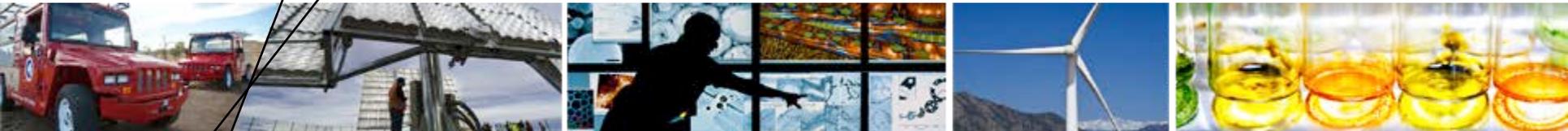


Use of Field Observations to Assess PV Module Reliability



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***3rdAtlas/NIST Workshop on PV
Materials Durability***

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Acknowledgements

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- Acknowledge the work of PVQAT and all those who work on the Task Groups
- Acknowledge the work of WG2 and all those who turn the research into international standards

Outline

- **Introduction**
- **What kind of observations are necessary?**
- **Observations of Degradation and Failures**
 - Pictures of each type
 - Discussion of each type
- **Discussion Topics for the Workshop**

Introduction

What information about modules do we wish to obtain from Field Observations?

- **Projected lifetime**
- **Performance**
 - Over initial period – do modules produce the energy promised?
 - Over long term – what is the degradation rate/curve?
- **Identify Failures**
 - How do modules in the field fail?
 - What are the failure rates?
 - What are the most common/severe failures?
- **Impact of Climate and Installation**
 - How do the degradation rates and failure rates depend on where and how the module is deployed?

What kind of observations are necessary?

- **For Performance short term**

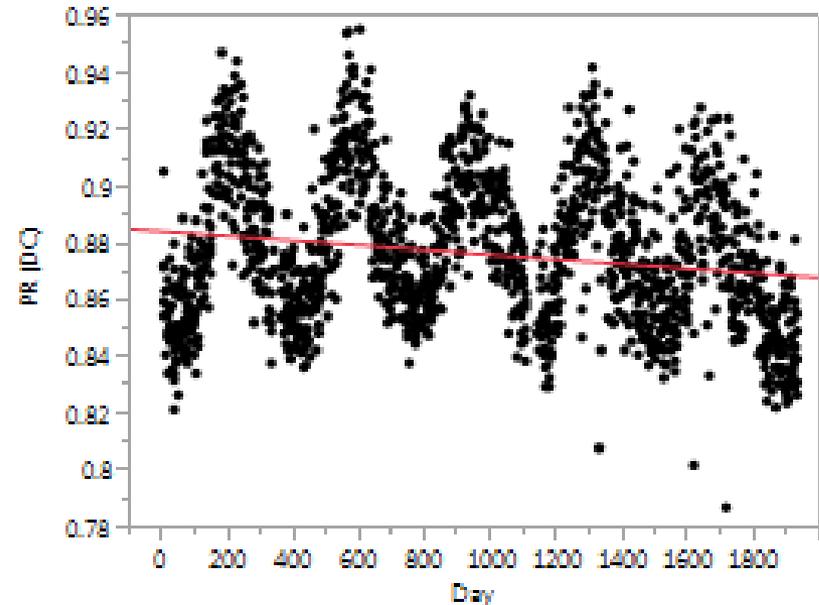
- To determine whether modules produce the expected energy you must continually measure the output power.
- See draft of IEC 61724-3: Photovoltaic system performance - Part 3: Energy evaluation method.
 - By using a standard method to determine the energy we can start making valid comparisons for different technologies.
 - This may also be a good way to evaluate our energy models used in the planning stage.
- This will be an important part of PV system conformity assessment under IECRE.

What kind of observations are necessary?

- **For Performance long term – determining degradation rate**
 - Best approach would be to continually measure energy output of the array. Even with all this data it is not always easy to determine the degradation rate. (See chart to right) In addition to the noise and seasonality, the output appeared fairly flat in the beginning but has begun a downward trend in the last year. So it is not only the rate but also the shape of the curve that is important.
 - According to Jordan (2016 Progress in PV) only 26% of degradation rate studies have 2 or more date points.
 - 74% of all the degradation rates he has reported are based on a single module or system measurement compared to nameplate.

Two take aways from this:

1. Many of these degradation rates are not very accurate and have been assumed linear when they may not be.
2. When deploying PV systems/modules at least take baseline measurements.

