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Proposals for "Qualification Plus" Tests and Comparative Rating System

Sarah Kurtz, John Wohlgemuth, Mike Kempe, Nick Bosco, Peter Hacke, Dirk Jordan, David Miller, and MANY from the community

SPIE Solar Energy + Technology Conference

Bankability Workshop, Chicago, IL

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Outline

- Challenge: Creating useful standards quickly
  - Qualification – What we've been using
  - "Qualification plus" – Tests that are being discussed
  - Comparative – Climate-specific rating system
  - Quantitative – Goal of Service Life Prediction

Challenge: Create Useful Standards

We've heard:

- It takes too long to make standards
- Requiring more tests adds cost and delays products

Our goals:

- Strive for sooner
- Identify useful tests (that align with field performance)
- Unify the testing approaches

We ask:

- If we didn't get it "right," help us fix it

Some Levels of Accelerated Testing

	Qualification	Qualification "Plus"	Comparative	Service Life
Purpose	Minimum design qualification	Enhanced design qualification	Comparison of products	Substantiation of warranty
Quantification	Pass/fail	Pass/fail	Relative	Absolute
Climate or application (mounting)	Not differentiated	Not differentiated	Differentiated	Differentiated
Specificity	Silicon, thin-film, CPV	For today, discuss Si only	Package specific?	Product specific
Chamber test times	Modules: < 2 months	Modules: ~ 3 months Materials: ~ 6 months	TBD	3 years ?

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Testing beyond current IEC tests

- Ed. 3 of IEC 61215 will have multiple revisions/additions
  - These will become available to the public over the next two years
  - Can we adopt improvements sooner?

- CEC has given us the opportunity to propose an optional “plus” version of their Eligibility Requirements
- Next slides describe “plus” requirements

Proposal to test “beyond” the standard

- Despite PV’s excellent success, some failures are seen in the field.
  - Propose 9 new tests
- Low prices motivate manufacturers to cut corners – might the corner be cut too short?
  - Propose more frequent/extensive testing
  - Propose oversight of quality management system

Proposal to test “beyond” the standard

- **Despite PV’s excellent success, some failures are seen in the field.**
  - **Propose 9 new tests**
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  - **Propose oversight of quality management system**

#1 Proposed testing “beyond” IEC 61215

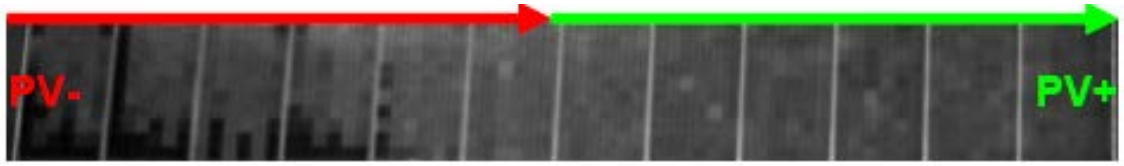
Failure type: ***Potential-induced*** degradation (module failure is caused by system voltage)

Proposed change: Apply system voltage during damp heat or similar condition.

Benefit: For systems that float (active circuit ungrounded), the degradation can be dramatic (tens of % in first year). New inverter designs have enabled this style of system design.

Comment: Test has been proposed to IEC.

Mani will discuss



Modules at negative end of string show degradation (indicated by black)

http://www.nrel.gov/docs/fy12osti/54581.pdf

#2 Proposed testing “beyond” IEC 61215

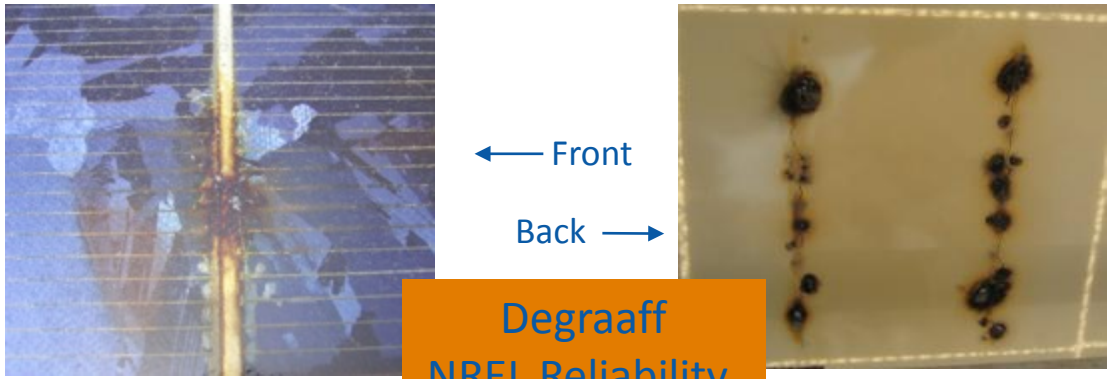
Failure type: Failure of connections within electrical circuit

