Progress in IEC PV Component Weathering Standards
Nancy Phillips

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DuPont Photovoltaic Solutions

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Outline

• Importance of component weathering
• Component testing in IEC standards
• IEC 61730-1 AMD1, Backsheet Weathering Requirement
• IEC 62788-7-2 TS: PV Component weathering
  • Status
  • Best practices
• Component weathering – future focus
Importance of PV component weathering

Degradation of components observed in the field

Observed failures can be screened out with standard component weathering tests

Component weathering allows for
- More samples
- Longer exposures
- More informative tests

Graph: %Elongation at break after A3 exposure

- 0hr
- 1000h
- 2000h
- 4000h

Examples:
- Encapsulant Delamination
  - from cell
  - from glass
- Frontside yellowing, 2 years
- Backsheet Delamination
- Backsheet cracking, 4 years, Italy
- Backsheet yellowing, 4 years
Component Testing in IEC Standards:
IEC 62788 series: Measurement procedures for materials used in photovoltaic modules

**Intended use:**
- Standardized approach to Supplier Data Sheets
- Test methods for research—understanding impact of components on module performance
- Reference by other standards

**Structure:**
- Some individual test methods
- Some compendium of test methods, with “data sheet”

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>TITLE</th>
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<tbody>
<tr>
<td>IEC 62788-1</td>
<td>Encapsulants</td>
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<tr>
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<td>Polymeric materials used for encapsulants - data sheet</td>
<td>Draft</td>
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<td></td>
<td>-1 Volume resistivity</td>
<td>Published</td>
</tr>
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<td></td>
<td>-2 Optical transmittance</td>
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<td></td>
<td>-4 Change in linear dimensions</td>
<td>Published</td>
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<td>-5 EVA degree of cure</td>
<td></td>
</tr>
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<td></td>
<td>-7 Test procedure for the optical durability of</td>
<td>Draft</td>
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<tr>
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<td>transparent polymeric PV packaging materials</td>
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<tr>
<td>IEC 62788-2</td>
<td>Frontsheets and Backsheets</td>
<td>Published</td>
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<tr>
<td>IEC 62788-5</td>
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<td>-1 Edge Seal test methods</td>
<td>Draft</td>
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<td></td>
<td>-2 Edge-seal durability evaluation</td>
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<td>-2 Moisture permeation testing with polymeric films</td>
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<td></td>
<td>-3 Adhesion testing of interfaces within PV modules</td>
<td>Draft</td>
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<tr>
<td>IEC 62788-7</td>
<td>Environmental Stress Tests</td>
<td></td>
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<tr>
<td></td>
<td>-2 UV weathering of PV polymeric components</td>
<td>Published</td>
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</tbody>
</table>

New Work Item: 62788-8-2, Abrasion tests
### IEC 62788-2 TS Table 3 – Uniform characterization form (UCF) for polymeric PV frontsheet or backsheets

