Approaches to Component Reliability in IEC Standards Development

NIST/UL Workshop on Photovoltaic Materials Durability

December 13, 2019

Nancy Phillips

DUPONT™

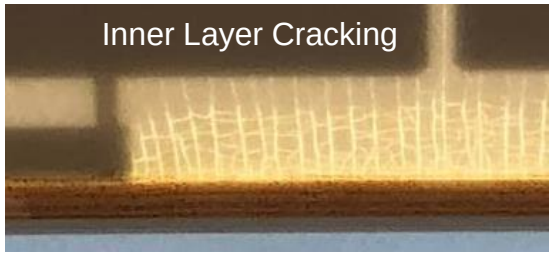
Problem statement:

- Significant issues with degradation of polymeric materials observed with fielded modules
  - 61215/61730 testing does not address this issue well

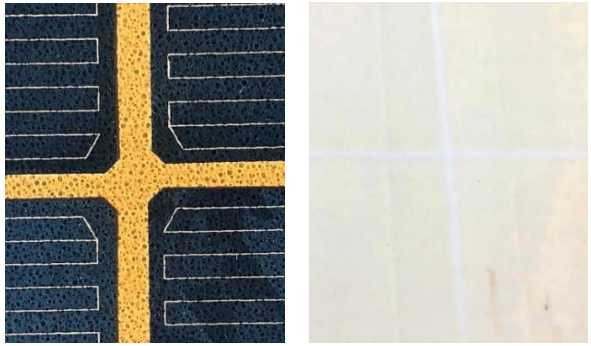
Recognized:

- Stress test methods not well established for very long durability analysis, relevant to target service life
- Multi-stress exposures (sequential or combi) are missing
- Some analyses better done at component level

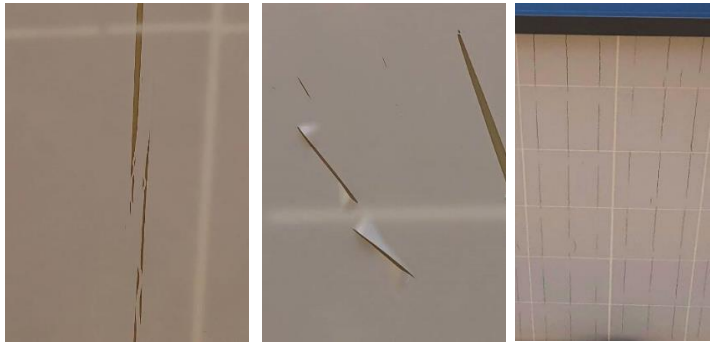
- ***Already too many test requirements…***
- Not enough known to select one “right” test set



