PV Component Weathering in IEC Standards – Development and Progress

NANCY PHILLIPS

3M RENEWABLE ENERGY DIVISION

Topics

- Background
- Relevant IEC standards
- 62788-7-2
  - Weathering Test design factors
  - Overview of the standard
  - Development of the specified exposures (a hindsight review)
- Referencing Standards
- Considerations for pass/fail criteria

Why is a standard for PV component weathering important?

- The industry has *over*-relied on damp heat, PCT, and *under*-relied on weathering exposures
- Both frontside and backside solar exposure can degrade materials
- No meaningful weathering requirements for polymeric materials
  - No mechanism to screen "known-bad materials"
- Weathering is more than a UV dose
  - Highly accelerated exposures often cause failure mechanisms not observed in the field→ False negatives AND False positives can result

What's needed: a rationally balanced set of stress exposures

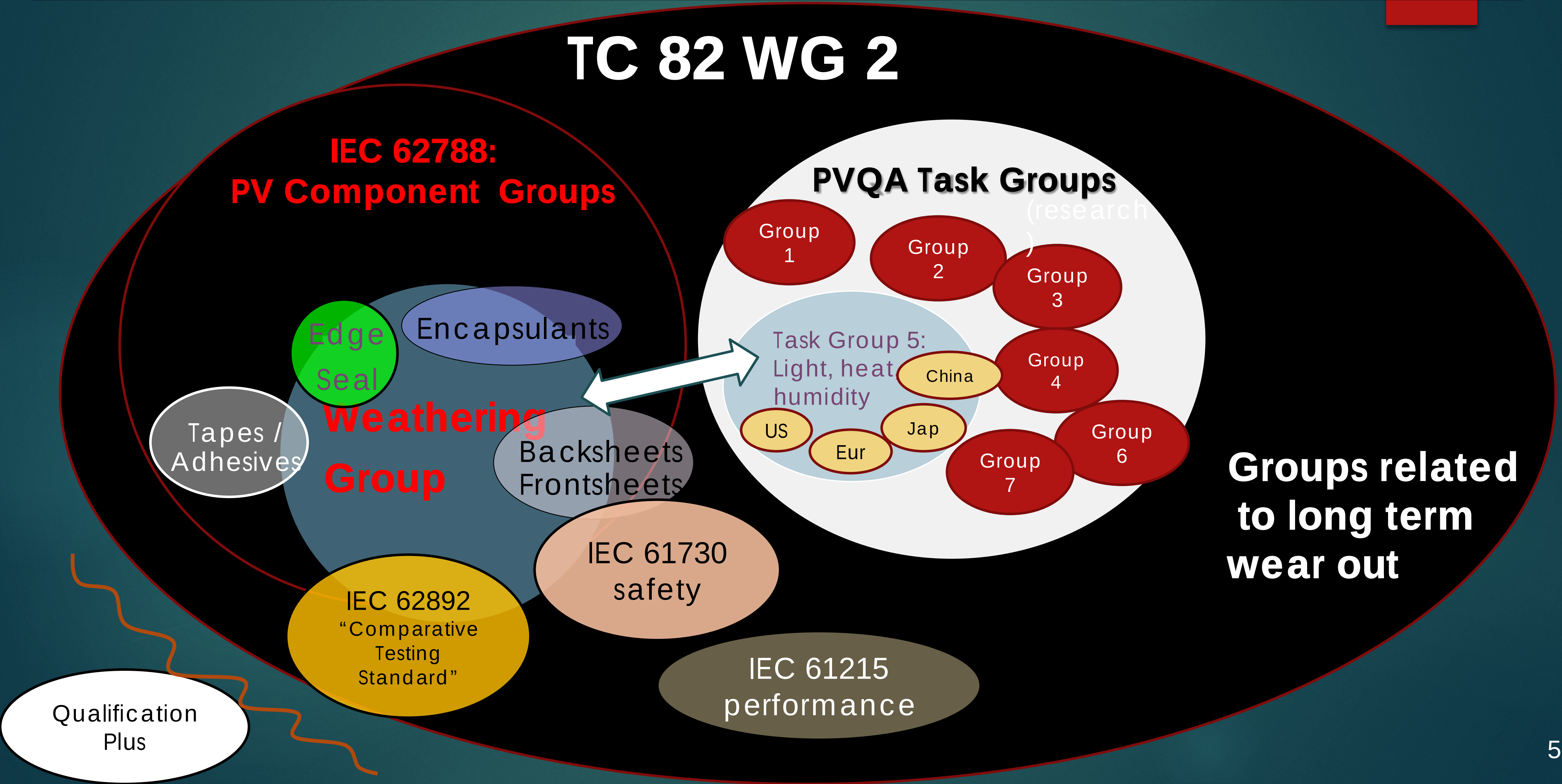
- Module v. component level testing: Lengthy exposure of modules is impractical

Odds of long term module reliability are improved with use of durable component polymeric packaging materials

Component Weathering Group - Activities

- General
  - Discussions of how to evaluate, characterize, and qualify weatherability of PV polymeric component materials
- Specific
  - Prepare 62788-7-2 CD, Weathering Tests for PV Components
  - Provide recommendations to referencing standards
- Not:
  - Service life discussions
    - Mechanisms of degradation
    - Activation energies

PVQAT Task Groups and related IEC Standards Projects



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IEC Standards related to Component Weathering

IEC Standard	Contains	Status
62788-7-2: Component Weathering (TS)	Sets of exposures & specimen configurations	circulating CD
62788-2: Frontsheet/Backsheet (TS)	Set of test methods, call-out of 62788-7-2 exposures and specimens	circulating CD
62892-3: Climate Specific Testing: Encapsulant Durability (TS)		NWIP in progress
62788-5-2: Edge Seal Durability (TS)		NWIP in progress
61730-1 ed 2: Module Safety Am 1: Backsheet/Frontsheet Weatherability	Reference to 62788-7-2 and 62788-2; Pass/Fail requirements	NWIP circulating in WG2.

- Intention is to have exposures in 62788-7-2 for reference by other standards
- Initial focus has been primarily on backsheets
- 62788-7-2 is evolving as other components are considered.