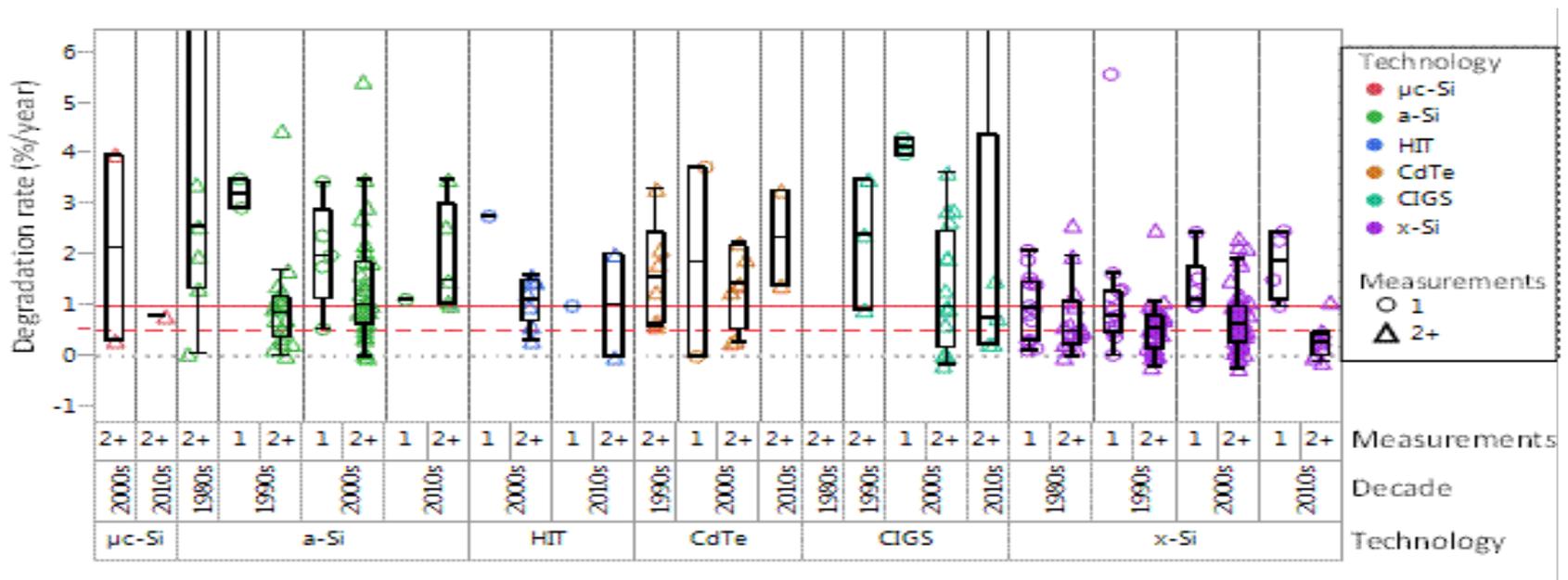


**Daily performance ratio using
DC power data with filtering –
from Jordan**

Degradation Rates

- C-Si median degradation of 0.5 to 0.6%/year with mean of 0.8 to 0.9%/year
- a-Si, μ -cry Si, HIT exhibits degradation rate of $\sim 1\%$ /year
- CIGS has demonstrated some low rates recently
- CdTe rates are higher but could represent less accurate data

From Jordan et al – accepted for Progress in PV



What kind of observations are necessary?

- **Identification of Failures and/or causes of degradation**
 - Visual inspection – use of inspection sheet to guide observations and provide for observations to be summarized in spread sheet
 - IR inspection – Good way to identify problems resulting from places where current flow is hampered
 - EL Inspection (In dark or using one of new day-light systems) – Good way to identify problems resulting from broken cells, broken glass and failure of junction.

What kind of observations are necessary?

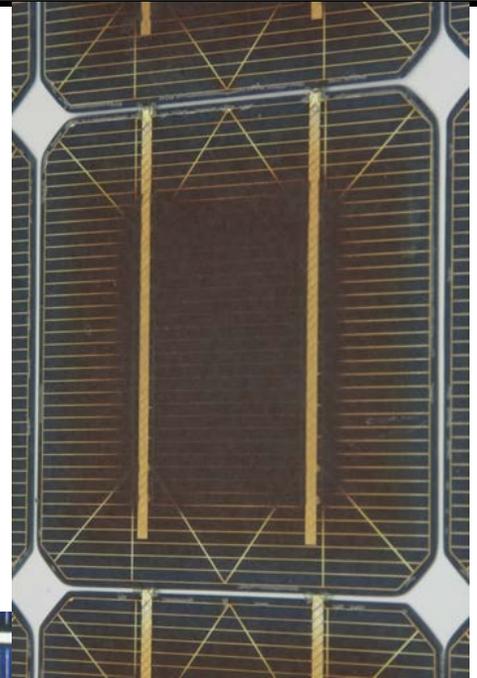
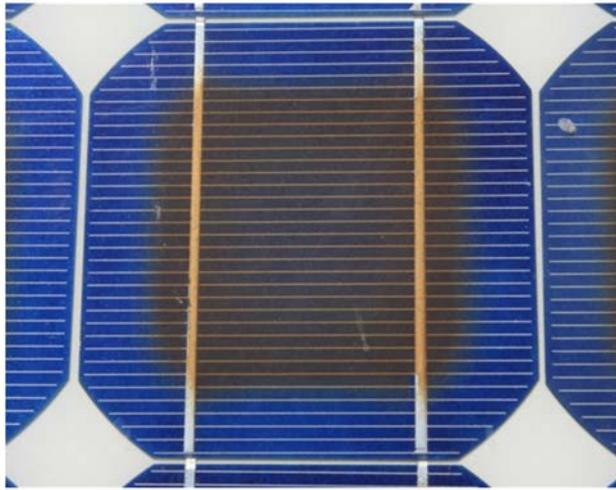
- **Impact of Climate and Installation**