Inner/Outer Layer Yellowing



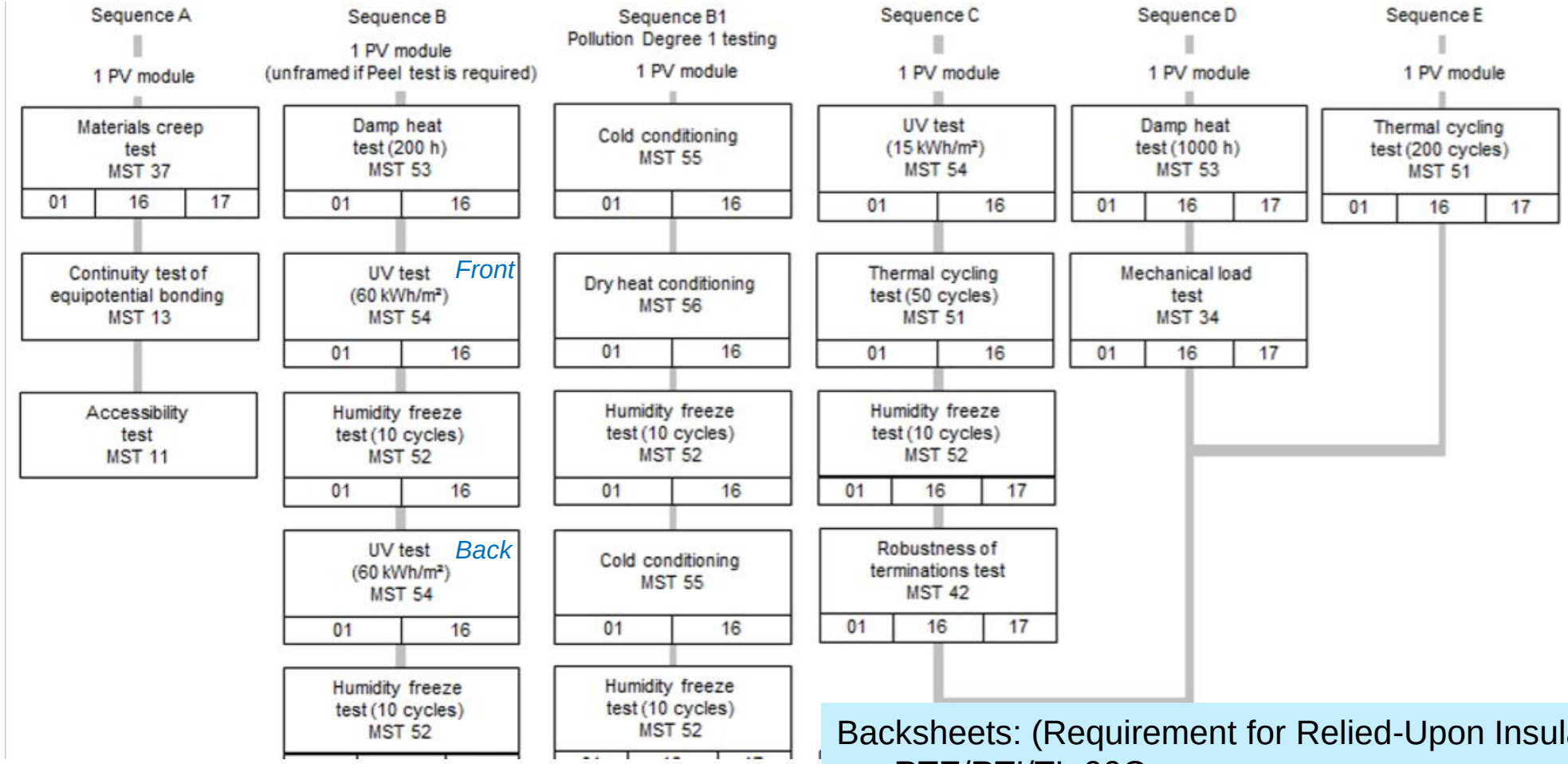
Outer Layer Cracking/Delam



Core Qualification Standards:

- **IEC 61730 PV module safety qualification**
- **IEC 61215 PV modules - Design qualification and type approval**

IEC 61730 Stress Testing



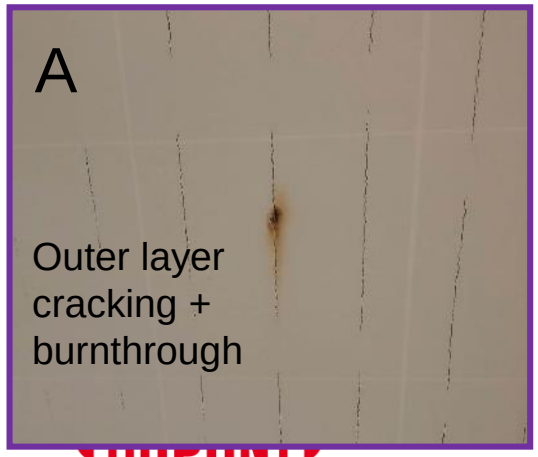
Backsheets: (Requirement for Relied-Upon Insulation)

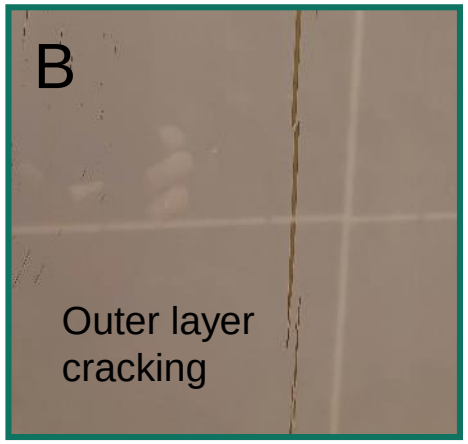
- RTE/RTI/TI>90C,
- minimum thickness
- Minimum BDVdc

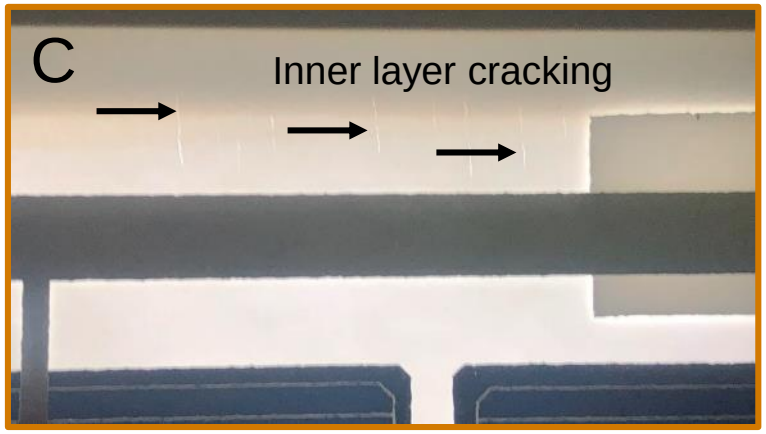
Backsheet Defects in High Desert, SW USA

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







Core Qualification Standards:

- **IEC 61730 PV module safety qualification**
- **IEC 61215 PV modules - Design qualification and type approval**

Adding Component Testing:

IEC 62788 Series: Measurement procedures for materials used in photovoltaic modules

- 62788-1: Encapsulants
- 62788-2: Frontsheets and Backsheets
- 62788-5: Edge Seals
- 62788-7: Stress exposures

Components:

- IEC 62790 *Junction Boxes for PV modules*
- IEC 62852 *Connectors for DC-application in PV systems*
- IEC 62930 *Electric cables for PV systems*.

