QA TG5: UV, temperature and humidity

http://pvqataskforceqarating.pbworks.com/ ⇒ goto 5. UV, temperature, and humidity

Wednesday, February 27, 11:00-11:15

Task-Force coordinated by:

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*Presented by David Miller, NREL, David.Miller@nrel.gov
Needs and Approaches

- Service life assessment needs to take UV-degradation seriously into account (up to 3000 kWh/m² in the desert for 25 years)

- Different suitable artificial UV radiation sources are available for ALT with varying spectral distribution of the irradiation

- Different spectral sensitivities of the tested materials have to be expected

- Are comparable tests in different labs possible?

- Can we accelerate tests by increasing UV intensity?

- Can we accelerate tests by increasing the sample temperature?
Present Activities

- Comparison of different light sources
- Test protocols for mini-modules in Japan
- Round Robin testing of encapsulants
- Round Robin testing of light sources and back-sheets
- Modelling the UV – irradiation locally and globally
**Aim:**

Comparison of the effect of different UV-sources on glass/encapsulant/backsheet laminates with different materials

- Spectral distribution of different UV-light sources leads to different degradation on different materials

- Stronger UV testing needs better definition of the test conditions

Spectra of radiation sources used in PV testing
UV – Round Robin Samples

- Samples:
  - manufacturers provide different back-sheet types
  - ISE produces laminates (usual glass and EVA, 13x20 cm) and 300 sample holders (till end of February)
**SOPIXIA**

UV – Round Robin Procedure

- **Time frame:** September 2013
- **Samples:**
  - manufacturers provide different backsheets types
  - ISE produces laminates (usual glass and EVA, 13x20 cm)
  - direct radiation on the back side and on the front glazing
- **Testing procedure:**
  - 2 temperature levels: 60° C, 80° C (e.g.) (Assessment of sample temperatures)
  - Irradiation: integral UV dose: min. 120 kWh/m²
  - Light sources and (spectral distribution) characterised radiometrically (Fluorescence, Metal-halide, Xenon)
  - 3 longpass and 2 neutral density filters provided by ISE
UV – Round Robin Procedure

Characterisation procedures after 0, 30, 60, 120 kWh (when available):

- Spectral hemispherical reflectance (UV-VIS-NIR)
  Calculation of Yellowness Index or adequate degradation indicator
- Raman / Micro-Raman spectroscopy
- FTIR-ATR measurements for BS
  Calculation of carbonyl-index
- Optical microscopy/AFM investigation for microcracks in BS
- Fluorescence for encapsulants

And .....?
UV – Round Robin Participants

- Backsheet manufacturers
  - Krempel
  - Toray
  - Feron
  - Coveme
  - Dupont
  - Toppan printing
  - Dunmore

- Test labs
  - ISE
  - JRC
  - Fiti
  - ITRI
  - KTI
  - NREL
  - Ametek

- Encapsulant: UV transparent EVA
- Small number of TPSE (given adherence to back-sheet required)
- Glass: Interfloat
UV – Round Robin Procedure

**Results**

- Differences of degradation in different labs
- Rough idea about spectral sensitivity of materials
- Proven UV-stability
- Acceleration possibilities by temperature increase
- Base for new materials/modules standard
UV – Round Robin Schedule

- Preparation and Testing
  - Purchasing of components (filters, etc) is finished
  - Back-sheet materials are collected
  - Production of Mini-modules and filter-holders in March 2013
  - Distribution of samples to test labs beginning of April 2013
  - Testing till August 2013 (at least 120 kW/m²)
    - intermediate telecons or meetings at NRELMRW, TC82 WG2 meeting

- Final characterisation of the samples and evaluation of data by Fraunhofer ISE August - September 2013

- Final discussion of the results during PVSEC2013 or fall meeting of TC82 WG2
Objectives:

(1) Develop the procedure for a suitable UV weathering test using mini-modules. Factors during the test: irradiation intensity, temperature, humidity. Experiment will help determine: test duration + characteristics to measure.

(2) A combination test or a sequential test series (if appropriate). UV weathering + Dynamic Mechanical load test. UV weathering + DH Test.