Proposed change: Increase ***thermal cycling*** from 200 cycles (~ 6 weeks) to 500 cycles (~ 15 weeks).

Benefit: This type of failure can lead to fires and/or catastrophic module failure.

Comment: There is evidence that 200 cycles gives confidence for ~ 10 y in the field; 500 cycles may give confidence closer to 25 y.

Wohlgemuth, 23rd EU PVSEC, p. 2663, 2008



Degraaff NREL Reliability Workshop, 2011

Wear-out mechanism

#3 Proposed testing "beyond" IEC 61215

Failure type: Cracked cells, etc. leading to disconnections

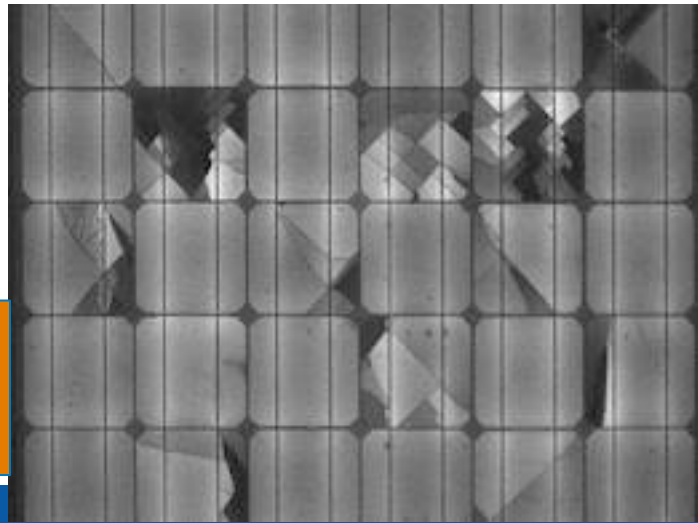
Proposed change: Apply ***Dynamic Mechanical Load*** before 50 thermal cycles and 10 humidity freeze cycles

Benefit: This type of failure can lead to fires and/or catastrophic module failure.

Geoff Kinsey will discuss

Comment: Today's thinner cells sometimes crack during shipping or snow/wind loading. At first, there may be no power loss, but after further stress, the metal interconnects may begin to break.

Note: this may be a faster way to achieve the stress of 500 thermal cycles – uncovers many types of failures



Wohlgemuth, 33rd PVSC, paper 420, 2008
Pingel, 24th European PVSEC, p. 3459, 2009
Koch, 25th European PVSEC, p. 3998, 2010

#4 Proposed testing “beyond” IEC 61215

Failure type: Degradation of ***encapsulant*** (yellowing, delamination)

Proposed change: Expose materials in “module-like” configuration to *UV* and heat for ~ 6 months (use test that was defined by STR ~ 15 y ago)

Charlie Reid will discuss

Benefit: Avoids degradation. Yellowing causes slow power decrease.

Comment: May be done by encapsulant manufacturer.

Note: Historically, encapsulant manufacturers used this sort of test, so field failures were small. Now, newer manufacturers may or may not use adequate testing; it’s not required in IEC 61215.