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Factors to consider in a "weathering test"

Practical: device capabilities

- Specimen size
- Temperature range
- Temperature cycling, water spray
- Etc

Test Method Design

- Exposure conditions:
  - Light source
  - Irradiance level
  - Chamber T and Black Panel T
  - Relative humidity
  - Duration of exposure (dosage)
  - Thermal cycling / water spray/ etc.
- Design of weathering specimen
- Post weathering evaluation method
- Pass/Fail criteria

Weathering Tests: Options and Issues *(February, 2015)*

Both front and back side exposures

Sample Preparation, optional, selected from:

- Film (Backsheet only)
- Package (will depend on evaluation tests)
  A. G/E/E/trm/BS
  B. G/E/E/BS

Light source/Exposure Settings (Irr/ChT/RH)

- Xenon: 0.8 W/m2/nm @ 340, 80C, 20%
- UVA: 0.8 W/m2/nm@ 340, 80C, (uncontrolled)
- Other?

Exposure time (hours) – options:

- Front/Back side
  - 4000/4000, 4000/2000, or 2000/2000

Evaluation test, Pass/Fail Criteria

- Visual (Qualitative): no visible yellowing or cracking
- Dielectric (key property): Minimum, or >XX% retention
- Mechanical (delta test): Minimum (20%), or >50% retention)

Issues:

Light Source

- Xe preferred by some as only choice
- UVA desired by some as equivalent to Xe
- Others in use: UVB, Metal Halide

Exposure setting

Need to establish practicality of 0.8/80/20%

Exposure time:

- Time to certification: 2000 hours too long?
- Time to ensure safe product: 4000 hours too low?
- Practicality for Industry
  - Prequalification of components, prior to certification of modules
  - acceptance of 3rd party testing

Evaluation tests:

- Dielectric test not established; post weathering evaluations less established; minimum value or % retention not established
- % Elongation – minimum value or % retention?

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IEC 62788-7-2 Component Weathering Exposures

- CD is in circulation, response period closes December 11
- This draft addresses a number of weathering objectives:

A. End goals:
   - *Safety specification*
     - High margin for safety, limited time for exposure
   - *Spec sheet*
     - Want results from comparable exposures; longer times possible
   - *Product development*
     - Studies on degradation rate, degradation mode

B. Differentiated stress level for different service environments

Mounting Configuration	Backside irradiance level	Frontside irradiance level	Module Temp
Rack Mount	high	high	low
Roof Mount	low	high	high

Weathering Setpoints in 62788-7-2 *(current)*

Ref.	Intended for	Exposure Side	ChT (°C)	BPT (°C)	Irr	% RH	Duration (hours)
A1 (Xe) (Rack)	All components	Front	~~70~~ 65	~~95~~ 90	0.8	20	1000, 2000, 3000, or 4000
	Backsheets (additional)	Back					
A2 (Xe) Roof	All components	Front	80	105			
B1 (UVA) Rack	All components	Front	ns	65	.8	ns	1000, 2000, 3000, or 4000
	Backsheets (additional)	Back					
B2 (UVA) Roof	All components	Front	ns	75	.8	ns	

These have shifted since the CD was submitted, and will continue to evolve as the issues are sorted out

Types of Weathering Specimens in 62788-7-2

Coupon designation	description	Laminated stack	include in report: ID of test material, lamination conditions, plus:
A	backsheet or frontsheet	film	
B	backsheet with representative filter #1	G/E/E/(trm)BS	generic description of stack, transparent release material, UV cut-off of encapsulant
C	backsheet with representative filter #2	Filter/backsheet	generic description of stack, UV cut-off of filter
D	Component material test coupon #1	G/E/E/BS	A) for a backsheet test: generic description of stack, type of encapsulant, UV cut-off of encapsulant B) for a matched component test (backsheet/encapsulant): anything other than the product ids?
E	Component material test coupon #2	FS/E/E/(rigid substrate)	A) for a frontsheet test: generic description of stack, type of encapsulant B) for a matched component test rontsheet/encapsulant) anything other than the product ids?
F	Component material test coupon #3	FS/E/E/(flexible substrate)	A) for a frontsheet test: generic description of stack, type of encapsulant B) for a matched component test (frontsheet/encapsulant) anything other than the product ids?
G	encapsulant / glass sandwich #1	G/E/G	generic description of stack, type of glass
H	encapsulant glass sandwich #2	G/E1/E2/G	generic description of stack, type of glass
I	J-Box adhesive coupon	G/E/E/BS/JBA/RS (t block)	

Informative: Post-weathering evaluation tests

		Evaluation Test		Weathering Exposure Recommendations		
Property	mat'l(s) to be evaluated	evaluation test	dimensions for evaluation test	weathering stack (from Table A)		post weathering prep (trim 0.5 cm from edges)
				type	description	
DC insulation strength	BS, FS	Vdc (oil)	*2 cm x 2 cm*	A or B	backsheet	cut to size
Visual (cracks, yellowing) - air side	BS, FS	MST-01	*2 cm x 2 cm*	A, B, C, D, E, F	none	na
Visual (cracks, yellowing) - cell side	BS	MST-01	*2 cm x 2 cm*	A, B,C	backsheet alone, or exposed with a separable filter	na
Mechanical strength	BS, FS	% elongation	*1 cm x 10 cm*	A, B	backsheet alone, or exposed with a separable filter	4 x 1 cm cut from a 5 cm wide strip, with 0.5 cm trimmed off edges
Backsheet or Frontsheet cohesive strength (intra layer adhesion)	BS, FS	180° peel test #1 (flex) (current test in 62788-2	*1 cm x 10 cm*	A	backsheet alone, or exposed with a separable filter	4 x 1cm cut from a 5 cm wide strip, with 0.5 cm trimmed off edges
Backsheet or Frontsheet cohesive strength (intra layer adhesion)	BS, FS	180° peel test #2 - (rigid) (possible additional test in 62788-2, using a G/E/E/BS coupoon for rigid backing)	*1 cm x 10 cm*	D,E	G/E/E/B coupon	(cut through to glass 4 x 1 cm strips,with 0.5 cm trimmed off edges)
Backsheet or Frontsheet cohesive strength (intra layer adhesion)	BS, FS	pluck test	*1 cm x 2.5 cm*	D,E	G/E/E/B or F/E/E/RS coupon	(cut 2 cm x 3 cm rectangle through films to glass; cement t-block to film.
Backsheet cohesive strength (intra layer adhesion)	BS, FS	shear test	*2.5 cm x 2.5 cm*	D,E	G/E/E/B or F/E/E/RS coupon	cut 2.5 cm x 2.5 cm square through films to glass; cement adherand to film
Backsheet / encapsulant adhesion	E and (BS or FS)	pluck test	*1 cm x 2.5 cm*	D,E	G/E/E/B or F/E/E/RS coupon	(cut 2 cm x 3 cm rectangle through films to glass; cement t-block to film.
Backsheet /encapsulant adhesion	E and (BS or FS)	shear test	*2.5 cm x 2.5 cm*	D,E	G/E/E/B or F/E/E/RS coupon	cut 2.5 cm x 2.5 cm square through films to glass; cement adherand to film
encapsulant transmission	E	transmission		G/E		
Glass/encapsulant adhesion	E	tbd				