DUPONT™

Post-stress evaluations in 62788-2 (Frontsheets/Backsheets)

UCF No.	Test Methods	Component evaluation Sheet Coupon Filtered Sheet	Package evaluation Coupon Minimodule	Fresh	1 000 h DH test	2 000 h UV (Xenon) exposure (4.10.3)	
					(4.10.2)	air side[a]	sun-facing side[b]
3	Tensile strength [MPa] (MD)	S, F	NA	✓	✓	✓	✓
	Tensile strength [MPa] (TD)			✓	✓	○	○
4	Elongation at break [%] (MD)			✓	✓	✓	✓
	Elongation at break [%] (TD)			✓	✓	○	○
5	Bond strength between layers of composition – or weakest link [N/mm] (for peelable layers)	S,F	NA	✓	✓	○	○
6	Bond strength between coatings or thin layers and film [rating scale] (for layers too thin or brittle to peel)	S,F	NA	✓	✓	○	–
7	Bond strength between a specific encapsulant and sheet [N/mm]	C	Coupon (BS/E) Minimodule (E/Cell)	○	○	○	○
8	Bond strength between a specific JBox adhesive and BS (N/mm)		Refer to IEC 62790	○	IEC 62790	–	–
12	dc breakdown voltage [kV]			✓	○	○	○
15	Visual inspection			✓	✓	✓	✓
16	Solar transmittance (for transmittive sheet only)			✓	○	○	○
17	Solar reflectance c(for reflective sheets only)			✓ (sun-facing)	○ (sun-facing)	–	○
18	Yellowness index DYI c			○	○	○	○
19	CIE L*a*b* (D65/10°) c			○	○	○	○
20	Specular gloss c			○	○	○	○

DUPONT™

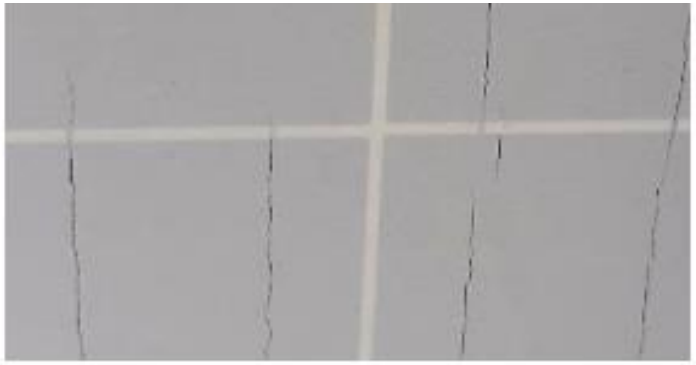
Core Qualification Standards:

- **IEC 61215 PV modules - Design qualification and type approval**
- **IEC 61730 PV module safety qualification**