- How do the failure modes vary with climate and mounting?
- How does the measured performance degrade as a function of the climate and mounting?
- How do the different climates impact stress levels on the module.

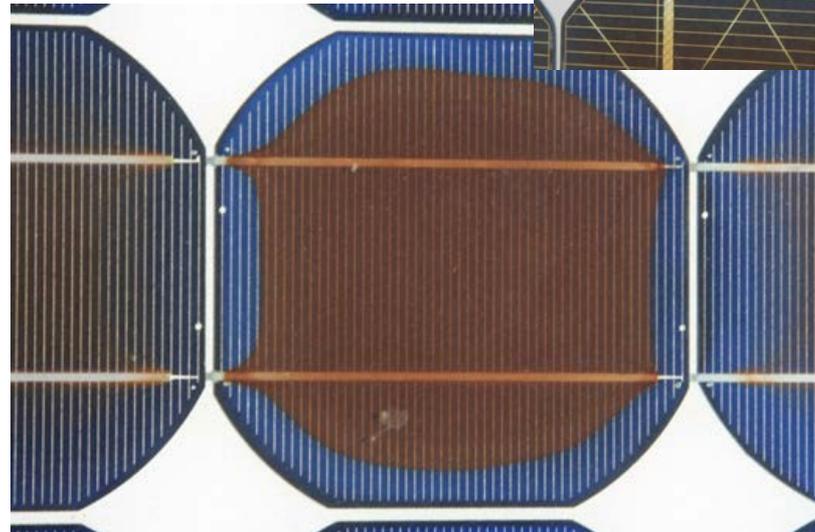
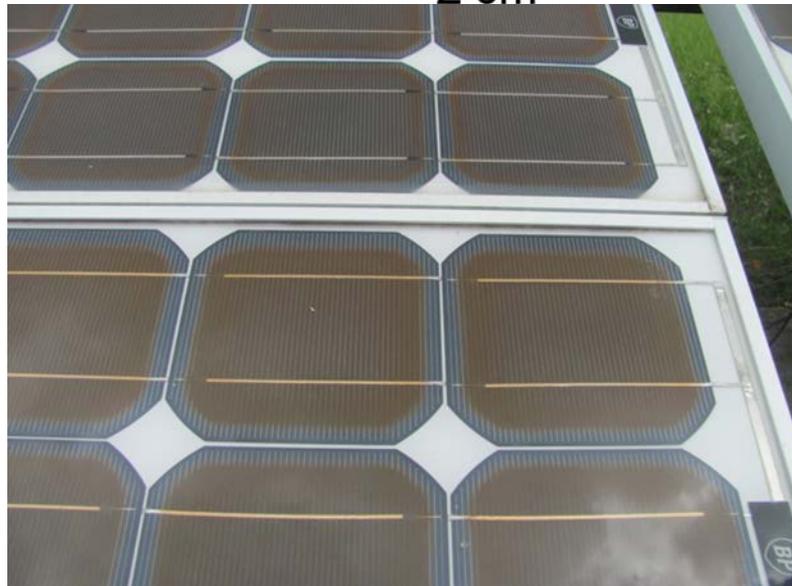
Observations of Degradation and Failures

- **Types of observed problems**
 1. Discoloration with loss of optical transmission
 2. Failure of interconnect ribbons and solder bonds
 3. Corrosion of cell metallization often accompanied by delamination of the encapsulant
 4. Broken or cracked cells
 5. Catastrophic failure including broken glass
 6. PID