<table>
<thead>
<tr>
<th>UCF No.</th>
<th>test name</th>
<th>reference</th>
<th>fresh</th>
<th>1 000 h DH test (4.10.2)</th>
<th>2 000 h UV (Xenon) test (4.10.3) with exposure of</th>
<th>air side a</th>
<th>sun-facing side b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dimensions and tolerances [µm]</td>
<td>4.2.2</td>
<td>✓</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>area weight and tolerances [g/m²]</td>
<td>4.2.3</td>
<td>✓</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>a) tensile strength [MPa] (MD)</td>
<td>4.2.4</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>b) tensile strength [MPa] (TD)</td>
<td>4.2.4</td>
<td>✓</td>
<td>✓</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>4</td>
<td>a) elongation at break [%] (MD)</td>
<td>4.2.4</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>b) elongation at break [%] (TD)</td>
<td>4.2.4</td>
<td>✓</td>
<td>✓</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>5</td>
<td>bond strength between layers of composition – or weakest link [N/mm] (for peelable layers)</td>
<td>4.3.6.2</td>
<td>✓</td>
<td>✓</td>
<td>o</td>
<td>o</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>bond strength between coatings or thin layers and film [rating scale] (for layers too thin or brittle to peel)</td>
<td>4.3.6.2</td>
<td>✓</td>
<td>✓</td>
<td>o</td>
<td>o</td>
<td>–</td>
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<td>7</td>
<td>bond strength between a specific encapsulant and sheet [N/mm]</td>
<td>4.3.6.3</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>–</td>
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<tr>
<td>8</td>
<td>bond strength between a specific junction box adhesive and sheet [N/mm]</td>
<td>4.3.6.4</td>
<td>o</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>9</td>
<td>RTE/RTI/TI [°C]</td>
<td>4.4.1</td>
<td>✓</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>10</td>
<td>dimensional stability in MD &amp; TD [%]</td>
<td>4.4.2</td>
<td>✓</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>11</td>
<td>relative thermal expansion [K⁻¹]</td>
<td>4.4.3</td>
<td>o</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>12</td>
<td>dc breakdown voltage [kV]</td>
<td>4.5.1</td>
<td>✓</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
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<tr>
<td>13</td>
<td>distance through insulation [µm]</td>
<td>4.5.2</td>
<td>✓</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>14</td>
<td>comparative tracking index (CTI)</td>
<td>4.5.3</td>
<td>✓</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>15</td>
<td>visual inspection</td>
<td>4.6.2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>16</td>
<td>solar transmittance (for transmittive sheets only)</td>
<td>4.6.4</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>17</td>
<td>solar reflectance c (for reflective sheets only)</td>
<td>4.6.5</td>
<td>✓</td>
<td>(sun-facing)</td>
<td>–</td>
<td>(sun-facing)</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>(for reflective sheets only)</td>
<td></td>
<td></td>
<td>(sun-facing)</td>
<td>–</td>
<td>(sun-facing)</td>
<td>o</td>
</tr>
<tr>
<td>18</td>
<td>yellowness index DYI c</td>
<td>4.6.6</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>19</td>
<td>CIE L<em>a</em>b* (D65/10°) c</td>
<td>4.6.7</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>20</td>
<td>specular gloss c</td>
<td>4.6.8</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
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<td>21</td>
<td>water vapour transmission rate [g/m²d]</td>
<td>4.7.1</td>
<td>o</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>22</td>
<td>resistance to recommended cleaning solvent</td>
<td>4.8.1</td>
<td>o</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
IEC 62788-7-2 TS: PV component weathering

Status
Published 2017!

Includes:
Menu of weathering exposure conditions
Descriptive options for test specimens
Informational annexes
• Characterizing the conditions of polymeric components in fielded modules
• Development of the test methods in this document and recommendations for use

<table>
<thead>
<tr>
<th>METHOD A: Xenon lamps</th>
<th>Chamber air temperature °C</th>
<th>Black panel temperature °C</th>
<th>Irradiance W/(m²·nm) at 340 nm</th>
<th>Relative humidity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>45</td>
<td>70</td>
<td>0,8</td>
<td>20</td>
</tr>
<tr>
<td>A2</td>
<td>55</td>
<td>80</td>
<td>0,8</td>
<td>20</td>
</tr>
<tr>
<td>A3</td>
<td>65</td>
<td>90</td>
<td>0,8</td>
<td>20</td>
</tr>
<tr>
<td>A4</td>
<td>75</td>
<td>100</td>
<td>0,8</td>
<td>20</td>
</tr>
<tr>
<td>A5</td>
<td>85</td>
<td>110</td>
<td>0,8</td>
<td>20 (nominal)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>METHOD B: Fluorescent UVA-340 lamps</th>
<th>Black panel temperature °C</th>
<th>Chamber temperature °C</th>
<th>Irradiance W/(m²·nm) at 340 nm</th>
<th>Relative Humidity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>55</td>
<td>Not specified</td>
<td>0,8</td>
<td>Typically not controlled</td>
</tr>
<tr>
<td>B2</td>
<td>65</td>
<td></td>
<td>0,8</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>75</td>
<td></td>
<td>0,8</td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td>85</td>
<td></td>
<td>0,8</td>
<td></td>
</tr>
<tr>
<td>B5</td>
<td>95</td>
<td></td>
<td>0,8</td>
<td></td>
</tr>
</tbody>
</table>
Component weathering: alignment with other standards

*Current (published, developing):*
- Other component standards
- Related to module safety – material relied-upon for insulation should be durable
- Related to module performance – material in the light path of the cell should maintain transparency

*In discussion:*
- Qualification of extensions to module design (equivalent BOMs)
- Long term reliability analysis

### Property Evaluation Methods
Refer to Reference 62788-7-2 for exposures

- **62788-7-2 Component Weathering Exposures**
<table>
<thead>
<tr>
<th>Chamber Air T (°C)</th>
<th>Black Panel T (°C)</th>
<th>Irradiance (W/(m²·nm)) @ 340 nm</th>
<th>RH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3</td>
<td>65</td>
<td>90</td>
<td>0,8</td>
</tr>
</tbody>
</table>