Wohlgemuth, 39th PVSC, 2013
Reid, SPIE, vol. 8825, 2013

Wear-out mechanism

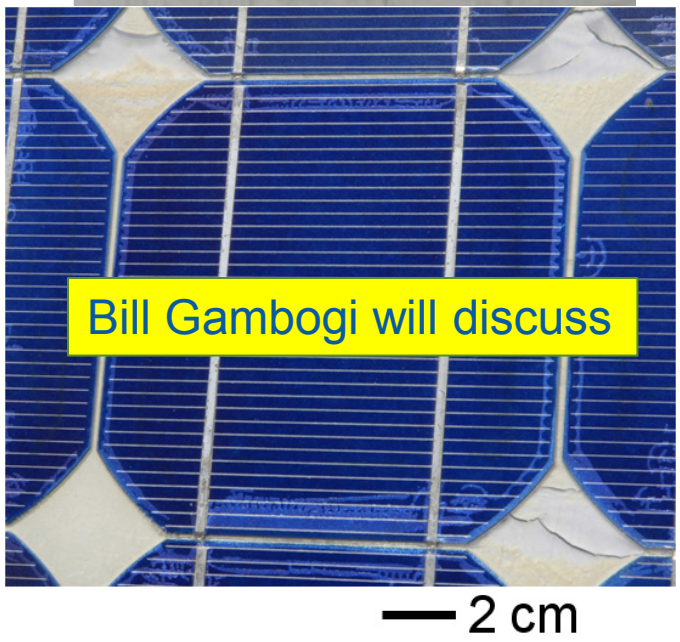
#5-7 Proposed testing “beyond” IEC 61215

Failure type: Degradation of backsheet, connectors and junction boxes (cracking, delamination) leading to losses in safety or performance

Proposed change: Expose ***backsheet, cables, and junction boxes*** to ***UV*** consistent with outdoor exposure

Benefit: Avoids safety and performance issues (e.g. if backsheet no longer provides adequate protection of the electrical circuit leading to shock hazard and/or to corrosion).

Comment: May be completed by component manufacturer.



Gambogi, et al, EUPVSEC 2012,
Gambogi, et al, NREL PVMRW 2013,
Gambogi, et al, 39th PVSC 2013

Wear-out mechanism

#8 Proposed testing “beyond” IEC 61215

Failure type: ***Hot-spots*** from local reverse bias during partial shading

Proposed change: Use ASTM E2481-06 hot-spot test (more cells and longer test)

Benefit: This type of failure can cause fires.

Comment: Is planned for adoption into IEC 61215.

ASTM E2481-06
TamizhMani & Sharma, SPIE 7048 (2008)

#9 Proposed testing “beyond” IEC 61215

Failure type: Bypass diode

Proposed change: Increase ***bypass diode*** thermal test from 1 h to 96 h.

Benefit: Some manufacturers used cheaper diodes that passed the 1-h test, but failed in the field.

Comment: Other bypass diode tests are in development. Failure of bypass diodes can lead to fires

Testing for Electrostatic Discharge (ESD) should be done in the factory

Zhang, et al, PVMRW 2013

Proposal to test “beyond” the standard

- **Despite PV’s excellent success, some failures are seen in the field.**
  - **Propose 9 new tests**
- **Low prices motivate manufacturers to cut corners – might the corner be cut too short?**
  - **Propose more frequent/extensive testing**
  - **Propose oversight of quality management system**

Test (sampling) methods

- All test samples must be ***random*** samples from production line (no engineering samples and no cherry picking)
- Number of test samples increased from 2 to ***5***
- ***Retest*** at least once per 4 months (small-volume manufacturers may have reduced requirement) by manufacturer and any failures addressed.