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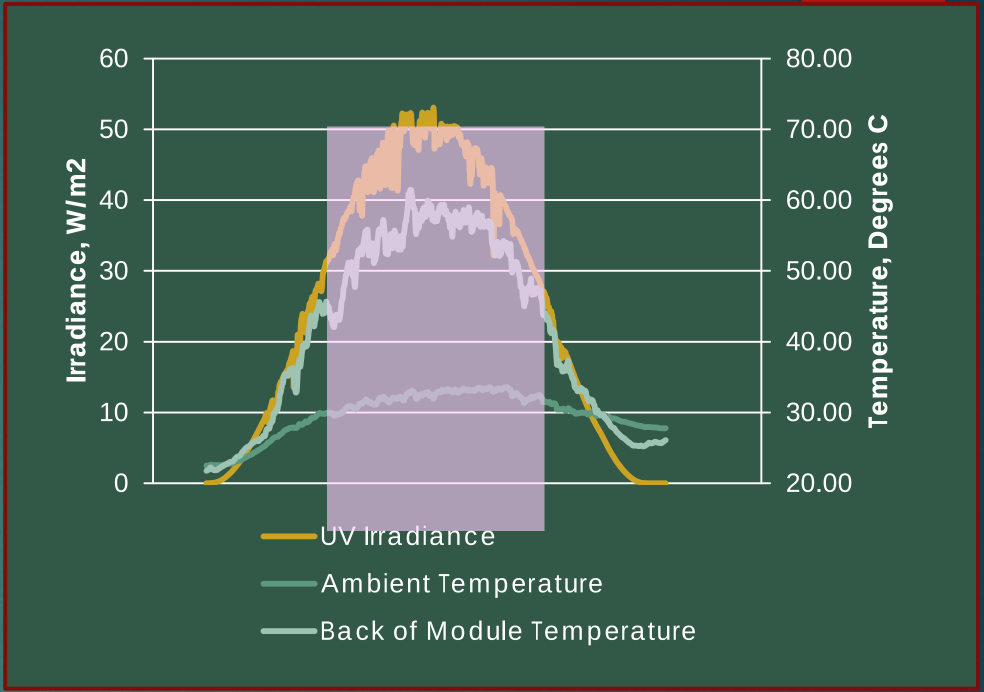
Developing a referencing set of field exposure conditions

Approach:

1. **Recognize irradiance and heat are synergistic.** Most solar irradiance related degradation occurs in the hours around solar noon
2. **Define characteristic conditions for referenced locations**
3. **Characterize module conditions at those locations**
4. **Use as a reference for defining exposure settings**

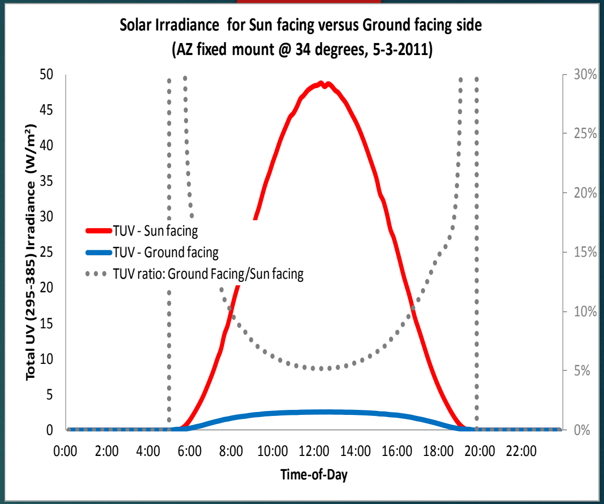


Most degradation will occur around solar noon, when T and UV are highest.

Consider ***time compression v. acceleration***
Setting at 85th percentile establishes a qualitative reference for "time compression" ➔ reasonable expectation of same degradation mechanism

Summary:

Reference In-Service Module Environment Characterizations.



Location	Appl. Type	Typical Max T (°C)		RH	Max Irr (W/m2)	TUV (annual) MJ/m2	
		air	module	(module)	front	front	back
Desert (Phoenix)	Rack	42	55	5.5	1070	347	35
	Roof	40	95	2.2			
Hot/Wet (Miami)	Rack	35	49	20	1000	334	33
	Roof	35	69	8			
Temperate (Sanary, FR)	Rack	27	44	14	1030	226	23
	Rack	27	67	14			

Oh, J., TamizhMani, G., Palomino, E., Proc. SPIE 7773 (2010)

Irradiance: Max Solar Noon

**estimated as 10% frontside*

Air T: 85th percentile daytime temperature (15% of annual daytime hours)

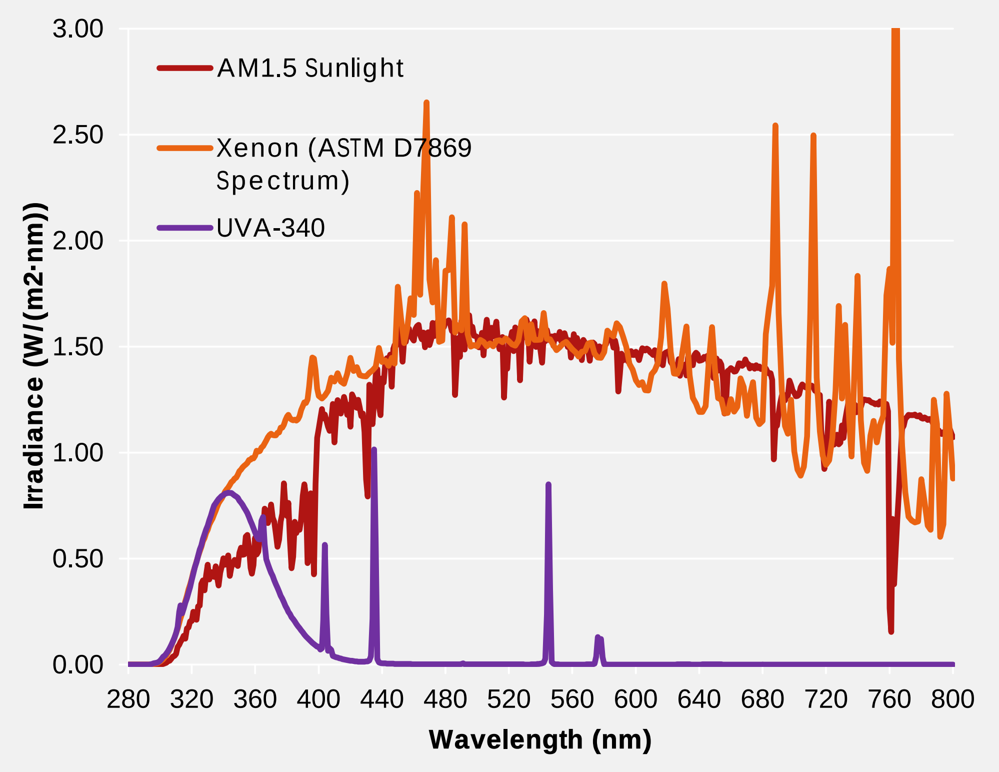
Module T (Rack Mount): 85th percentile black panel temperature