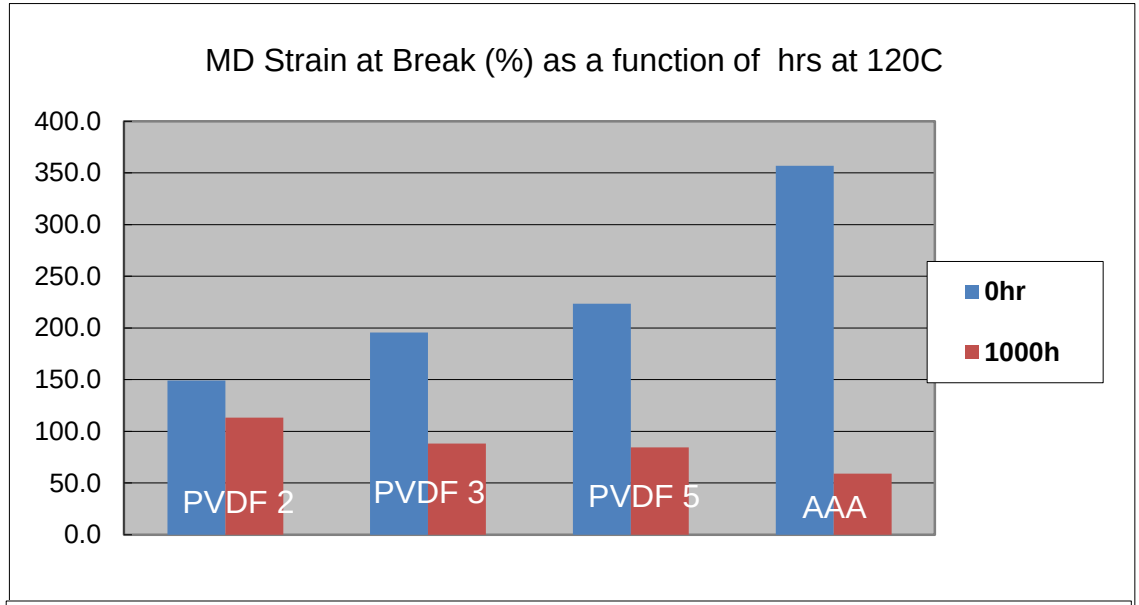
IEC 61730 AMD1

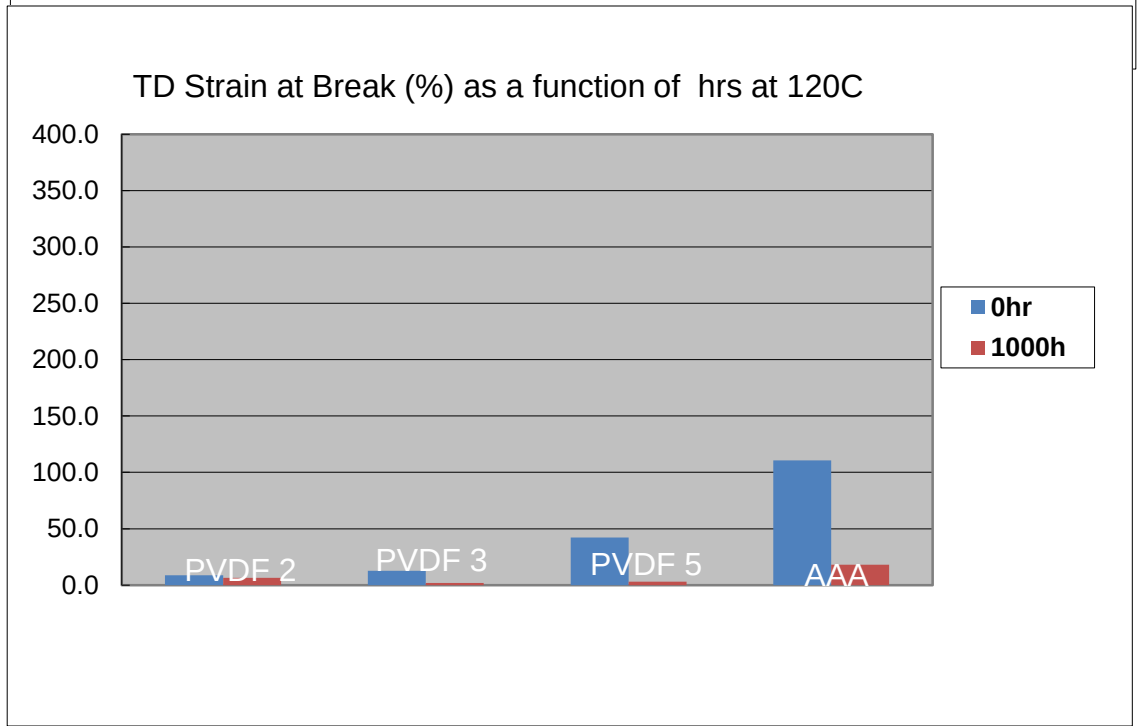
- Will include requirements for component pre-qualifications:
  - **IEC 62788-2-1 *Safety Requirements for Frontsheets and backsheets***
  - IEC 62790 *Junction Boxes for PV modules*
  - IEC 62852 *Connectors for DC-application in PV systems*
  - IEC 62930 *Electric cables for PV systems*).

DUPONT™



No significant change in tensile strength after oven aging

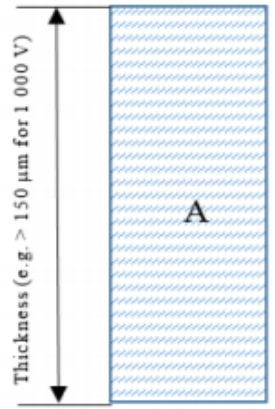
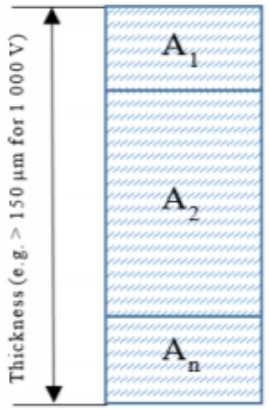