Why we need to test “beyond” the standard

- **Despite PV’s excellent success, some failures are seen in the field.**
  - **Propose 9 new tests**
- **Low prices motivate manufacturers to cut corners – might the corner be cut too short?**
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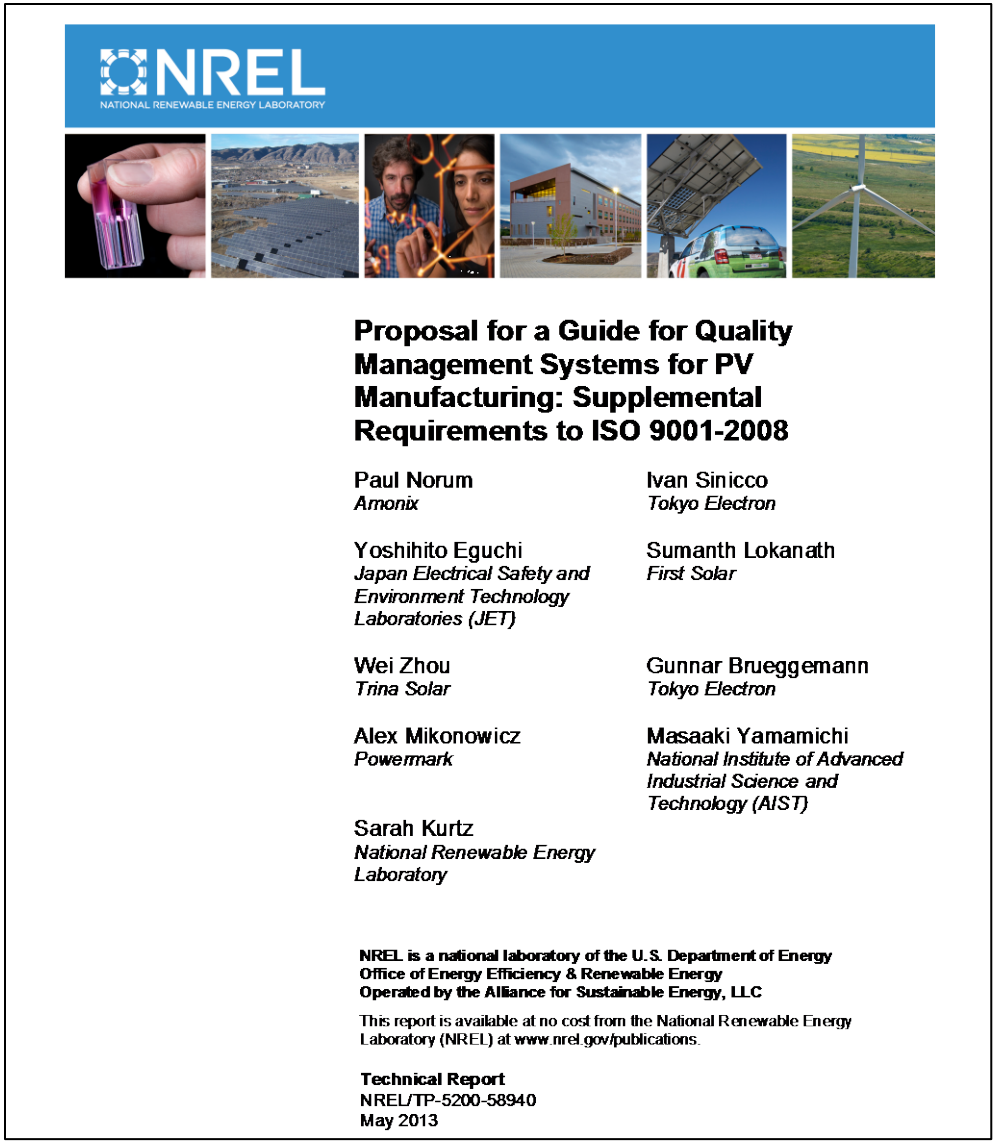
Quality Management: PV-specific ISO-9001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Proposal for a Guide for Quality Management Systems for PV Manufacturing: Supplemental Requirements to ISO 9001-2008

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Technical Report
NREL/TP-5200-58940
May 2013

Organization controls the PV module's design to align the expected lifetime with its relationship to the organization's warranty

- Builds on Japanese standard*
- Report at http://www.nrel.gov/docs/fy13osti/58940.pdf

***Before launching their recent incentive program, Japan created**: "JIS Q8901-2012 Terrestrial photovoltaic (PV) modules-Requirement for reliability assurance system (design, production, and product warranty)"

Levels of Accelerated Testing

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“Features” versus “Grades”

Customers want to differentiate, but some companies don’t want to be graded

Acceptable: “Features” (examples)

- Climate:
  - Desert
  - Tropical
  - Temperate
- Mounting
  - Open Rack
  - Close roof
- Hail test
  - 3 cm
  - 5 cm
- “Better than qualification test”
  - 2X, 3X, 4X

Unacceptable: “Grades”

- A, B, C
- Score of 1 to 10
- Score of 1 to 100
- One to Five stars

Proposed rating system for climate and mounting

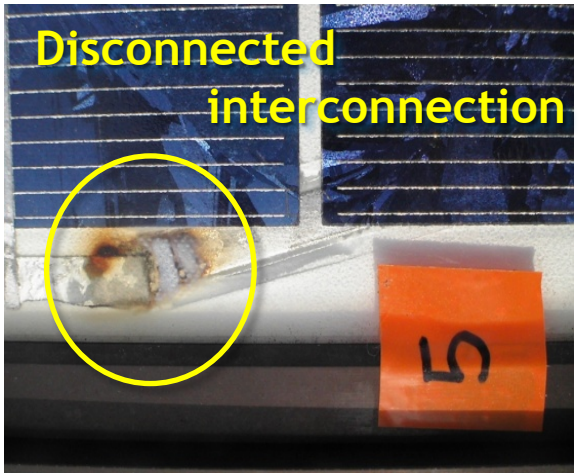
IEC 60721-2-1 Climate Designation	Mounting classes	
	Rack mount	Close-roof mount
Moderate (Temperate)		
Warm Damp, Equable (Tropical)		
Extremely Warm Dry (Desert)		