Module T (Roof Mount): Modeled using 85th percentile daytime T

Selection of irradiance setpoints

- Light Source: Xe
  - (as specified in ASTM D7869)
- Irradiance level:
  - Long service life calls for time compression + “acceleration”
  - Maximum exposure time of 6 months targeted
  - Front side irradiance from ASTM D7869
    - uses the highest irradiance in common standards, 0.8 W/m2/nm@340.
    - Slightly higher than max annual solar noon
  - Backside irradiance ➔ same as frontside
    - Target: only one exposure setting for front and back
    - Dosage over 6 months approaches estimated 25 year service life in Arizona

Light Sources: Xe, UVA



Set-point analysis

- Xe: Set point: 0.8 W/m2/nm @ 340
- UVA:
  - Match 340 nm irradiance level
    - Close match for 300-360 nm
- Same exposure times
- Total UV dose will be lower

- Expect different results from Xe for materials with a broader action spectrum
  - TPU encapsulant
  - PET

Table 2. Target UVA Exposures

#	Target Sample T	ChT	BPT	Irr W/m2/nm@340	RH
B1	70	na	65	0.8	na
B2	80	na	75	0.8	na

Exposures using other light sources

- Recognition that other light sources may find use
- For reporting weathering results using an alternative light source, 62788-7-2 specifies a method for characterizing the spectrum
- Reporting to Include
  - Figure: Overlay of Targeted spectrum with referenced solar spectrum
  - Table: comparison of irradiance levels for every 20 nm over 300-400 range

Temperature Setpoints

Recently: debate over Chamber T of 60C v. 70C for A1 exposures (for backsheets)

➔ 65°C

<u>How much acceleration to target?</u>

Reference data:

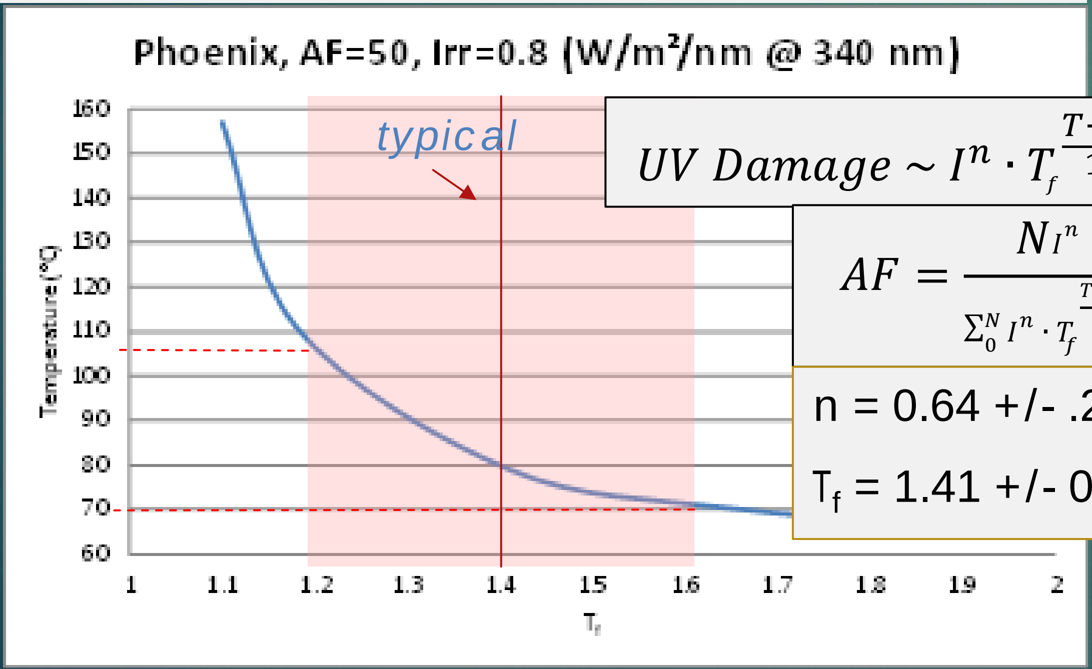
- 85^{th} percentile values for Arizona:
  - Rack: 55C
  - Insulated Roof: 95C
- Calculated setpoint temperature to achieve same backside degradation as 25 years in Arizona (see plot next slide)
  - <u>4000</u> hours exposure at 0.8 W/m2/nm: 70C – 105C
  - For a <u>2000</u> hour exposure time➔ well below service life stress
- PET Tg ~ 75C:
  - Properties may be different above and below Tg
  - Modules may see peak values at that range, but not sustained values

Importance of Temperature

Model: Effect of temperature on degradation rate

From Mike Kempe, NREL, using model from Fischer

Setpoint temperature exposure to achieve same degradation as 25 years in AZ (backside = 10%)



$$UV\ Damage \sim I^n \cdot T_f^{\frac{T-T_o}{10}}$$

$$AF = \frac{N_{I^n}}{\sum_0^N I^n \cdot T_f^{\frac{T-T_o}{10}}}$$

n = 0.64 +/- .2

T_f = 1.41 +/- 0.23

PVQAT Encapsulant Sample

ChT

80°C

60°C

45°C

Light Source: Xe, Daylight Filter
Irradiance: 1 W/m2/nm@340
RH: 30%
Exp. time: ~ 4320 hours