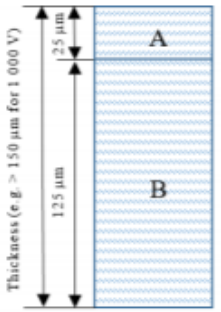
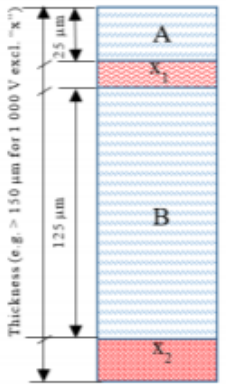
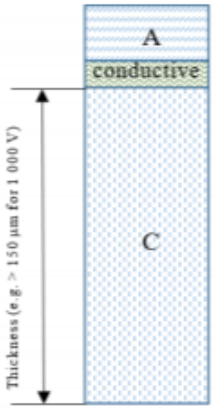


Alignment pre-CD 62788-2-1 with 61730-1 & -2

- **Update figure with layer stack schematics from 61730-1 AM1**

Backsheet constructions and Relied-Upon Insulation (RUI)

a) Singe-layer	
a1) Single monolithic layer	a2) Single combined layer
	
Pass, if layer A fulfils the requirements of 5.3.2 a) for single layer reinforced insulation and distance through insulation.	Pass, if co-extruded combined single layer $A_1A_2...A_n$ fulfils the requirements of 5.3.2 a) for reinforced insulation and distance through insulation.

b) Multi-layer		
b1) Multi-layer without auxiliary layers	b2) Multi-layer with non-RUI polymeric layers "x"	b3) Multi-layer with conductive layer
		
Pass, if each layer A and B fulfil the requirements of 5.3.2 b) for basic insulation and the combined multilayer fulfils the requirements of 5.3.2 b) for reinforced insulation and distance through insulation.	Pass, if each layer A and B fulfil the requirements of 5.3.2 b) for basic insulation and the combined multilayer fulfils the requirements of 5.3.2 b) for reinforced insulation and distance through insulation excluding the "x" layer(s).	Pass, if layer C fulfils the requirements of any of a1), a2), b1) or b2), excluding the conductive layers and excluding all layers above conductive layer in direction of air-side.

AGFA

IEC 62788-2-1 Safety Requirements, Frontsheets and Backsheets

Test Matrix

No.	Test name	Clause	final product (unexposed)	1000 h DH test clause 5.9.2 FBST 08	2000 h UV test clause 5.9.3 FBST 09
FBST 01	Visual inspection	5.2	YES (r, s)	YES	YES
FBST 02	Dimensions and tolerances [µm]	5.3	YES (r, s)	–	–
FBST 03	Distance through insulation [µm]	5.4	YES	–	–
FBST 04	TI or RTE (RTI) [°C] and thermal failsafe test (Elongation at break)	5.5	YES*	–	–
FBST 05	CTI test	5.6	YES	–	–
FBST 06	DC breakdown voltage	5.7	YES (s)	YES	YES
FBST 07	Tensile strength [MPa]	5.8	YES (s)	YES	YES
FBST 07	Elongation at break [%]	5.8	YES (s)	YES	YES

Note:

)* For FBST 04, tests are conducted on single layers, not on final product.

DUPONT™

Core Qualification Standards:

- **IEC 61215 PV modules - Design qualification and type approval**
- **IEC 61730 PV module safety qualification**

IEC 61730 AMD1

- Will include requirements for component pre-qualifications:
  - **IEC 62788-2-1 *Safety Requirements for Frontsheets and backsheets***
  - IEC 62790 *Junction Boxes for PV modules*
  - IEC 62852 *Connectors for DC-application in PV systems*
  - IEC 62930 *Electric cables for PV systems*).

Beyond qualification

- **IEC 63126:** Testing for High T applications
- **IEC 63209:** Extended testing of PV module for risk analysis
  - Part 1: Modules
  - Part 2: Durability characterization of polymeric component materials and packaging sets