Discoloration Examples



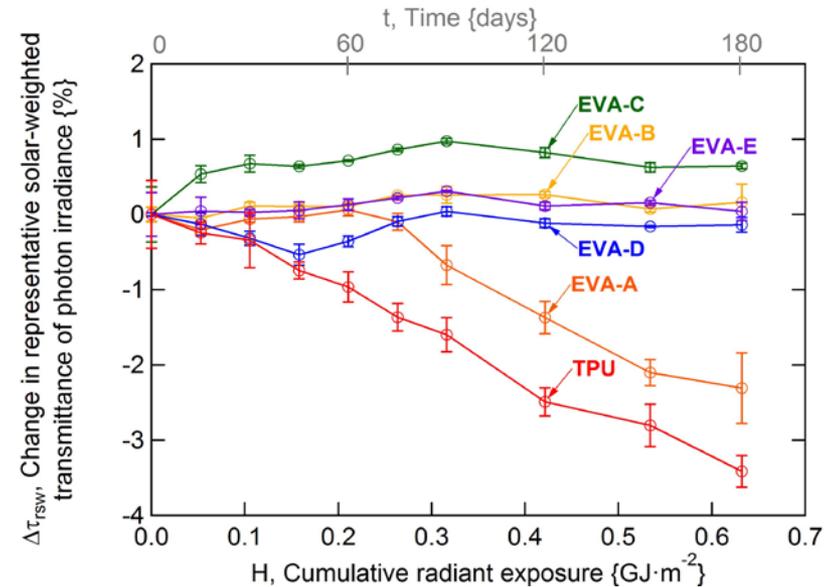
— 2 cm



Discoloration discussion

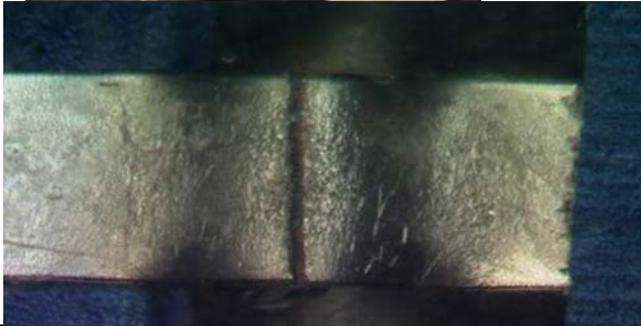
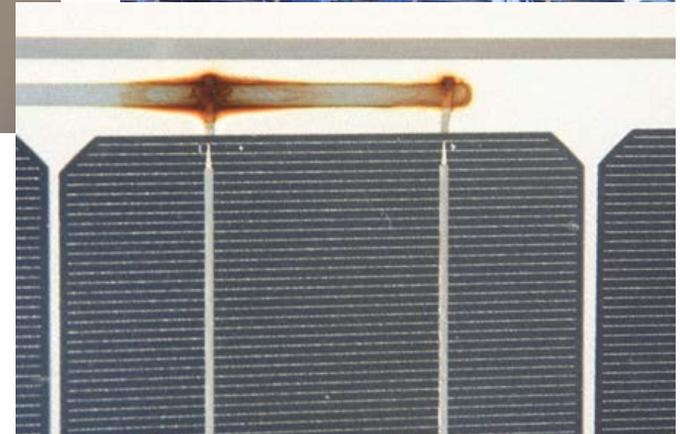
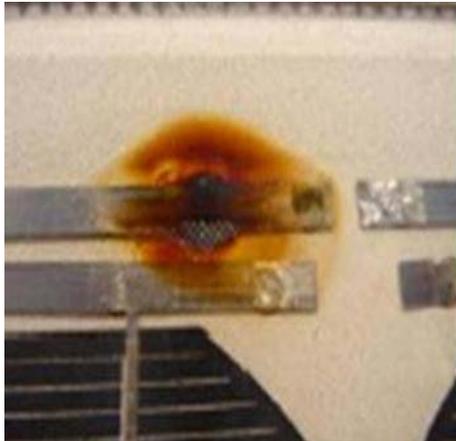
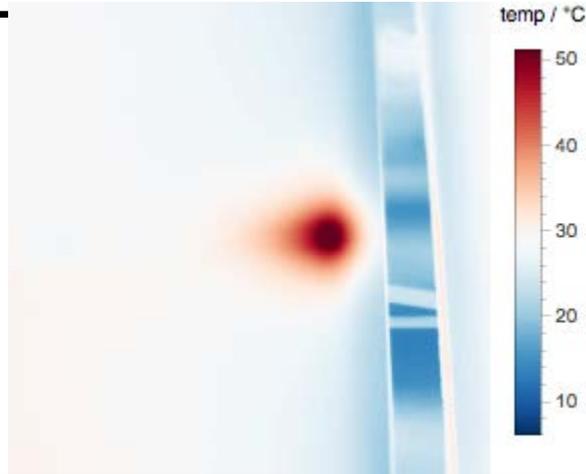
- **Jordan (27th EU PVSEC 2012) reports that**
 - **Discoloration is the most reported field observation**
 - **For c-Si power loss correlates with loss in short circuit current to which discoloration contributes**
- **According to STR (Tucker, 20th EU PVSEC 2005) and PVQAT Task Group 5 (Miller, 42nd IEEE PVSC 2015) discoloration of EVA is due to :**
 - **UV and high temperature**
 - **Additives not the EVA matrix**
- **New formulations do not discolor**

