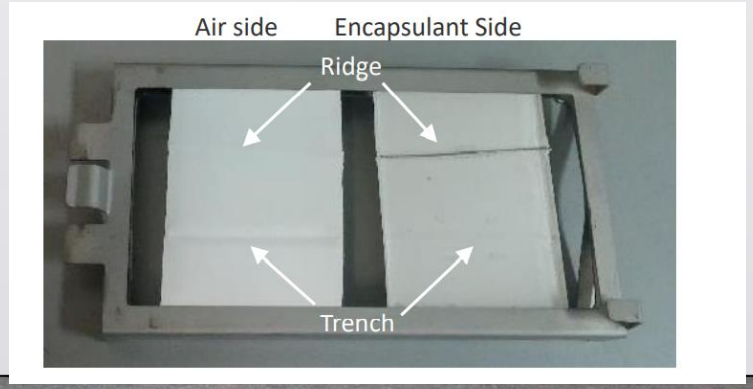
– = material characterization not required

IEC TS 62788-2 Ed 2 (DTS in progress) *New Test Methods*

- **Thermal Failsafe**
  - Parallel to RTI/RTE/TI
  - Single point thermal stability of individual RUI layers; % Elongation at break (% retention) after 2000 h 120˚C
- **Sequential UV/TC stress test (aka "Solder bump test")**

  Reference: Michael Kempe, Nancy Phillips, Joshua Morse, Xan McPherson, Derek Holsapple, "Sequential Multi-Factor Stress Testing For Backsheet Durability Evaluation", 2021 NREL Reliability Conference. Contact: *Michael.Kempe@NREL.gov*





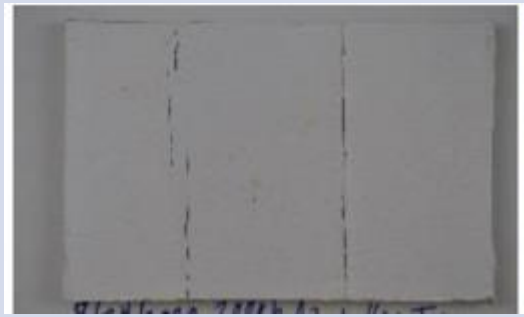
Stress sequence;

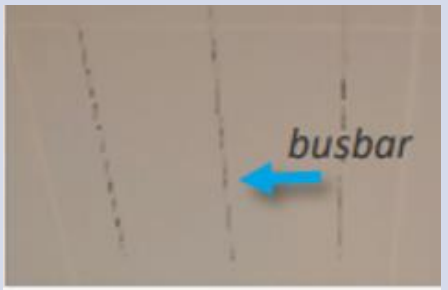
(UV / TC) * 3

Solder bump examples, after 3 x (UV1000h/200TC)

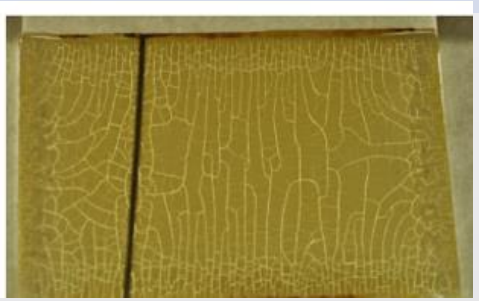
Air side **Cell side** **Field example**

- AAA: cracking all the way through the backsheet, TD direction, both air side and cell side exposures

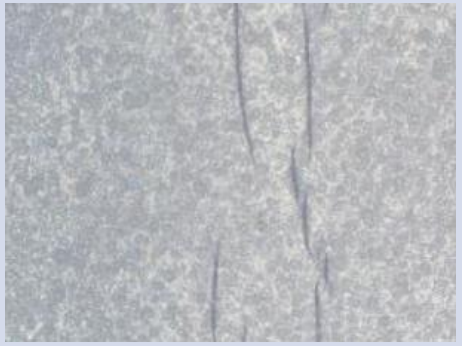




PET1: front side cracking after both air side and cell side exposure, similar to what's seen in the field