DUPONT™

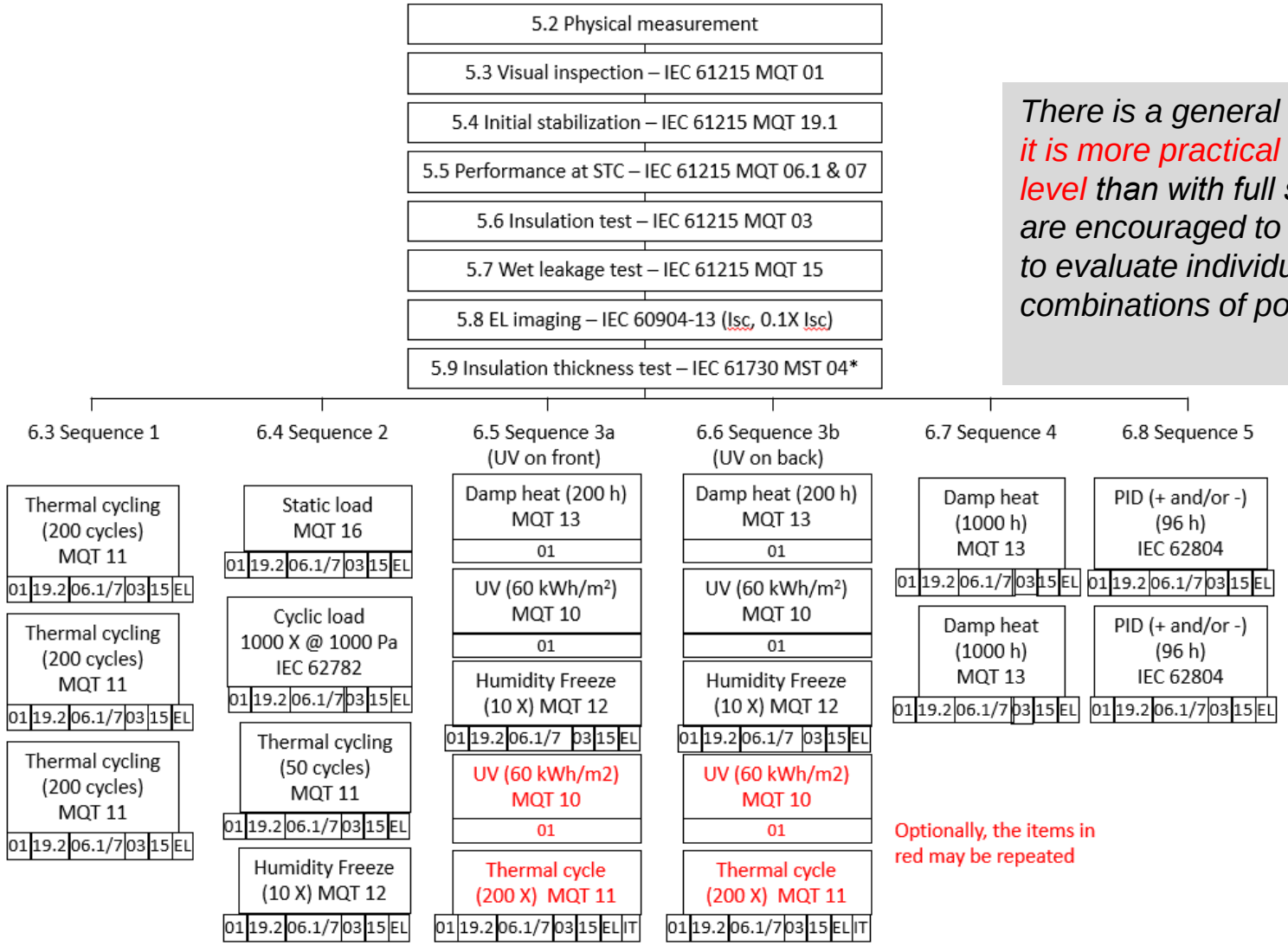
IEC 63126: Testing for High T Applications

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	(75 ± 2) °C	+15 °C, (90 ± 2) °C	+25 °C, (100 ± 2) °C
		Part 1	I_{SC}	1.15 * I_{SC} for diode T	1.15 * I_{SC} for diode T
		Part 2	1.25 * I_{SC}	1.4 * I_{SC} for stress	1.4 * I_{SC} for stress
IEC 61730		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)	4.10.3	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		Marking, Upper Limit Temperature (ULT)	no requirement	95 °C	105 °C
IEC 62790		Range of temperature (upper ambient temperature)	no requirement	95 °C	105 °C

* - Following publication of IEC 62788-2-1, this standard will take the place of IEC TS 62788-2 and the test reference will be FBST 09. Pass/fail requirement from IEC 62788-2-1 shall be followed.

DUPONT™

63209 Extended testing of PV module for risk analysis
Part 1 – Modules



There is a general consensus that for extended UV exposures, it is more practical to test at the component or mini-module level than with full size modules…Users of extended test data are encouraged to use extended coupon or mini-module tests to evaluate individual polymer components, and specific combinations of polymeric components

DUPONT™

IEC 63209 Part 2:
Durability characterization of polymeric component materials and packaging sets

Data for risk analysis some combination of test data from:

A.Component specific testing

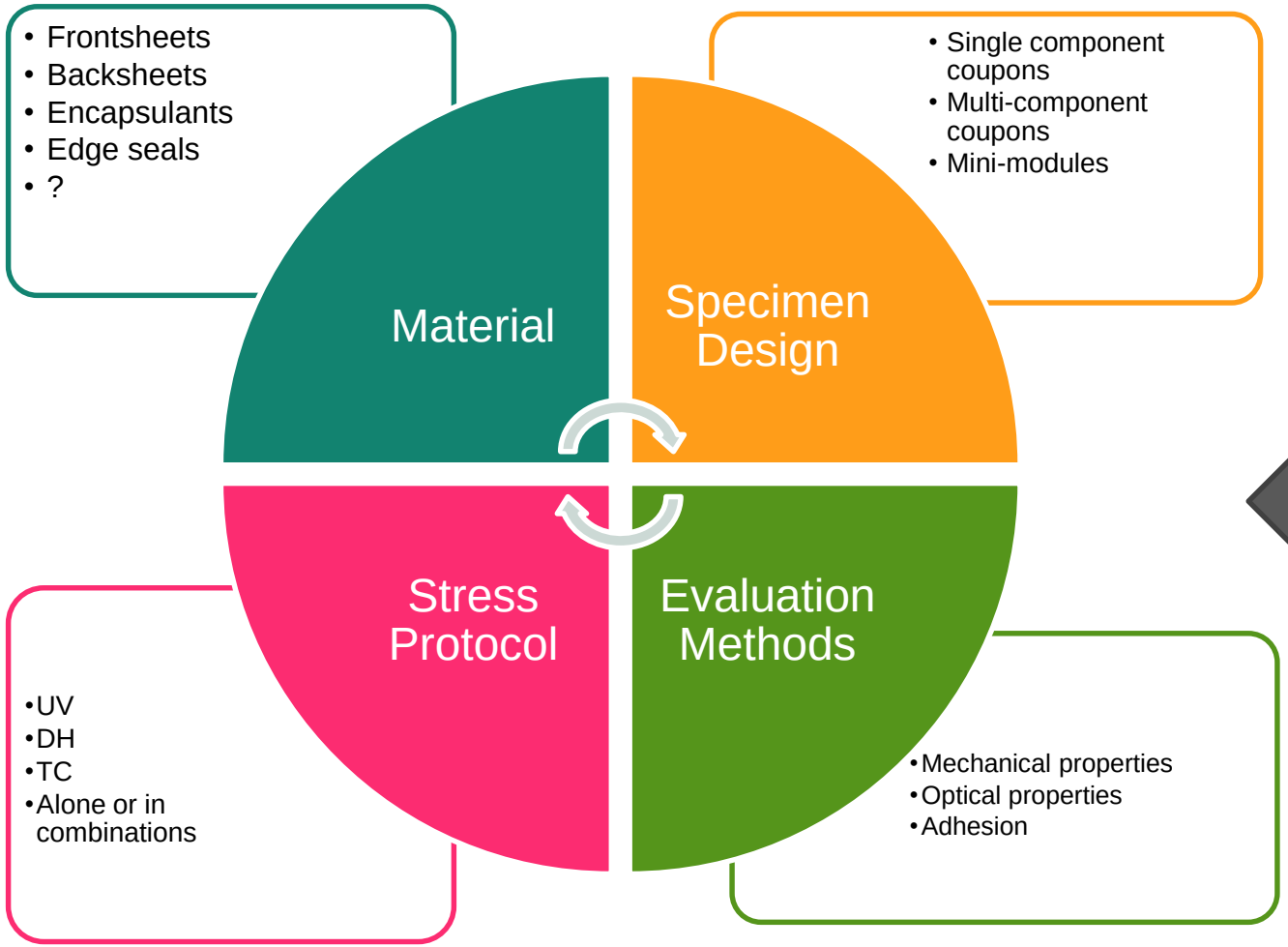
B.BOM specific coupon testing

C.Minimodule AND/OR “structured coupon” testing

- **All possible tests for all different specimens is too much!**
- Need to determine a set which allows for good analysis

DUPONT™

Considerations



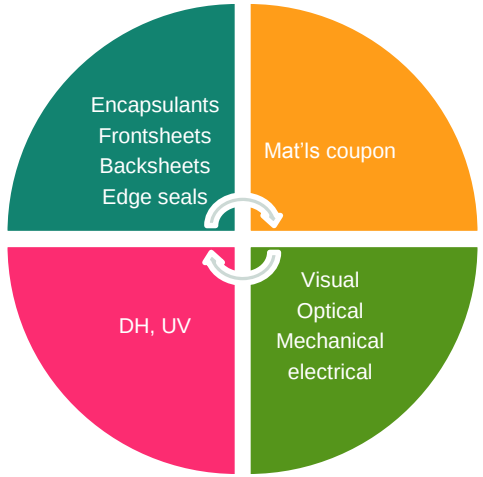
Related to observed field degradation

I. Component level testing

- Utilizes test methods established in 62788 series (and Jbox,Connectors and Cables standards)
- Evaluation tests and specimen designs described in standards
- UV Stress exposures from 62788-7-2
  - Longer exposures to be included

	polymeric frontsheet/backsheet			encapsulant	
stress:	DH	UV front (A3)	UV back (A3)	DH	UV
duration	1000 h	2000 h, 4000 h Optional: additional increments of 4000 h, up to 16000 h	2000 h, 4000 h	1000 h	4000 h Optional: additional increments of 4000 h, up to 16000 h
targeted failure modes	- changes to key materials properties (potential early indicators); - maintenance of key properties above minimum values				
tests:	- color - tensile - Vdc BDV (opt) - adhesion within the BS/FS			- transmission - adhesion to glass	