From Miller, 42nd IEEE PVSC 2015



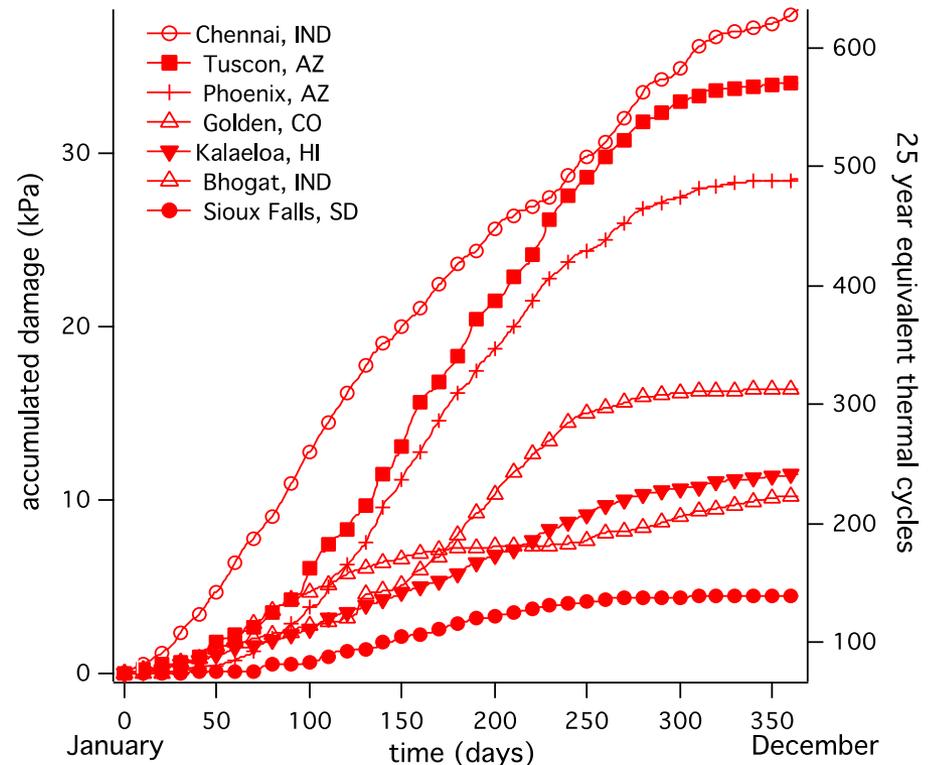
Change in transmittance with radiant exposure (H) for the center of coupons aged with UVA-340 lamps, with the chamber controlled at 60°C and uncontrolled %RH).

Failure of Interconnect Ribbons and Solder Bond



Discussion of interconnect and solder bond failures

- Some module types that pass the 200 thermal cycles in Qualification test suffer failures in field.
- Is this due to 200 TC not being enough stress or is it due to manufacturing defects?
- Bosco modeling (submitted for publication) shows that different climates result in significantly different stress levels (See diagram).
- So we may have to test differently for different locations.



From Bosco – submitted to
Microelectronics Reliability

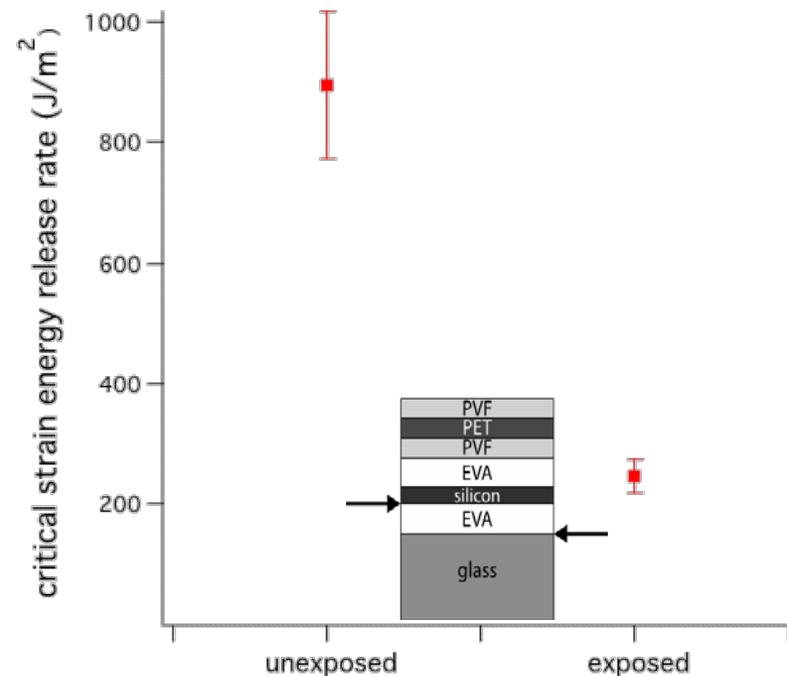
Corrosion of Metallization and Delamination