PVDF2: air side cracking along the ridge line



IEC 63209 Series

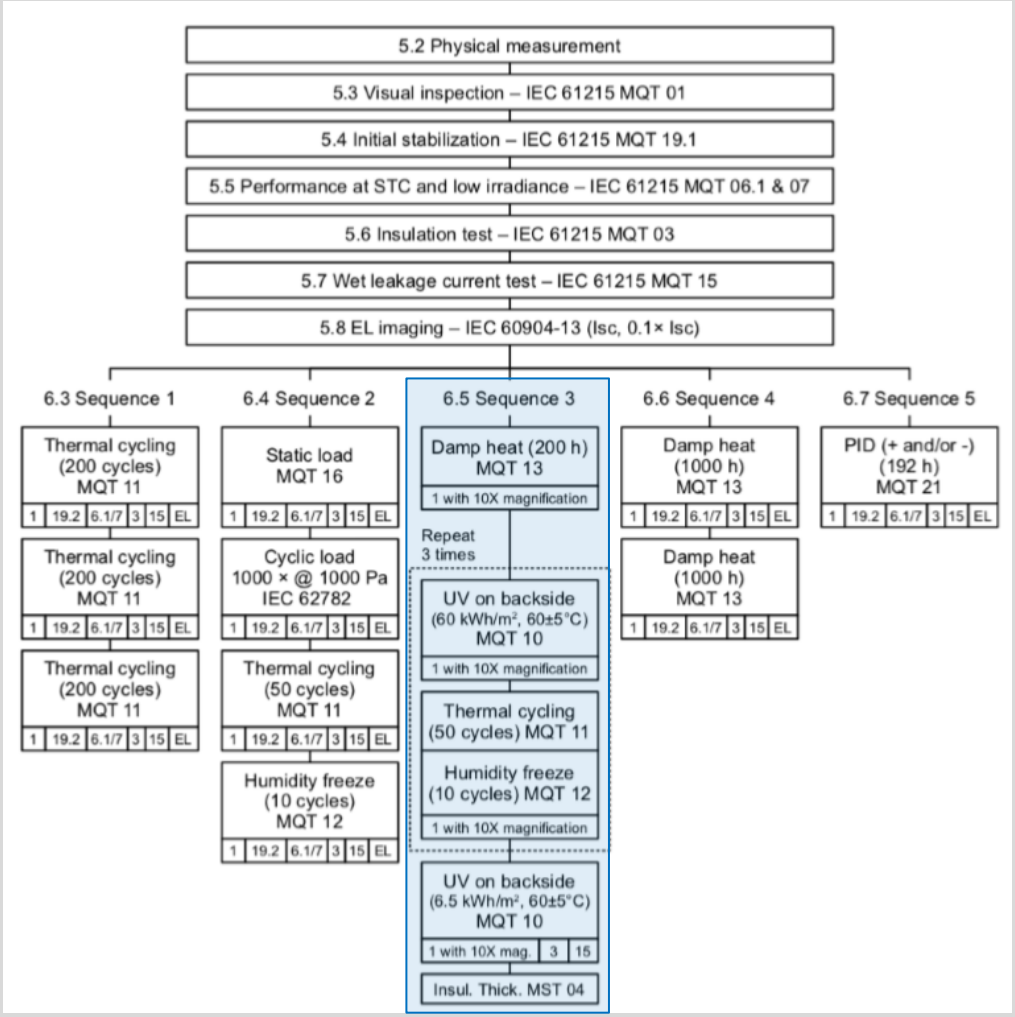
IEC 63209 Series - Extended Stress Testing of PV Modules

IEC TS 63209 provides a standardized method for evaluating longer term reliability of photovoltaic (PV) modules and for different bills of materials (BOMs) that may be used when manufacturing those modules.

- **Part 1: PV Modules**
  - *Published*
- **Part 2: Component materials and packaging**
  - Extensions of stress exposures for components
  - BOM specific coupon testing

  DTS almost ready for circulation

EXTENDED STRESS TESTING OF PHOTOVOLTAIC MODULES – Part 1: Modules



"Some known failure modes can not be accurately addressed, most notably those related to long-term ultra-violet light (UV) exposures. …These failure modes are expected to be **better addressed at a materials coupon level in part two of this TS series. "**

IEC TS 63209-2 c-Si modules, G/BS construction – Single component testing

Polymeric Components
- **Backsheet**
- **Encapsulant 1**
- **Encapsulant 2**

Start with testing defined in IEC 62788-1, and -2, extend the stress exposures:

Single Component Testing							
Component	**specimen**	**stress**	**hours**		**evaluation methods**	**reference**	**report**
			base	**extended**			
Backsheet	BS	DH	1000h	-	visual, mechanical	IEC TS 62788-2	values, % retention
	G/E*/E*/BS	A3 UVX (front)	4000h	6000h	visual		observation
	G/E*/E*/(trm)/BS	A3 UVX (front)	4000h	6000h	visual, mechanical		values, % retention
	BS	A3 UVX (back)	2000h	4000h	visual, mechanical		values, % retention
	RUI layers (RTI)	thermal	*na*	-	mechanical		value
	RUI layers (thermal failsafe)	120C	2000h	-	mechanical		values, % retention
Encapsulant(s)	G/E1/G	A3 UVX (front)	4000h	6000h	Transmission, visual, yellowness, UV cutoff	IEC 62788-1-7	value , % retention
	G/E2/G						

A3 (from IEC 62788-7-2) is used for UV exposures – good match to solar spectrum (D7869 compliant); irradiance and time @T are specified
G: Glass; E: Encapsulant; BS: Backsheet, trm: transparent release material as in IEC TS 62788-2

IEC TS 63209 c-Si modules, G/BS construction – BOM specific testing

Not captured with single component testing:

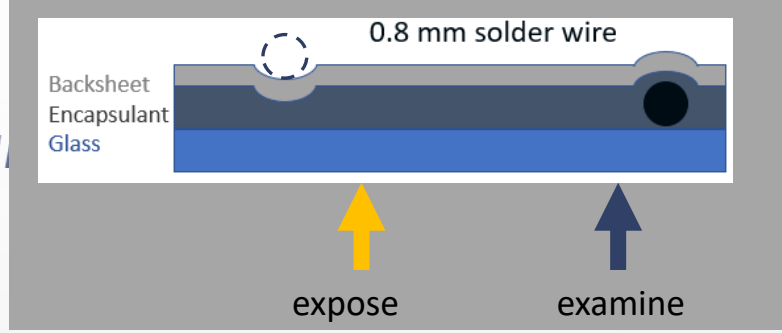
Polymeric Components
- **Backsheet**
- **Encapsulant 1**
- **Encapsulant 2**

Other BOM materials
- **Cell**

- **Backsheet cracking (frontside and backside)**
  - Backsheet/encapsulant interactions
  - Effect of module structure
  - Included:
    - Solder bump coupons ➔ referenced from IEC 62788-2 amendment (in progress)
    - Minimodules with sequential stress tests ➔ referenced from IEC 63209-1
- **Delamination – adhesion tests**
  - Peel tests: viscoelastic contributions limits value of comparative tests
  - Included: IEC 62788-6-3: single cantilevered beam test (CD2 circulating in IEC)
- **Effect of components on PID***
  - Can be influenced by interactions of cell, backsheet, encapsulant
  - Correlation to module performance not defined
  - Included as a minimodule test, referenced from IEC 63209-1
- **Stress Exposures: a combination of stresses is important, and may be different for different failure modes**

*Inclusion of PID still under discussion. Not necessary for testing to complement IEC TS 63209-1, but potentially useful for screening components for long term reliability.

Importance of BOM-specific coupon tests:



Effect of encapsulant on front side degradation

Solder bump experiments

Table 5. First Round of Blocking/Transmitting samples.
Cell side exposure only.
R=Reflected light, T=Transmitted light, MD=Machine Direction, TD=Transverse Direction.

Material Nickname	Material Orientation	Light (R/T)	EVA #1, UV Transmitting						EVA #2, UV Blocking					
			1000 A3	1000 A3 200 TC	2000 A3 200 TC	2000 A3 400 TC	3000 A3 400 TC	3000 A3 600 TC	1000 A3	1000 A3 200 TC	2000 A3 200 TC	2000 A3 400 TC	3000 A3 400 TC	3000 A3 600 TC
PET1	MD	R												
		T												
	TD	R												
		T												
PET2	MD	R												
		T												
	TD	R												
		T												
TPT	MD	R												
		T												
	TD	R												
		T												
AAA	MD	R												
		T												
	TD	R												
		T												
FEVE	MD	R												
		T												
	TD	R												
		T												

~~*Hypothesis #1: Use of EVA with no UV absorber will accelerate degradation.*~~

Hypothesis #2: EVA formulation has a different stabilization package, likely including radical stabilizers.