Provisional schedule:
• 4 cell mini-module test 2000 cumulative hours: 2013 June
• Examination of UV weather resistant test of 1 cell module: 2013 October
• Examination of a compound or sequential test: 2013 October
• International proposal for a new comparative UV weathering test system and certification including the test of a full-size module, a mini module, and materials: 2014 May.
UV weathering test of 4-cells small size module

Irradiance ・・・ 90 W/m² (UV 300-400nm)
   Nearly 2x UV (ASTM G173 Xenon Lamp)

Chamber temp. ・・・ 65 °C
Chamber humidity. ・・・ No Control
   (typical 1–10%RH)

Test Modules ・・・ 4-cells, polycrystalline Si
Termination ・・・ Open circuit
Backsheet ・・・ Multilayer laminated PET
Encapsulant ・・・ EVA (all: fast cure)
   EVA A ・・・ Within the shelf life
   EVA B ・・・ Over the shelf life

Sample ID and Test sequence

<table>
<thead>
<tr>
<th>ID</th>
<th>EVA</th>
<th>UV330h 1st RUN</th>
<th>UV660h 2nd RUN</th>
<th>UV990 3rd RUN</th>
<th>UV1320 4th RUN</th>
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<tr>
<td>120410-01</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>120410-02</td>
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<td>Back side</td>
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<tr>
<td>120410-03</td>
<td>A</td>
<td>Front side</td>
<td></td>
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<tr>
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<td></td>
<td>Back side</td>
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<tr>
<td>120710-02</td>
<td>B</td>
<td>Front side</td>
<td></td>
<td>Back side</td>
<td></td>
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<tr>
<td>120710-03</td>
<td>B</td>
<td>Back side</td>
<td>Front side</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X: Thermocouple gage
□: Junction BOX

* The front or back side is irradiated
Irradiation on Front :990h + on Back :324h

<table>
<thead>
<tr>
<th>P_{\text{max}} \text{ decreased}</th>
<th>1.5 to 2% approximately</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Isc Decreased</th>
<th>1.5 to 2% approximately</th>
</tr>
</thead>
</table>

No major performance loss.

I_{\text{sc}} \downarrow \text{ with } P_{\text{max}} \downarrow \text{ is consistent with encapsulation discoloration.}
Slight yellowing of BS was observed. Yellowing of BS differs on a cell vs. off of a cell.

When UV light irradiation was carried out on the front side, after irradiation on back side, yellowing of the backsheet increased significantly.

→ Result: higher temperature on cell?

Test sequence I:
Front side 990h → + Back side 324h

Test sequence II:
Back side 330h → + Front side 984h
Motivation for the $E_a$ Interlaboratory Experiment

• As in Kempe, "Group 3: Understanding the Temperature and Humidity Environment Inside a PV Module", knowing $E_a$ is critical to prescribing and interpreting a <UV and temperature> mediated test.

• Unfortunately, $E_a$ is not known for the common UV PV degradation modes.

$$k = A \left[ \frac{T}{T_0} \right]^n e^{\frac{-E_a}{RT}}$$

Critical unknowns (Goals for the interlaboratory experiment):

1. Quantify $E_a$, so that applied test conditions can be interpreted.

2. Provide a sense of the range of $E_a$ that may be present by examining "known bad", "known good", and "intermediate" material formulations.

3. Determine if there is significant coupling between relevant aging factors, i.e., UV, temperature, and humidity. 

What factors does TG5 need to consider?

4. Investigate the spectral requirements for light sources by comparing $E_a$ for different sources, i.e., Xe-arc, UVA 340. 