Reality check: PET Data from 70°C exposure

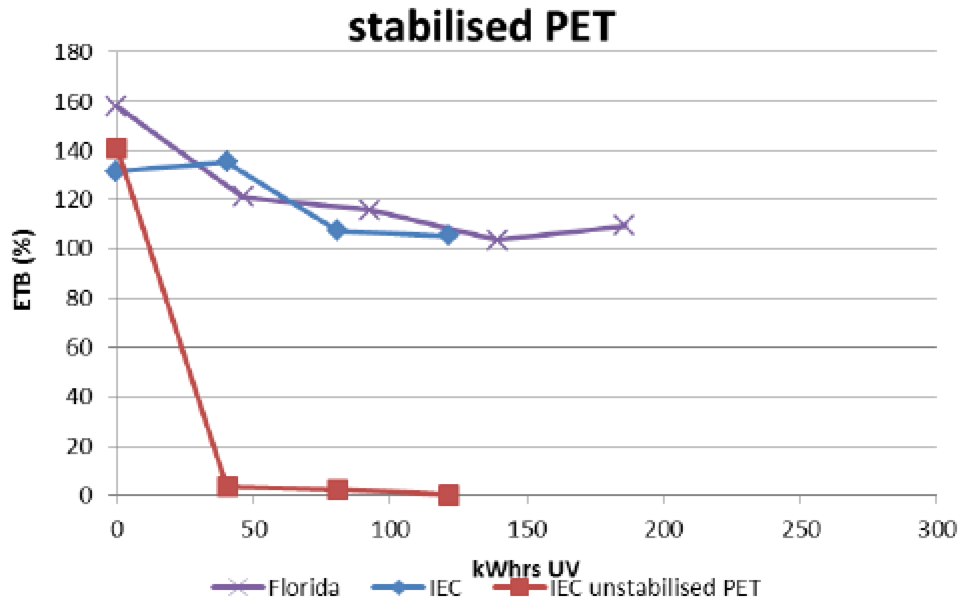
Data from DuPont Teijin (Emily Parnham)

Compares data from Florida w/ proposed A1 exposure (ChT=70C, BPT = 95C, Irr=0.8 W/m2/nm@340):

Shows good differentiation between PET films

Comparison of proposed test with outdoor (Florida) Mechanical

DuPont Teijin Films



- Good correlation of mechanical properties between Florida outdoor weathering and IEC proposed test
- Unstabilised PET film embrittles before 10% retention reached at <500hrs

Correlates to less than 6 years in Spain

3

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NWIP in TC 82 circulation

61730-1 ed 2 am 1
PV Module Safety Standard

IEC 62788-7-2 exposure A1, using Xe as in ASTM D7869

Chamber Air Temperature (°C)	Black Panel Temperature (°C)	Irradiance (W/(m²/·nm @ 340 nm)	RH (%)	Exposure Time (hours)
~~70~~ 65	~~95~~ 90	0.8	20	2000

5.5.1.2.3 Endurance to weathering stress

5.5.1.2.3.1 Weathering specimens

Specimens can be prepared as described in **IEC 62788-7-2 Section 5, types A, E, F, or G**

5.5.1.2.3.2 Laboratory Weathering Exposure

Weathering specimens shall be exposed as described in **IEC 62788-7-2 exposure A1.**

For backsheets separate weathering specimens shall be prepared with one set exposed with the sun-side facing the lamp, the other exposed with the air-side facing the lamp.

5.5.1.2.3.3. Evaluation Tests, Criteria for Qualification

Exposed and unexposed materials will be evaluated using the test procedures in the table, and a pass/fail determiniation made based on the listed criteria

Test Method	End-point Passing Criteria	Reference
Visual Examination	No visual signs of degradation. No cracks, bubbles, delaminations,	MST-01
Mechanical Properties Test Method – to be defined	To be defined	ISO 527-3 **IEC 62788-2** To be defined
DC Breakdown Voltage	> 2 kV + 4 *V(system) AND 50% retention	**IEC 62788-2** IEC 61730-1 ed 2

Other Referencing Standards

- IEC 62788-2, Backsheet Standard
- IEC 62788-5-2, Edge Seal Durability (NWIP)
- IEC 62892 Stress exposures for different application/climate configurations – Part 3: Encapslant Transmittance
- Etc.

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Pass/Fail Considerations:

IEC 61730-1 ed 2 am 1: a work in progress

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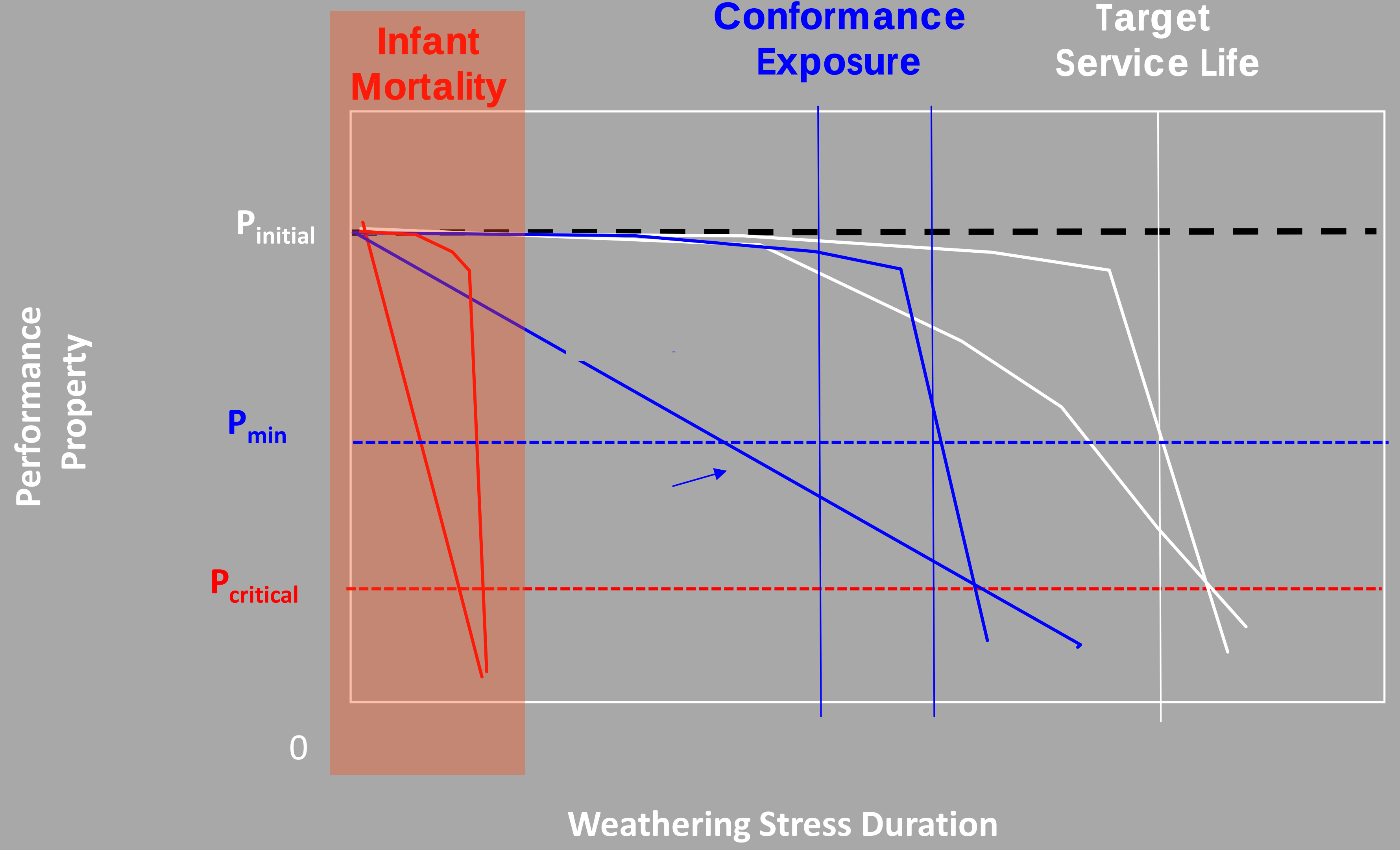
Visual Examination	No visual signs of degradation. No cracks, bubbles, delaminations,	MST-01
Mechanical Properties Test Method – to be defined	To be defined	ISO 527-3 IEC 62788-2 To be defined
DC Breakdown Voltage	> 2 kV + 4 times V(system) AND 50% retention	IEC 62788-2 IEC 61730-1 ed 2

Needs validation



Infant Mortality
Conformance Exposure
Target Service Life
Performance Property
$P_{initial}$
P_{min}
$P_{critical}$
0
Weathering Stress Duration

Stay tuned…

- Remaining issues to address:
  - 61730-1 ed 2 am 1
    - Which test to use for mechanical properties?
      - Tensile.elongation
      - Fracture analysis
      - Mandrel test
    - Establishment of pass/fail criteria
  - How to address colored materials (e.g. black backsheet)
    - With current approach, the sample temperature will be much higher – not true in the field
  - Multiple climate "categories" for a safety standard?
    - How many different module ratings systems to include?
  - Cycling (humidity-freeze-thaw; thermal cycling; water spray…)

IEC Component Weathering Group active participants

Kurt Scott, Atlas

Mike Kempe, NREL

Marina Temchenko, Madico

Sean Fowler, Q-Lab

Takao Amioka, Torey

Tom Earnest, DuPont

Xiaohong Gu, NIST

Greg O'Brien, Arkema

Mark Brandenburg, Feron

John Wohlgemuth

Chris Flueckiger, UL

David Burns, 3M

Emily Parnham, DTF

Juergen Jung, AGFA

Rene Eugen, Isovoltaic

David Miller, NREL

George Kelly

Keito Arihara, DNP

Bill Brennan, DTF

Gerhard Kleiss, SolarWorld

Jim Bratcher, Honeywell

Michael Koehl, Fraunhofer

Peter Seidel, First Solar

Toshiaki Hayashi, Fujifilm

Guido Volberg, TUV Rheinland

Bengt Jaekel, UL

Questions?

Round robin

- EXPERIMENTAL GOALS
- TIMING
- PARTICIPANTS
- MATERIALS TO BE TESTED
- EXPERIMENTAL DETAILS

Emily Parnham, DTF

Experimental Goals

Primary (Round Robin = consistency; multiple locations)

Emily Parnham

- Goals
  - Consistency of exposure
  - Ability to run exposures at higher temperatures
- Current scope
  - Unstabilised PET
  - UV stabilised PET (pigment)
  - UV stabilised PET (UV absorbers)
  - TPT backsheet
- Also look at variability between machines: ensure different devices included

Secondary (single location experiments)

Nancy Phillips

- Goals
- Address technical questions:
  - Comparison of backsheets
  - How different are test results with pre-cut or post-cut samples
  - Comparison of Method A and Method B (light sources)
  - Single layer Tedlar – does it show any changes after exposure?
- Experimental design/coordination:
  - "Local site coordinator" will decide on what materials to run; useful to get input, possibly materials from the group

Further materials for testing – Primary or Secondary?

- *Arkema offered "poor" backsheet*
- *Feron offered backsheet with EVA*

Participants

Site	Weathering device	Contact
3M	Atlas Ci-5000	Nancy Phillips
NREL	Atlas Ci-5000	David Miller
Isovoltaic	Q-Sun	Rene Eugen
DTF	Atlas Ci-5000	Emily Parnham
Dupont		Bill Gambogi
Atlas	2 x devices	Kurt P. Scott
Q-lab		Sean Fowler
Suga		Mr. Shin Watanabe

- 8 participant sites
- 9 devices
- 3 device types

Round Robin Materials

- PETs (3M to provide)
  - Table below shows options (commercial materials)
- Backsheet (known good)
  - 170 micron TPT (37 microns oriented Tedlar) (Isovoltaic to provide)

	Tere-phthalate	EG	DEG	UVA	% Pigment
Clear 25007	68%	31%	0.50%	-	--
UV Clear 25004	68%	30%	2.00%	0.20%	--
White 25010	68%	31%	0.50%	-	10