Thermal and mechanical fatigue issues seen everywhere

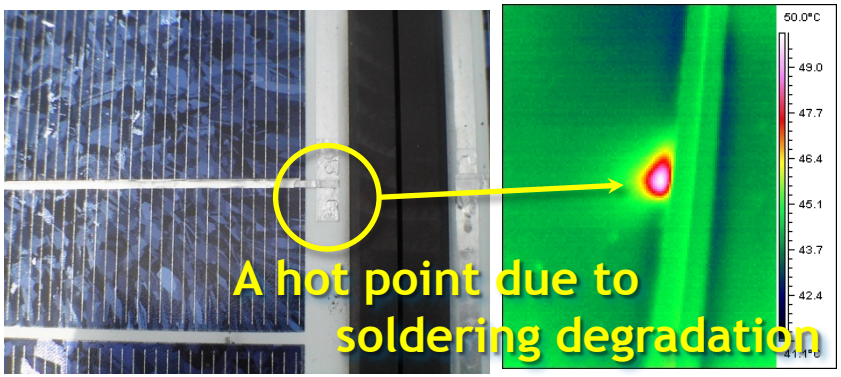
Kato, 2012

http://www1.eere.energy.gov/solar/pdfs/pvmrw12_tuesam_aist_kato.pdf

- **Failures are frequently reported in all climates**
- **Field data and modeling imply that 500 thermal cycles would be better than 200**



- **Propose: Increase thermal cycles; use faster cycles or dynamic mechanical loading (DML) to reduce time - *details TBD***



Proposed rating system for climate and mounting

Proposal:

Increase stress to avoid fatigue-related failures commonly reported today.

So far, we do not have clear evidence that this failure varies systematically with climate.

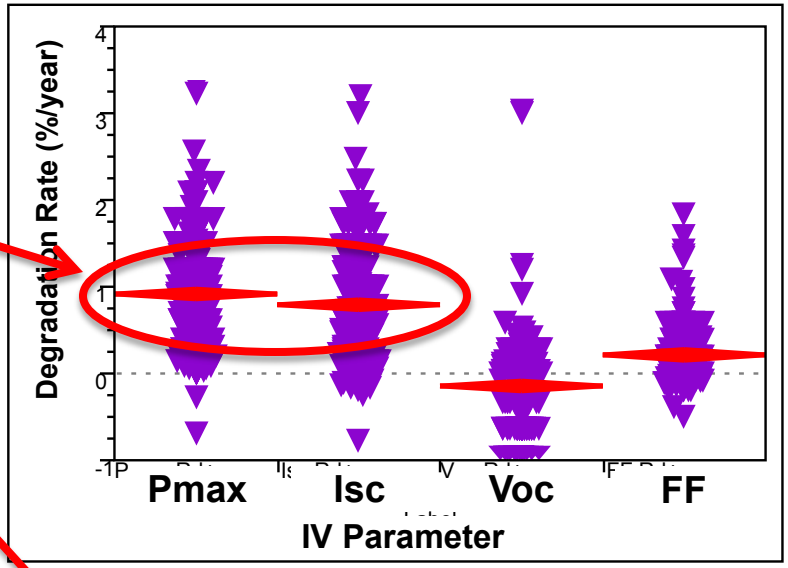
IEC 60721-2-1 Climate Designation	Mounting classes	
	Rack mount	Close-roof mount
Moderate (Temperate)	500 thermal cycles or DML + 200 TC	500 thermal cycles or DML + 200 TC
Warm Damp, Equable (Tropical)	500 thermal cycles or DML + 200 TC	500 thermal cycles or DML + 200 TC
Extremely Warm Dry (Desert)	500 thermal cycles or DML + 200 TC	500 thermal cycles or DML + 200 TC