Discussion of Corrosion and Delamination

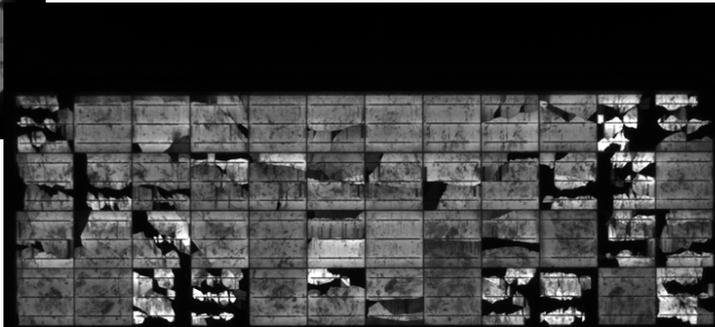
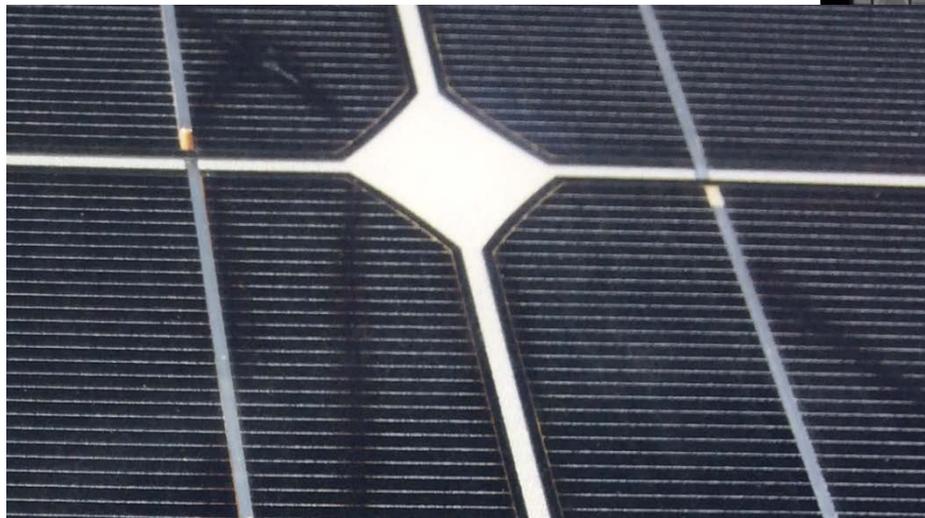
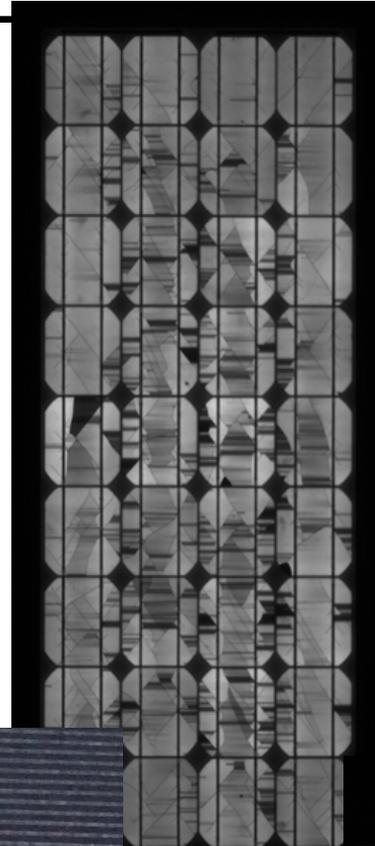
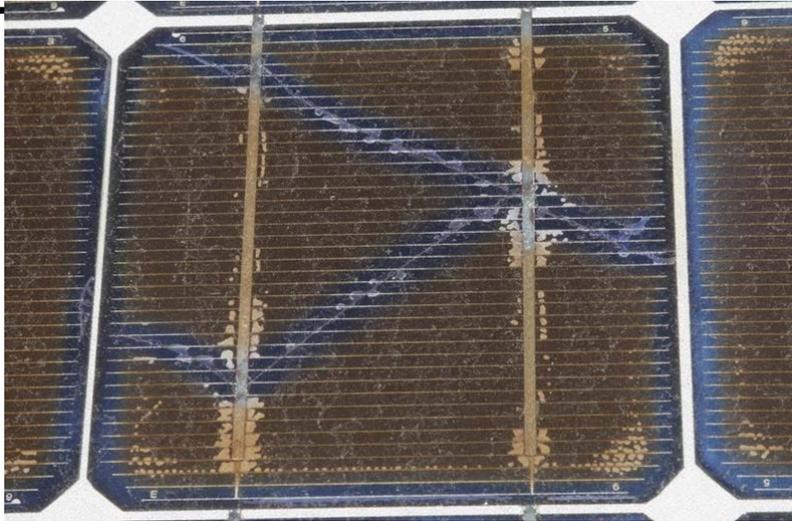
- Most of the time corrosion and delamination occur together.
- Also see corrosion along the bus bars – Is this related to poor solder flux clean-up, poor adhesion between ribbon and EVA or both?
- Which surface tends to delaminate (Glass-EVA or cell-EVA). Have seen both.
- Experiment with 27 year old Arco modules, comparing sample exposed to sun versus one stored in a shed – looks like glass-EVA interface adhesion decreased by factor of 20 but still there was no delamination.