Experimental Details

EXPERIMENTAL DETAILS		Comments/Questions
Exposure:		
Light source	Xenon with filter per ASTM D7869	
Irr level	0.8 W/m2/nm	
Chamber T/BPT	65C/90C	To be confirmed in next telecon or Cape Town
RH	20%	
Duration (#)	4	250, 500, 1000, 2000 hours Expect that unstablized PETs will fall to pieces by 1500 hours All samples: 250, 500, 1000 Durable samples: additional exposure to 2000 hours.
Post-weathering evaluation testing		
post weathering evaluation testing - non destructive	YI, IR	b*, YI, gloss at DTF
post-weathering evaluation testing - destructive	a) tensile or % elong. b) BDS (from CF)	IR measurements, microscopy at NIST(?) Mechanical testing as defined in 62788-2, primary at DTF. (Test specimen size 10 mm x 12 cm)
Project Management		
Round Robin experiment	Emily	
Secondary experiments	Nancy	individual sites to manage own expts; Nancy will coordinate as needed
Sample delivery	Isovoltaic, 3M	
Status review	Emily	
Data compilation & analysis		
Mechanical properties test team	Emily, Rene,	others doing mechanical properties testing
Round Robin statistics	Emily, Juergen	
IR data	Xiaohong	

Materials:

PETs:
- Unstabilized clear
- White
- Stabilized clear

Backsheets:
- TPT
- "known bad"

Experiments run in parallel:

	Goals	3M	NREL	Isovoltaic	DTF	Dupont	Atlas	Q-lab	Suga	NIST*
1	**Comparison of evaluation test results at multiple locations** tion, color, gloss, (breakdown strength)	x	x	x		x				
2	**Comparison of backsheets (NREL)**		x							
3	**Pre-cut compared to post-cut samples**									
4	**Comparison of** (light sources)									
5	**Single layer Tedlar**?									
6	**Breakdown Strength –**	x								
7	**Strain plus fragmentation analysis**	maybe								x
8	Comparison of 65C and 70C ChT exposure				x					
9	With and without E layer on backsheet									
10										

Selected Experimental Results

1. PVQAT 5 Backsheet data
2. PVQAT TG 5 Encapsulant data

Effect of

- light source
- irradiance set-point
- temperature

1. PVQAT TG 5 Backsheet Experiment (Michael Koehl)

- Variables:
  - Backsheets
  - Light sources
  - Edge-cut filters
  - Temperatures

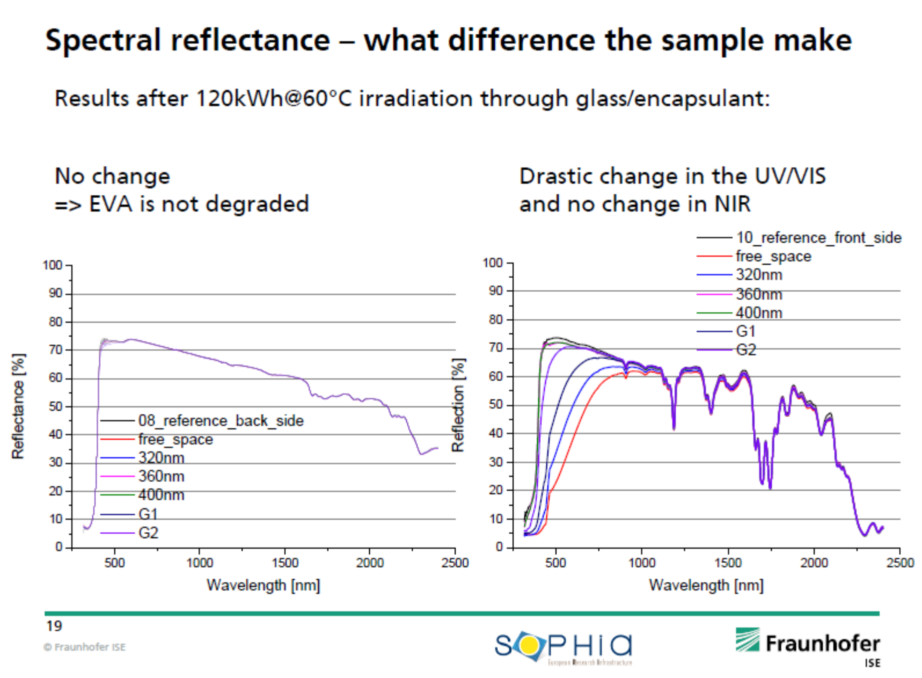
- *Selected slides follow, with comments from discussion at Sophia workshop*

Exclusion of EVA as contributor to degradation response

- The two figures show data for two different materials, showing difference in degradation after exposure.
- Samples were covered with a series of edge-cut filters.

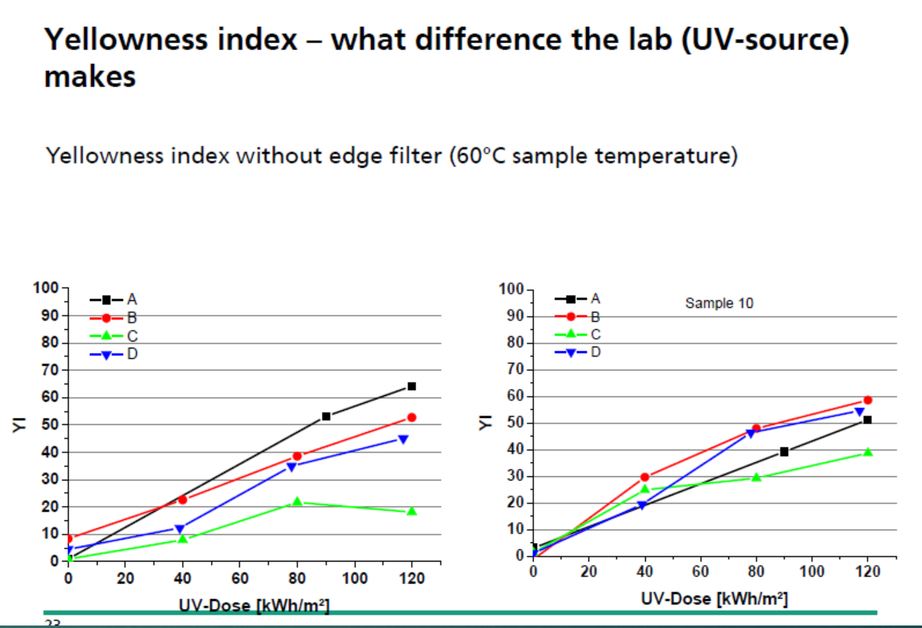
Key points:

- No changes in the first material. Neither the backsheet nor the EVA have changed after exposure
- Second material shows significant degradation from the reference material
- Significant differences between edge cut filter results demonstrates spectral sensitivity of material