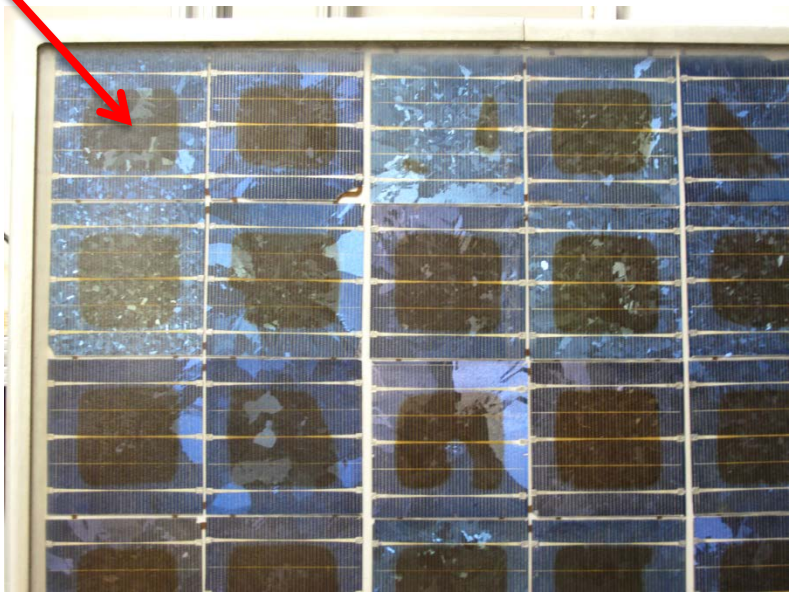
Question: Should the details of the test vary with climate?

UV effects usually increase in hot environment

- **Loss of current linked to decrease in performance; frequently associated with EVA discoloration**
- **Discoloration is caused by UV exposure, especially at higher temperatures**

- **Proposal: Increase UV exposure with appropriate temperature**





Proposed rating system for climate and mounting

Proposal:
Increase UV exposure with appropriate temperature & humidity.
Use measurements and modeling to select temperatures.

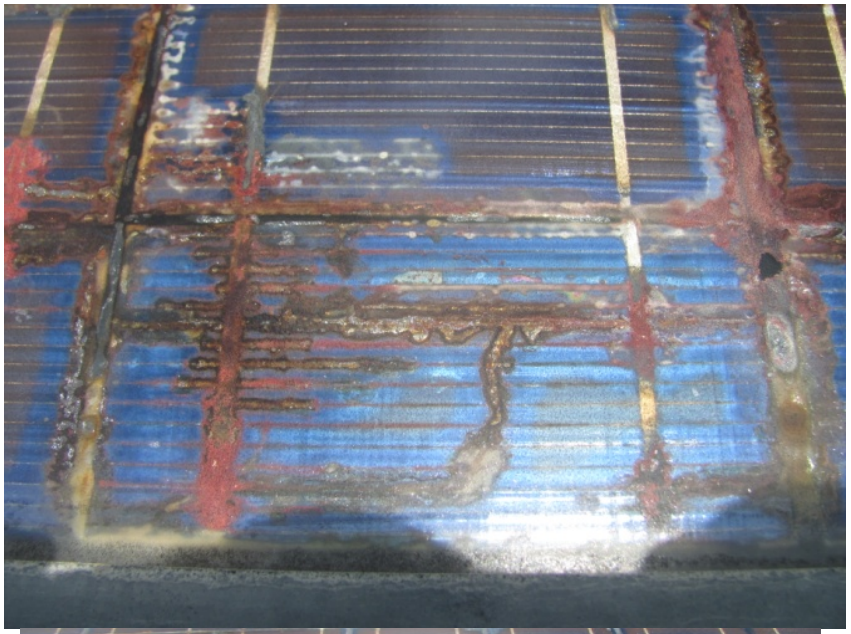
IEC 60721-2-1 Climate Designation	Mounting classes	
	Rack mount	Close-roof mount
Moderate (Temperate)	500 thermal cycles or DML + 200 TC Increased UV exposure at 60° C*	500 thermal cycles or DML + 200 TC Increased UV exposure at 80° C*
Warm Damp, Equable (Tropical)	500 thermal cycles or DML + 200 TC Increased UV exposure at 80° C*	500 thermal cycles or DML + 200 TC Increased UV exposure at 100° C*
Extremely Warm Dry (Desert)	500 thermal cycles or DML + 200 TC Increased UV exposure at 80° C*	500 thermal cycles or DML + 200 TC Increased UV exposure at 100° C*