Typical pre-exposure adhesion between glass and EVA $\sim 2000 \text{ J/m}^2$



See Talk by Nick Bosco tomorrow

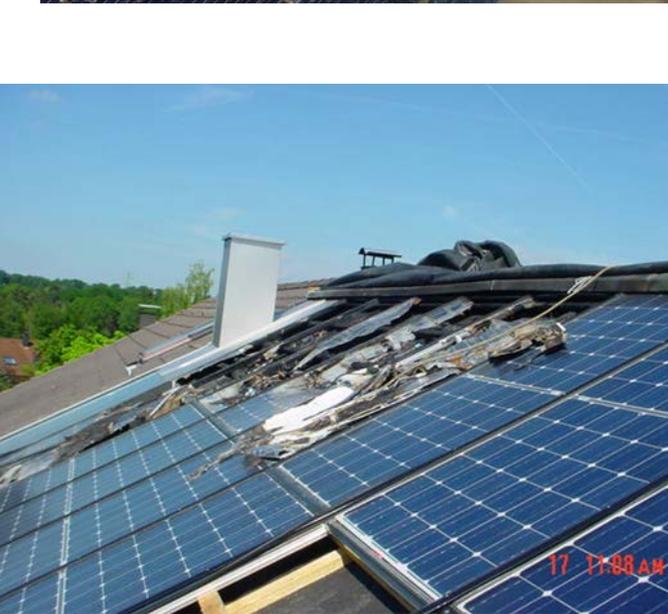
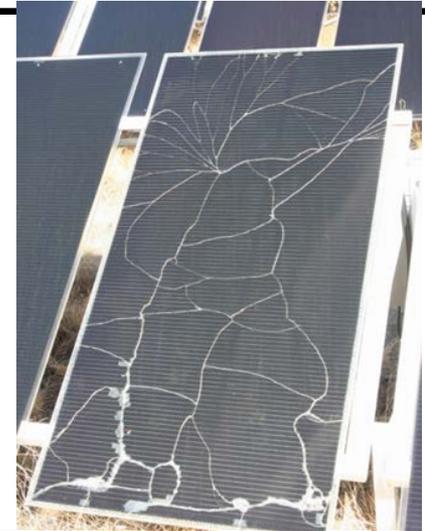
Broken or cracked cells



Discussion of broken and cracked cells

- **Do all cracks lead to power loss? Probably not, but how do we know which will?**
- **When/how do they break?**
 - **Because of manufacturing**
 - **During shipping and handling**
 - **During installation**
 - **During operation**
- **Tools to help**
 - **Outdoor EL to test in situ**
 - **A stress test sequence to evaluate the sensitivity of a particular module type to cell breakage – maybe Cyclic (dynamic) mechanical loading followed by TC & HF.**