Effect of light source on different samples

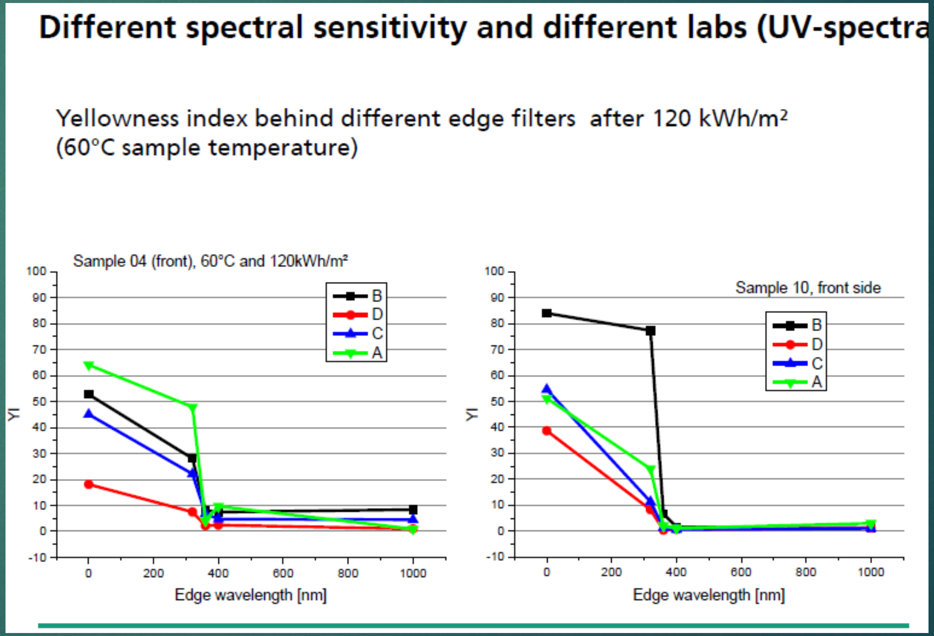
- The two figures show two different materials, no filter, different light sources, as function of exposure time. YI as function of exposure time/UV dose.
- Key points:
  - increasing YI with increasing exposure time
  - Different results observed with different light sources
  - The difference in the "differing results with different light sources" is different with 2 materials.
    - *Changes in rank ordering of materials*



Effect of cut-off filter

Key points:

- Large differences between light sources with 0, 320 nm cut off; smaller differences at 360, virtually no difference at 400.
- “Action spectrum” different for the materials – leads to different behavior with filters



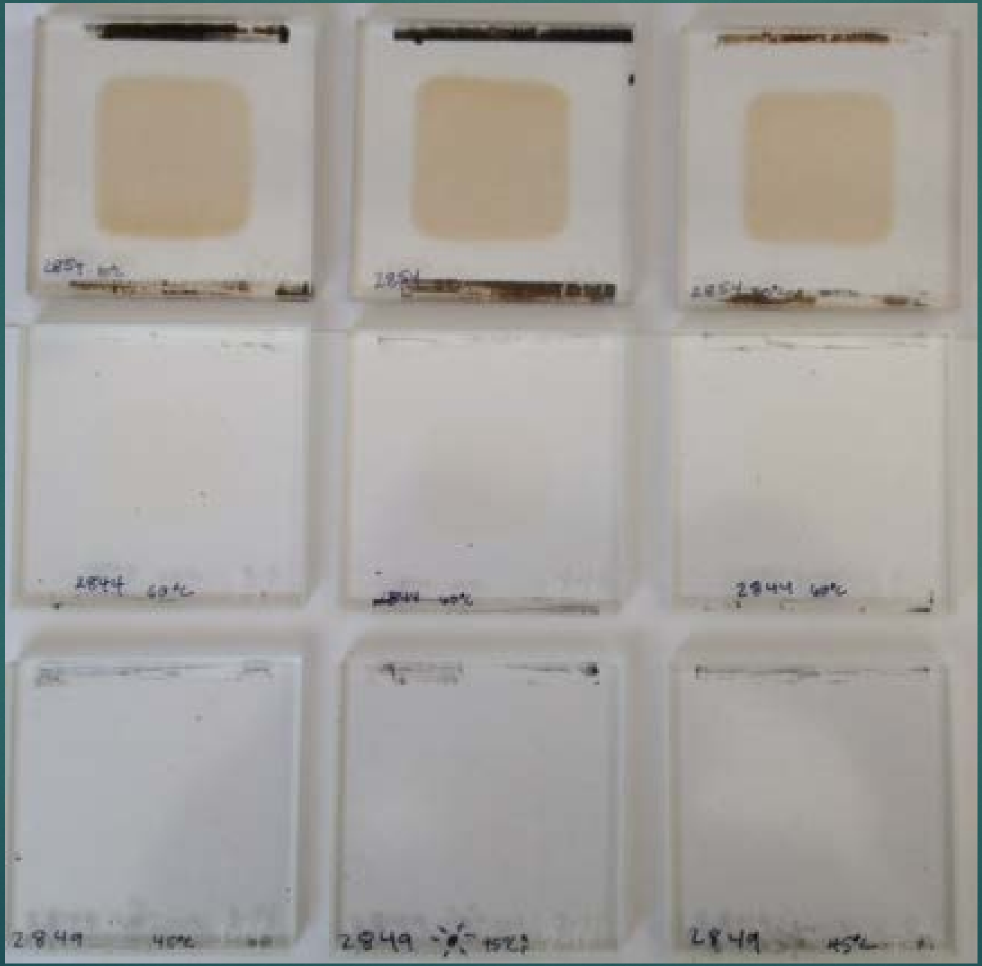
2. PVQAT TG 5 Encapsulant, Effect of temperature

Chamber T

80°C

60°C

45°C



PVQAT Compressive Shear samples
Glass/Encapsulant/Glass

Light Source: Xe, Daylight Filter
Irradiance Setpoint: 1 W/m2/nm@340
RH: 30%
Temperature as shown
Exp. time: ~ 4320 hours
Exp. dosage (295nm-385nm): ~1240 mJ

Conclusions

- Temperature, light source, irradiance levels: Each can have a large effect on weathering degradation
- Data highlights difficulties in comparing results from different light sources
  - **Light sources cannot be considered equal alternates**
- "UV dosage" supplies some context, but is a misleading metric
  - **Use of "UV dosage" as a single exposure metric is inappropriate**
- Service life estimates will require multiple exposures, with multiple data points
- Best case for a generic exposure: typical maximum degradation conditions
  - "Typical maximum" temperatures will be very different, with climate and mounting configuration