Test duration - Place holder for discussions



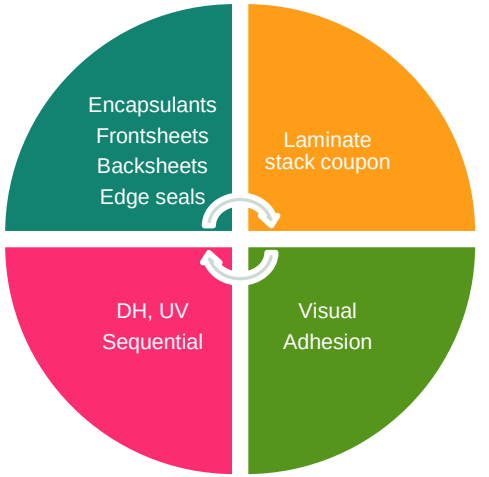
II – Polymeric packaging materials (specific BOM)

	materials stack coupon				
stress:	DH	UV front (A3)	UV back (A3)	**Frontside Sequential**	**Backside Sequential**
duration	1000 h	2000 h, 4000 h Optional: additional increments of 4000 h, up to 16000 h	2000 h 4000 h	Sequential Testing (TBD) w/ long UV exposure)	Sequential Testing, including UV, DH, TC - suggest MAST = DH/UV/TC/UV/TC/UV
targeted failure modes	- loss of adhesion - changes in key material properties				
tests:	- visual (color, delam) - adhesion - glass to encapsulant - encapsulant to backsheet - other?				

Adding combination stress exposures

Place holder for discussions:

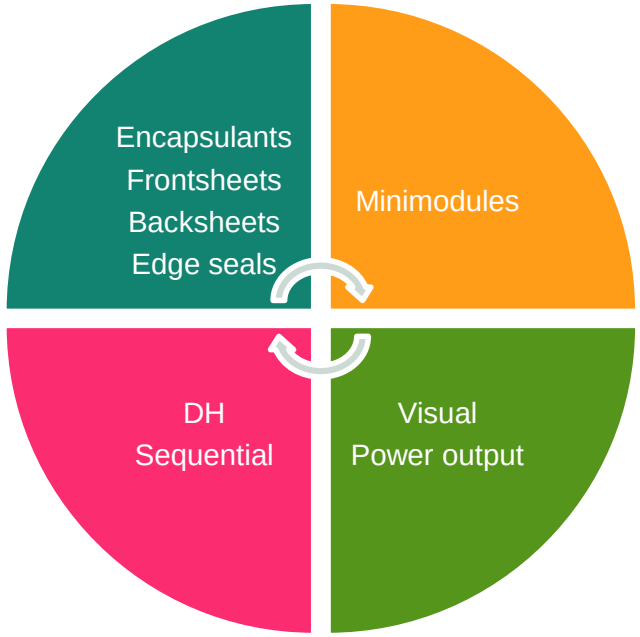
- Exposure duration
- Sequential testing -



III – Minimodules (specific BOM)

	Materials stack w/ cells/wiring		
stress:	DH	**Frontside Sequential Testing**	**Backside Sequential Testing, including UV, DH, TC -** suggest MAST
duration	1000h	TBD, include long UV exposure	DH 1000 UV1000 3 x (TC200 + UV1000)
targeted failure modes	delamination backsheet cracks		
tests:	visual (color, cracks, delamination bubbles…) power output ?		

Adding stresses:
- 3D structure
- Voltage



Anticipated: multi-step approach

- Multiple components, multiple module designs can be considered – not all at once
  - *Expect this may take multiple Parts*
- Path forward:
  1. Review of 62788 Series, Jbox, Connector and Cable standards
     - Consolidate exposures and testing into one document for “Risk Analysis” with 63209-1 data
     - Consider extended sequences
     - Consider new sequences *(if easily agreed)*
  2. Project Team to identify biggest gaps, and focus efforts; options:
     - Combined stress sequences
     - Adhesion testing
     - BOM-specific testing
     - Consider extended sequences
  3. Parallel test plans to help identify useful combinations of testing

DUPONT™

Test Plan Sets

		Solder Bump Coupon A3 exposures + TC		Flat Coupon A3 exposures			63209 front-side seq	63209 back side seq
	specimen	FS coupon+	BS coupon+	FS laminate	FS trm	BS film	1-cell m-mod	full size modules
	mat'l orientation	MD and TD		TD only			MD (aligned to ribbon dir.)	
	Post-stress test	visual	visual	visual	visual tensile	visual tensile	visual	visual
BS	prior observations							
PET1	front side cracking reduction of %E	x	x	x	x	x	x	z
PET2	yellowing, fs cracking	x	x	x	x	x	x	
PVDF1	back side cracking	x	x		x	x		
PVDF2	back side cracking	x	x		x	x		x
PVDF3	unknown	x	x		x	x		
TPT	known good	x	x	x	x	x	x	
TPE	known good							x
AAA	fs and bs cracking	x	x	x	x	x	x	x
FEVE	front side cracking	x					x	

DUPONT™