c-Si modules, G/BS construction – BOM specific testing

Polymeric Components
- Backsheet
- Encapsulant 1
- Encapsulant 2

Other BOM materials
- Cell

BOM-specific (multi-component) testing

Component, failure mode	specimen	stress	Hours/# of cycles		evaluation methods	reference	report
			base	extended			
BS cracking (back)	G/*wire*/E/BS	1000hUV/200TC	1 or 2x	2 or 3x	visual	62788-2	semi-quantitative metric
BS cracking (front)	G/*wire*/E/BS						
BS cracking (back), delamination	minimodule	DH200, (A3 (**back**)-1000/TC50/HF10)*3, A3-100 (high fidelity version of IEC 63209-1 6.5)			visual IEC 61215-2: MQT 03 Insulation test (5.6) MQT 15 Wet leakage test, (5.7) IEC 61730-2: MST 04 Insulation thickness (5.9)	63209-1	values
BS cracking (front), delamination	minimodule	DH200, (A3 (**front**)-2000/TC50/HF10)*3, A3-100					
Adhesion:							
BS-E2	G/E1/E2/BS	DH	1000	500 DH/2000h A3/ 1000h DH	SCB (IEC TS 62788-6-3) or 180˚ peel	62788-6-3	value, % retention
		A3 (front)	2000				
E1-E2	G/E1/E2/glass slide	500 DH/2000h A3/1000h DH	1x	2X		62788-6-3 62788-1-1	
E1-cell	G/E1/cell		1x	2X			
E1-glass	G/E1/glass slide		1x	2X			
PID*	minimodule	+/- V, DH, light recovery	96	192		61215-1-1 63209-1	Comparison to baseline

*include with test method:

results not representative of module performance; not to be used for reporting with IEC 63209-1; may be helpful for comparing effect of polymeric components on PID

c-Si modules, G/G construction

Polymeric Components
- Encapsulant 1
- Encapsulant 2

Other BOM materials
- Cell

Single Component Testing							
Component	**specimen**	**stress**	**hours**		**evaluation methods**	**reference**	**report**
			base	**extended**			
Encapsulant(s)	G/E1/G	A3 UVX (front)	4000h	6000h	transmission	62788-1-7	value
	G/E2/G	A3 UVX (front)	4000h	6000h	transmission		value

BOM-specific (multi-component) testing							
Degradation Mode	**specimen**	**stress**	**hours**		**evaluation methods**	**reference**	**report**
			base	extended			
Adhesion:							
E1-E2	G/E2/E1/glass slide	500 DH/2000h A3/1000h DH	1x	2x	SCB (IEC TS 62788-6-3)	62788-6-3 62788-1-1	value, % retention
E1-cell	G/E1/cell	500 DH/2000h A3/1000h DH	1x	2x			
E1-glass	G/E1/glass slide	500 DH/2000h A3/1000h DH	1x	2x			
Delam	minimodule	DH200, (A3 (**back**)-1000/TC50/HF10)*3, A3-100 *(high fidelity version of IEC 63209-1 6.5)*			visual IEC 61215-2: MQT 03 Insulation test (5.6) MQT 15 Wet leakage test, (5.7) IEC 61730-2: MST 04 Insulation thickness (5.9)	63209-1	values
Delam	minimodule	DH200, (A3 (**front**)-2000/TC50/HF10)*3, A3-100					
PID*	minimodule	HV+/- w/DH, light recovery	96	192		61215-1-1 63209-1	

*include with test method:

results not representative of module performance; not to be used for reporting with IEC 63209-1; may be helpful for comparing effect of polymeric components on PID

Summary

- **To remedy the problems observed with backsheet field failures:**
- **IEC TS 62788-2** (backsheet standard) is incorporating new characterization tests:
  - Thermal failsafe: single-point thermal endurance test for RUI layers
  - Coupon sequential test / solder bump test
- **IEC 61730 Ed 3** requires prequalification of polymeric components, including backsheets
- **IEC 62788-2-1** (backsheet safety requirements) has new backsheet requirements
  - Thermal failsafe
  - Air-side and cell-side UV weathering
  - Minimum breakdown voltage of RUI layers and backsheets, initial and after exposure
- **IEC TS 63209-2** (extended PV component testing)
  - Extended encapsulant and backsheet testing, and BOM specific testing

Thank you!