Is visible light required in addition to UV light?
Degradation Mechanisms for Crystalline Si PV

Failure/degradation mechanisms from the literature†:

• Corrosion of AR coating on glass (Group 3/Group 5)
• Corrosion of cells (Group 3/Group 5)
• Corrosion of electrical interconnects (Group 3/Group 5)
• Crazing of glass. Crazing/roughening of front surface (Group 3/Group 5)
• Delamination of encapsulation (Group 3/Group 5)
• Diode failure during “hot spots” (Group 4)
• Discoloration of encapsulation (Group 5)
• Embrittlement of back sheet (Group 5)
• Embrittlement of encapsulation (Group 5)
• Embrittlement of junction box material and wire insulation (Group 5)
• Fatigue of solder bonds (Group 2)
• Fatigue of interconnects [open circuits/arcing ] (Group 2)
• Fracture of cells (Group 2)
• Fracture of glass/superstrate (Group 2)
• Ground faults (Group 3/Group 5)
• Junction box and module connection failures (Group 2)
• Soiling of glass/superstrate (TBD)
• Structural failures (TBD)


Literature*, site inspections, and industry feedback suggest these are most common

Study these
Details of the \( E_a \) Test Specimens

- (4) custom EVA formulations, (1) TPU product proposed for study.
- EVA to be extruded at NREL; specimens to be laminated at NREL.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Comment</th>
<th>Mass (g)</th>
<th>Mass (g)</th>
<th>Mass (g)</th>
<th>Mass (g)</th>
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</thead>
<tbody>
<tr>
<td>Elvax PV1400</td>
<td>Dupont EVA resin, 33 wt% VAc</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>Dow Corning Z6030</td>
<td>Silane primer, gamma-methacryloxy propyl trimethoxysilane</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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</tr>
<tr>
<td>Tinuvin 770</td>
<td>Hindered amine light stabilizer (HALS)</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>N/A</td>
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<tr>
<td>Tinuvin 123</td>
<td>Non-basic aminoether-hindered amine light stabilizer (NOR-HALS)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.13</td>
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<tr>
<td>TBEC</td>
<td>Curing agent, OO-Tertbutyl-O-(2-ethyl-hexyl)-peroxycarbonate, 0.133kPa at 20C</td>
<td>N/A</td>
<td>1.5</td>
<td>1.5</td>
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<tr>
<td>Lupersol 101</td>
<td>Curing agent, 2,5-Bis(tert-butylperoxy)-2,5-dimethylhexane</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>Naugard P</td>
<td>Phosphite anti-oxidant (AO)</td>
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<td>Tinuvin 328</td>
<td>Benotriazole UV absorber (UVA)</td>
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<td>N/A</td>
<td>N/A</td>
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<td>Cyasorb 531</td>
<td>Benzophenone UV absorber</td>
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<tr>
<td>Comments</td>
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<td>&quot;Known bad&quot;, &quot;slow cure&quot; &quot;Intermediate&quot;, &quot;fast cure&quot; &quot;Intermediate&quot;, &quot;fast cure&quot; &quot;Known good&quot;</td>
<td></td>
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</table>

- 50x50mm\(^2\) quartz/encapsulation/quartz geometry for transmittance.

- Details of adhesion experiment to be determined.
The $E_a$ Interlaboratory Experiment Enables a Wider Range of Study

- Discoloration & adhesion will be studied in detail at different institutions using the same make & model of instrument (*i.e.*, Ci5000, QUV).
- This overcomes the difficulty of limitedly-available aging equipment.

- A standard condition (70°C in chamber) allows a broad variety of other instruments to also be compared.