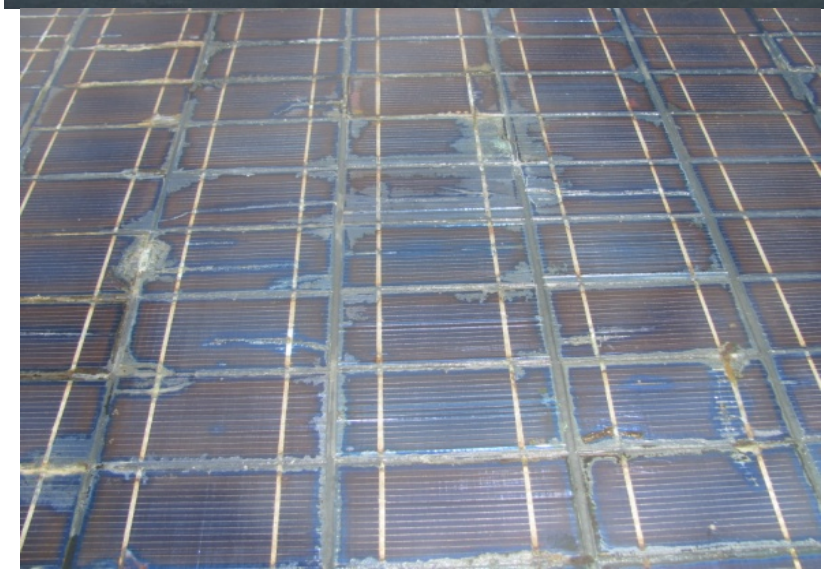
*Temperatures are estimates; final values TBD, but should vary with mounting/climate.

Humidity can cause corrosion

- **Failures are sometimes reported**
- **Corrosion usually follows delamination**

- **Proposal: Use UV exposure + humidity freeze to induce any delamination, then expose to damp heat to cause corrosion**





Proposed rating system for climate and mounting

Proposal:

After UV exposure add humidity freeze and damp heat.

Use measurements and modeling to select conditions.

IEC 60721-2-1 Climate	Mounting classes	
	Rack mount	**Close-roof mount**
Moderate (Temperate)	500 thermal cycles or DML + 200 TC Increased UV exposure at 60° C*, followed by 10 cycles of humidity freeze and short damp heat	500 thermal cycles or DML + 200 TC Increased UV exposure at 80° C*, followed by 10 cycles of humidity freeze and short damp heat
Warm Damp, Equable (Tropical)	500 thermal cycles or DML + 200 TC Increased UV exposure at 80° C*, followed by 10 cycles of humidity freeze and 1000 h damp heat	500 thermal cycles or DML + 200 TC Increased UV exposure at 100° C*, followed by 10 cycles of humidity freeze and 1000 h damp heat
Extremely Warm Dry (Desert)	500 thermal cycles or DML + 200 TC Increased UV exposure at 80° C*, followed by 10 cycles of humidity freeze and short damp heat	500 thermal cycles or DML + 200 TC Increased UV exposure at 100° C*, followed by 10 cycles of humidity freeze and short damp heat

*Temperatures and other details are estimates; final values TBD.

Application-specific ratings

- **Existing tests:**
  - Hail
  - Mechanical strength (snow and wind load; moving snow)
  - Salt
  - Ammonia
  - Sand

Proposal:

Document existing tests along with climate-specific rating to provide complete information

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Service Life Prediction Standard?

- How would you write a standard for making a Service Life Prediction?