- **62788-n**
  Property Evaluation Methods
  Reference 62788-7-2 for exposures

- **61730 AM1 Module Safety (Committee Draft)**
  Frontsheet/Backsheet Weathering Pass/Fail Requirements
  Reference 62788-7-2 (exposures)
  Reference 62788-2 (test methods)

- **61215 PV Module Performance (Future version)**
  Frontsheet/Encapsulant Weathering Pass/Fail Requirements
  Reference 62788-1-7 (durability evaluation)
  Reference 62788-7-2 (exposures)
  Reference 62788-1-4 (test method)

- **63126 PV Modules – High T operation (NP)**
  Stress exposures at higher T
IEC 61730-1 AMD 1, Backsheet weathering requirement

Status: Committee Draft circulating in IEC

Specimen Exposures
- Sun-facing side exposed specimens
  - Visual inspection
- Air-facing side exposed specimens
  - Visual examination
  - % Elongation

Laboratory Weathering
- Exposure conditions
  - Frontsheets and white / clear backsheets: A3 (65C/90C ChT/BPT)
  - Black or coloured backsheets, A2 (55C/90C ChT/BPT)
- Exposure time:
  - 2000 hours
  - additional set: 4000 hours if using the alternate pass/fail criteria.

Ongoing Discussion Topics
Aiming for resolution by April 2018
- Exposure ChT/BPT: (A2 v. A3, or other) → compare to field results
- Exposure consistency
- % Elongation consistency
- Pass/fail criteria: minimum value after 2000 and 4000 hours, currently at 25% (absolute value)
- Specimen geometry for sun-side exposures
- Condition and duration of the optional thermal pre-conditioning step.

Pass/Fail Criteria

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Specimen</th>
<th>End-point Passing Criteria</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Examination (using front and back lighting)</td>
<td>Both sun-facing and air-facing specimens</td>
<td>No visual signs of degradation on sun-facing side or air-facing side when viewed under standard laboratory lighting and backlit lighting. No cracks, bubbles, or delamination</td>
<td>MST-01</td>
</tr>
<tr>
<td>% Elongation</td>
<td>Air-facing specimen</td>
<td>50% retention* after 2000 hours AND 25% minimum value, OR 25% minimum value after 4000 hours</td>
<td>IEC TS 62788-2</td>
</tr>
</tbody>
</table>

*Supplier may request preconditioning of the sample for up to 100 hours at up to 100 °C as requested by supplier (no additional humidity added)
Developing Best Practices for Consistency of Exposures

Research and Round Robin studies
- PVQAT TG 5X, Study #1: Encapsulants
- IEC Component Weathering: Backsheet RR Study
- PVQAT TG 5X, Study #2: Frontsheets/Encapsulants

Backsheet RR Study: Target: A3 exposure consistency
- Experiment:
  - 9 Laboratories, devices from 3 different suppliers
  - 3 PETs with different expected durabilities, 1 BS
  - All samples measured at 1 laboratory
- Results:
  - test method consistency issues – confounds weathering consistency
  - Qualitative: fairly consistent, some outliers observed
- Follow-up analysis:
  - Survey of exposure conditions – weathering participants
  - Temperature survey

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RR Exposure Data
White PET after A3 exposures

Sample: Commercial white PET (WPET)
Exposure: 9 Different Laboratories, IEC 62788-7-2 A3
  - 0.8 W/m²/nm@340 nm,
  - ChT65C, BPT 90C, RH=20%

Evaluation Methods: (all at one laboratory)

**Color (b*) and IR:**
- Lab 8 results a little high, lab 6 a little low

**Elongation:**
- Variability in unweathered samples is high (next slide)
- Needs to be addressed – in progress
- Makes conclusions difficult ➔ Qualitative analysis only
- 1000 H: 2 outliers (7, 8)
- 2000 H: 3 outliers (4,7,8)

**Analysis in progress:**
- Results: reasonably consistent with outliers removed
- Different metrics show different labs as outliers
- Different degradation modes activated by UV and heat; ➔ IR, b* are surface measures, % E is measures bulk
- Measured temperature differences do not correlate with outliers
Test Method consistency
Elongation at break

WPET Data (unweathered)
• Lab A
  • Random samples
• Lab B
  • Cross-web samples

• Test method *can* be done with good repeatability
• Need to define Best Practices
  • Materials sampling, preparation, equipment, method, etc.
Temperature survey

Thermocouples still circulating
- White and Black Backsheets
- Free films and G/E/BS Laminates