Catastrophic failure including broken glass



Discussion of catastrophic failures

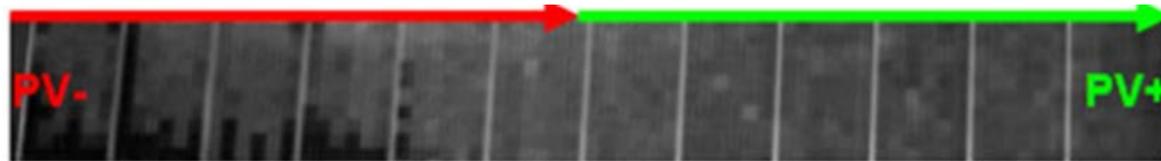
- **Reasons for such failures**

- **Projectiles – vandals or maintenance team**
- **Over heating –**
 - series arcs from open circuits,
 - Arcs from ground faults
 - bad solder bonds
 - bad electrical termination (especially in j-box)
- **Poor mounting or framing systems**
 - Inadequate support for Snow load
 - Mounting system puts stress on modules that causes breakage
- **Bad installation practices**
 - Walking on modules
 - Stressing and even dropping during handling
 - Penetrating the insulation package with mounting hardware
- **Stress built into module (especially for non-tempered glass) – edge pinch**

Outdoor EL picture of broken glass



PID



For c-Si

- PID does not usually cause a visual defect
- Impact is seen with EL and IR cameras (some severely shunted cells) and in measured power loss.

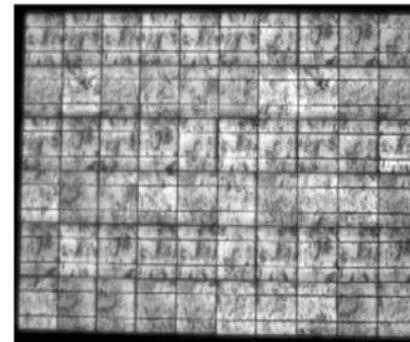
Panel level: example

For thin films

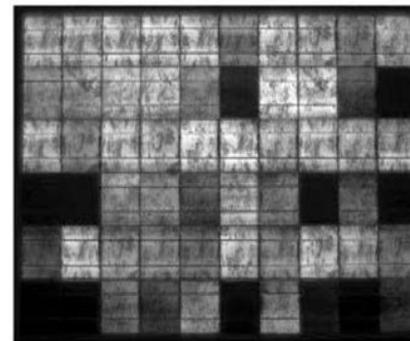
- A variety of degradation modes including some that are visually observable.



-600 V – 12 months



EL image of a panel before 100hr 1000V PID...



...and after (-32% power loss).

Key feature: Leakage current

Discussion Topics

- **The new EVA formulations and other new encapsulants do not appear to discolor and lose transmittance, does that mean Isc losses have been eliminated?**
- **Failure of solder bonds – Are they mostly manufacturing defects?**
 - **If so how do we reduce their occurrence?**
 - **How can we test for solder bond failures if they fail on a statistical basis?**
 - **Since the modeling shows how different the stress levels can be how fine a climate mesh must we use to assess the necessary thermal cycle testing?**

Discussion Topics - continued

Delaminations and Corrosion

- **What interface is most susceptible to delamination**
- **The 27 years of exposure had a significant impact on the adhesion between glass and EVA yet most of the modules in the system had no observable delaminations.**
- **What level of adhesion is sufficient for 25/30 year life?**
- **Do the delaminations we see in the field represent loss of process control?**
- **Is it likely that we can develop a set of accelerated stress tests that do a better job than the qualification tests at evaluating modules for their susceptibility for delamination?**

Discussion Topics - continued

Broken or cracked cells

- How serious an issue have they been?
- Is it getting worse as cells get thinner or better as each cell has more bus bars?
- Will glass-glass modules have fewer broken cells?
- How can standards help?
 - Guideline for factory QMS
 - Transportation standard
 - Installation standard
 - Maintenance and Operation standard
 - IECRE system

Discussion Topics - continued

Catastrophic failure

- **Need to distinguish module issues from handling and installation issues.**
- **Will standards on module mounting systems and installation practices reduce the post factory problems?**
- **Can we develop tests that stress the modules in their mounting system?**
- **How can we test modules for their susceptibility to break or to suffer an open circuit or ground fault? Or isn't it worth it since the numbers that fail are low.**

Discussion Topics - continued

PID

- **Can we agree on a qualification test for PID?**
- **Can it have a single test method or does it require several to duplicate the liquid water and humid air parts of the day?**
- **How PID resistant should the module be?**
- **Is there a place in the market for non-PID resistant modules?**
- **Should the PID test for c-Si and thin film modules be the same, similar or totally different?**

Conclusions

Field Observations

- Help us understand how PV modules perform and what failure modes they suffer from.
- Guide the development of accelerated stress tests to duplicate the failures seen in the field.
- Provide examples for our modelling to show how the stresses encountered in the terrestrial environment effect module performance.

What we need going forward

- Better understanding of why/how PV modules degrade in performance
- Improved accelerated stress tests for:
 - Climate specific tests now under development (IEC 62892)
 - Lifetime predictions as part of a module manufacturer's Quality Management System
- Continued validation of PV module models to tie accelerated stress tests to field performance in different climates and mounting configurations.