- The failure mechanisms that limit the life of a product may vary

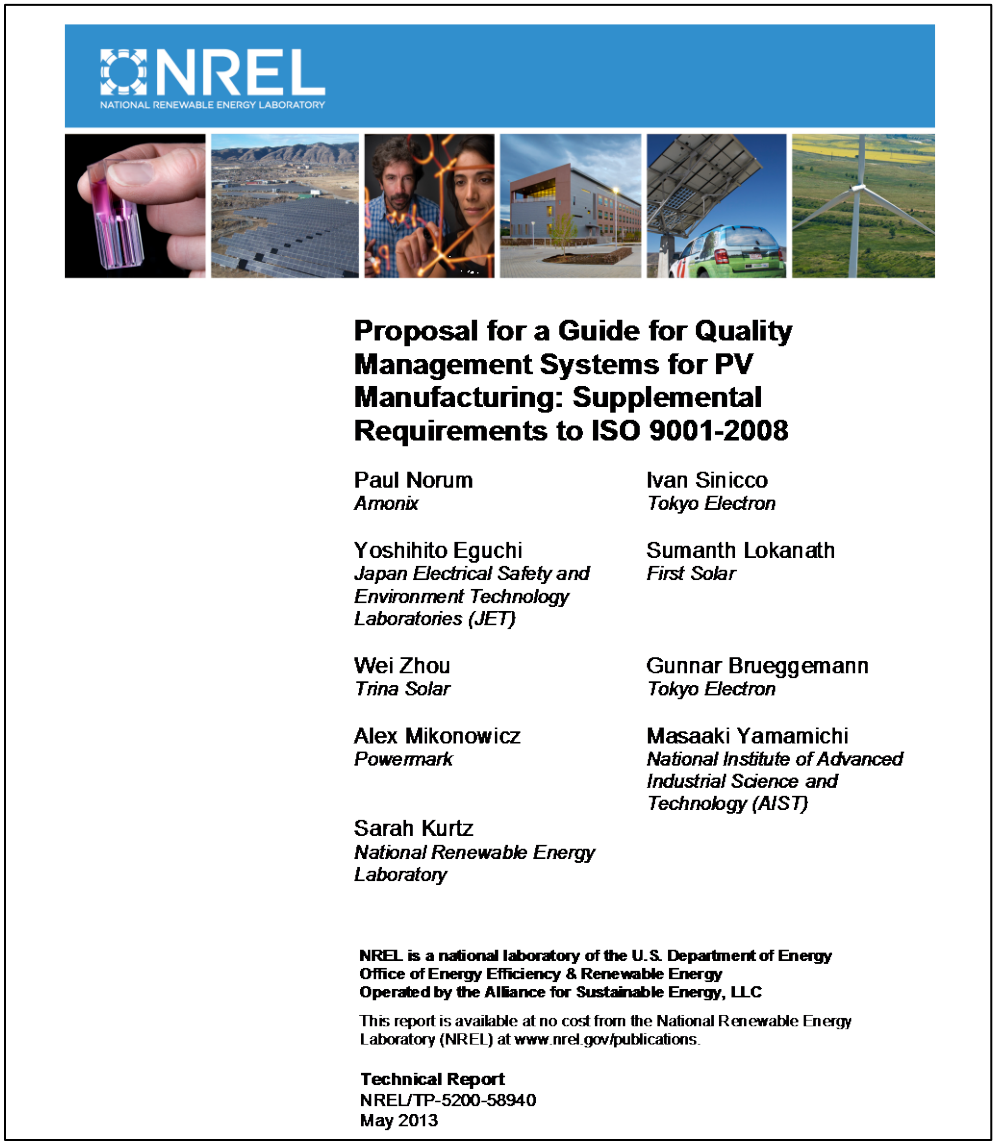
Service Life Prediction

1. Identify failure/degradation mechanisms that determine end of life
2. Quantify reaction rates
3. For given use environment, apply rates in a model to estimate expected lifetime
4. Verify model by comparing with field data

This step-by-step procedure is clear, but the actual tests are not

This procedure is similar to quality management

Propose: Implement Service Life Prediction within Quality Management System



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- The best quality management systems assess whether the product can meet the warranty – this is the best place to quantify Service Life
- A complete Service Life Prediction takes many years to create and verify – most aspects of the product design must be "frozen" first
- Propose to differentiate with ratings:
  - New product (~6 months)
  - Practiced (~2 years)
  - Mature (~5 years)

Summary

- **"Qualification Plus"** tests improve over IEC 61215
  - Nine tests that go "beyond" IEC 61215 (**new**)
  - Random product sampling and periodic testing (**new**)
  - Robust quality management system (PV-specific version of ISO 9001) (**new**)
  - Propose as optional version of CEC eligible hardware list
- **Climate-specific**, **comparative** tests
  - Desert, Tropical, Temperate
  - Open-rack or Close-roof mounting
- Quality Management System is the pathway to defining a standard method for ascribing **Service Life**
- We look for your feedback and support