- White film
  - Good consistency
  - Most relevant to RR
- Laminate samples
  - Outliers
  - Generally - consistent results between devices
- Outliers within same device set

<table>
<thead>
<tr>
<th>lab</th>
<th>Black BS, Lam</th>
<th>White BS, Lam</th>
<th>Black BS, Film</th>
<th>White BS, Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Atlas Ci4000</td>
<td>85.5</td>
<td>75</td>
<td>86.4</td>
</tr>
<tr>
<td>2</td>
<td>Atlas Ci5000</td>
<td>112.7</td>
<td>84.3</td>
<td>90.9</td>
</tr>
<tr>
<td>3</td>
<td>Atlas Ci5000</td>
<td>112.7</td>
<td>84.3</td>
<td>90.9</td>
</tr>
<tr>
<td>4</td>
<td>Atlas Ci5000</td>
<td>90.3</td>
<td>74.9</td>
<td>91.8</td>
</tr>
<tr>
<td>5</td>
<td>Atlas Ci5000</td>
<td>89.8</td>
<td>79.4</td>
<td>88</td>
</tr>
<tr>
<td>6</td>
<td>Atlas Ci3000</td>
<td>93.1</td>
<td>77.7</td>
<td>92.1</td>
</tr>
<tr>
<td>7A</td>
<td>Q-Lab Q-Sun XE-3</td>
<td>86.5</td>
<td>74.6</td>
<td>90.2</td>
</tr>
<tr>
<td>7B</td>
<td>Q-Lab Q-Sun XE-3</td>
<td>82.1</td>
<td>72.9</td>
<td>85.6</td>
</tr>
<tr>
<td>8</td>
<td>Q-Lab Q-Sun XE-3</td>
<td>90.8</td>
<td>79.2</td>
<td>90.6</td>
</tr>
<tr>
<td>9</td>
<td>Suga SX75</td>
<td>90.8</td>
<td>79.2</td>
<td>90.6</td>
</tr>
</tbody>
</table>

1 standard deviation: 9 4 2 2
Survey of exposure details, BS RR study

Nominally: IEC 62788-7-2, A3

Questions in the following categories:
• Type of chamber
• Specimen fixture and mounting
• UV source
• Temperature Control
• Humidity verification

Differences:
• Fixed v. rotating rack
• Sample back: open, or on rack
• Optical filter (Boro/Boro v. RightLight/Daylight/Quartz)
• Black Panel (Insulated v. non-insulated)

NOTE: some of these are in the specification, but not clearly called out

Need to improve:
• Communicate standard practices
• Add additional “best practices”
## Component weathering - future focus

### PVQAT TG5x potential research topics

### Standardized weathering exposures
- Define typical consistency between devices with A3 condition
- Develop “Best Practices”
- Exposures for High Temperature applications A4 or A5 (?) (IEC 63216)

### Potential new exposures

**Within the weathering device:**
- Addition of water spray, and/or thermal cycling
- Similar to ASTM D7869 (light/dark; water spray, T changes)

**Beyond the weathering device**
- Thermal cycling, damp heat, ...

### Test Methods
- Improved post-weathering evaluation test methods
- Weathering sample form factor
  - Polymeric package (v. component) testing
  - Backsheet specimens

### Practical application/validation
- Comparing field/application/laboratory weathering
- More data on encapsulants, backsheets, and frontsheets
Future directions: applications of component weathering

- **62788-7** (Environmental stress protocols for polymer components)
  - Improved best practices
  - New weathering exposures

- **62788-x** (Component test methods)
  - New test methods for weathered materials

- **IEC 62915-?** Retest guidelines
  - Extension of module design qualification (alternate BOMs)

- **IEC ?**: Data collection from extended stress testing of PV modules for risk analysis

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Preliminary draft, New Proposal (S. Kurtz)

This Technical Specification describes a consistent data collection methodology to identify photovoltaic module strengths and weaknesses by applying stresses and characterizing changes caused by those stresses. For some specific tests, coupons or minimodules may be most appropriate. This Technical Specification describes data collection rather than defining pass-fail criteria for issuance of a certificate. The data are designed for two primary purposes:

- Documentation of results of qualification testing such as those defined in IEC 61215 and IEC 61730 as a basis for evaluating adequate design qualification and type approval of terrestrial photovoltaic (PV) modules suitable for long-term operation in general open-air climates.

- Identifying variability in a module’s response to long-term stress in order to assess the risk associated with variability of manufacturing or design.
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