<table>
<thead>
<tr>
<th>PARTICIPANT (INSTRUMENT MODEL)</th>
<th>UV LIGHT INTENSITY</th>
<th>LIGHT SOURCE, FILTER</th>
<th>CHAMBER TEMPERATURE (°C)</th>
<th>CHAMBER RELATIVE HUMIDITY (%)</th>
<th>MATCH FOR &quot;VERY LOW&quot; (~7%)</th>
<th>UVA 340 fluorescent (no filter)</th>
<th>UVA 340 fluorescent (no filter)</th>
<th>NO LIGHT field deployment (outdoors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M (Ci5000)</td>
<td>NOMINAL (92 W⋅m⁻² for 300≤λ≤400)</td>
<td>Xe Arc (right-light/cira filter)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
</tr>
<tr>
<td>3M (Ci5000)</td>
<td>NOMINAL (92 W⋅m⁻² for 300≤λ≤400)</td>
<td>UVA 340 fluorescent (no filter)</td>
<td>50 (&quot;high&quot;) 70 90</td>
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<td>3M (Ci5000)</td>
<td>NOMINAL (92 W⋅m⁻² for 300≤λ≤400)</td>
<td>UVA 340 fluorescent (no filter)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
</tr>
<tr>
<td>ATLAS (Ci5000)</td>
<td>NOMINAL (92 W⋅m⁻² for 300≤λ≤400)</td>
<td>UVA 340 fluorescent (no filter)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
</tr>
<tr>
<td>Mitsui (SX120)</td>
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<td>UVA 340 fluorescent (no filter)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
</tr>
<tr>
<td>NREL (Ci5000)</td>
<td>NOMINAL (92 W⋅m⁻² for 300≤λ≤400)</td>
<td>UVA 340 fluorescent (no filter)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
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<td>25 ambient</td>
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<tr>
<td>CWRU (QUV)</td>
<td>NOMINAL (92 W⋅m⁻² for 300≤λ≤400)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
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<td>25 ambient</td>
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<tr>
<td>ATLAS (UV TEST)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
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<td>25 ambient</td>
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<td>QLAB (QUV)</td>
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<td>UVA 340 fluorescent (no filter)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
</tr>
<tr>
<td>Fraunhofer (custom)</td>
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<td>UVA 340 fluorescent (no filter)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
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<td>Fraunhofer (custom)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
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<td>25 ambient</td>
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<tr>
<td>NREL (custom)</td>
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<td>UVA 340 fluorescent (no filter)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
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<tr>
<td>ATLAS (EMMA in Phoenix)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
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<td>25 ambient</td>
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<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
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<tr>
<td>ATLAS (rack in Phoenix)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>~7% (&quot;very low&quot;)</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
</tr>
<tr>
<td>NREL (rack in Golden)</td>
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<td>50 (&quot;high&quot;) 70 90</td>
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<td>50 (&quot;high&quot;) 70 90</td>
<td>25 ambient</td>
</tr>
</tbody>
</table>

| SUMMARY OF PARTICIPATING LABORATORIES AND TEST CONDITIONS |

- Rate of degradation will be compared against field data to allow site specific acceleration factors to be computed.
- Outdoor data should help verify validity of the test.
- Separate experiment at NIST (same EVA’s) will determine action spectrum
Summary of QA TG5 (UV, T, RH)

- Goal: develop UV & temperature facilitated test protocol(s) that may be used to assess materials, components, and modules relative to a 25 year field deployment.

Round-robin (under Sophia project)
- Emphasis on backsheets
- Examination of source (spectral) dependence

Mini-module round-robin (QA Task-5 Japan)
- Examining backsheets and encapsulation
- Apply a combination or series of aging plus dynamic mechanical or DH tests?

_\[E_a\]_ interlaboratory study
- Examining discoloration and delamination of encapsulation
- Quantify coupled and (irradiation) source dependent effects

Upcoming talks in QA TG5 session:
- David Burns and Kurt Scott, “Light Sources for Reproducing the Effects of Sunlight in the Natural Weathering of PV Materials, Components and Modules”
  (light sources, indoor weathering equipment, spectral effects on materials)
- Charlie Reid, Jayesh Bokria, and Joseph Woods, “Accelerated UV Aging and Correlation with Outdoor Exposure of EVA Based PV Encapsulants”
  (results of a field study)
Goal and Activities for QA TG5 (UV, T, RH)

- IEC qualification tests (61215, 61646, 61730-2) presently prescribe up to 137 days equivalent (IEC 60904-3 AM 1.5) UV-B dose
- Goal: develop UV & temperature facilitated test protocol(s) that may be used to assess materials, components, and modules relative to a 25 year field deployment.

Core Activities:
1: (weathering and climates… location dependent information)
   e.g., known benchmark locations… Miami, FL; Phoenix, AZ
2: (standards from other fields of work)
   summary exists from Kurt Scott et. al.
3: (test conditions)
4-1 (collect information about observed failure mechanism)
   e.g., the literature, site inspections
4-2 (find appropriate models for ALT procedures)
5: (suitable UV sources)
   summary exists from David Burns et. al.
6: (proposal for accelerated service testing)
7: (laboratory verification of acceleration of proposed test standard/failure mechanism)
   Japan mini-module study, Sophia round-robin, $E_a$ interlaboratory study