Special Testing for Modules Deployed in Hot Use Environments – Are We Doing This in a Low-Cost Way?

Ingrid Repins,[1] Dirk Jordan,[1] Nick Bosco,[1] Chris Flueckiger[2]
[1]National Renewable Energy Laboratory
[2]Underwriters Laboratories

A workshop at:
Solar Power International
Monday, September 12, 1:00 PM
Las Vegas, Nevada

NREL/PR-5J00-67348

NATIONAL RENEWABLE ENERGY LABORATORY

Special Testing for Modules Deployed in Hot Use Environments – Are We Doing This in a Low-Cost Way?

INTRODUCTION

Ingrid Repins

Solar Power International
Monday, September 12, 1:00 PM

Your Instructors

Ingrid Repins, *National Renewable Energy Laboratory, USA*
Dr. Repins is a member of the reliability group. She has worked for 25 years in PV characterization, process research, and manufacture. She brings an in-depth understanding of materials science and device physics.

Dirk Jordan, *National Renewable Energy Laboratory, USA*
Dr. Jordan focuses on evaluation of outdoor module performance data. He specializes in the analysis of these data to quantify PV module degradation rates. He is well-known for publications with statistical analysis of reported degradation rates.

Nick Bosco, *National Renewable Energy Laboratory, USA*
Dr. Bosco focuses on failure analysis and accelerated testing. He specializes in infrared imaging (see photo) and other diagnostic techniques, as well as analysis and development of accelerated tests for mechanical fatigue.

Chris Flueckiger, *Underwriter's Laboratory, USA*
Christopher Flueckiger is the Principal Engineer for Renewable Energy at Underwriters Laboratories. Chris joined UL in 2000 working in the Power Distribution, Medical, and ITE groups. Chris is a technical representative to the Standard Technical Panel and is an active participant in IEC.

Today's Agenda

1:00	**Introduction to Problem**	**Ingrid Repins**
1:30	**Experimental Evidence**	**Dirk Jordan**
1:55	**Why the highest temperatures are the most stressful to PV modules during thermal cycling**	**Nick Bosco**
2:20	**Break**	
2:40	**Safety Aspects**	**Chris Flueckiger**
2:55	**Proposal for Guidelines**	**Chris Flueckiger**
3:20	**Discussion:** – Is the "Guideline Approach" the best way? – What is best solution for long term?	**All**
4:10	**Wrap-up summary of discussion**	**Ingrid Repins**
4:25	**Survey**	**All**
4:30	**Adjourn**	

Please hold questions until the brief Q&A period following each presentation, or until the group discussion.

Background Information

Aspen, Colorado

Average temperature

5° C (42° F)

San Francisco, California

Average temperature

14° C (57° F)

Agua Caliente, Arizona

Average temperature

24° C (76° F)

Most accelerated tests used in current standards were derived from this range.

Module qualification testing should not be a "one size fits all" approach.

Background Information

- **The proposed new IEC standard (subject of this workshop) provides guidelines as to how to modify temperature limits in four existing standards to better describe performance in hotter climates.**
- **Manufacturers can choose a testing temperature above the current levels to help demonstrate durability in hotter environments.**
- **The proposed guidelines will address the test temperature requirements in IEC 61215 (module design), IEC 61730 (module safety), IEC 62790 (junction box safety) and IEC 62852 (connectors)**

Outline for Background Information

1. What are standards?
2. How are standards used?
3. Why were current standards derived from temperate environments?
4. Limits of the qualification tests that are used in standards.

What is a standard?

A standard is a document that…

- Describes that test procedures in adequate detail that results can be reproduced from one lab to the next

Example: Wet leakage current test from PV safety standard

IEC 61730-2 / UL 1703

In-depth description of everything you need to know to do the test: apparatus, procedure, data to be recorded, calculations, etc.

Title: IEC 61730-2:

Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing

4.15 Wet leakage current test (MQT 15)

4.15.2 Apparatus

a) A shallow trough or tank of sufficient size to enable the module with frame to be placed in the solution in a flat, horizontal position. It shall contain a water/wetting agent solution sufficient to wet the surfaces of the module under test and meeting the following requirements:

Resistivity:	3 500 Ω/cm or less
Solution temperature:	(22 ± 2) °C

The depth of the solution shall be sufficient to cover all surfaces except junction box entries not designed for immersion.

b) Spray equipment containing the same solution, if the entire junction box is not going to be submerged.

c) DC voltage source, with current limitation, capable of applying 500 V or the maximum rated system voltage of the module, whichever is more.

d) Instrument to measure insulation resistance.

4.15.3 Procedure

All connections shall be representative of the recommended field wiring installation, and precautions shall be taken to ensure that leakage currents do not originate from the instrumentation wiring attached to the module.

a) Immerse the module in the tank of the required solution to a depth sufficient to cover all

…..

What is a standard?

A standard is a document that…

- Describes that test procedures in adequate detail that results can be reproduced from one lab to the next
- Is produced by a recognized standards organization

Examples of ANSI-accredited Standard Development Organizations in the U.S.	Acronym	Primary Focus
ASTM International	ASTM	Test methods
Institute of Electrical and Electronic Engineers Standards Association	IEEE SA	Electrical systems, particularly grid interactions
National Fire Protection Association	NFPA	National Electric Code
Underwriters Laboratory	UL	Product Safety Testing and Standards
TUV Rheinland International	TUV	PV Testing

ANSI (American National Standards Institute) also represents the U.S. for the two major **international** standards organizations: International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC)

Process involving national committees and technical experts ensures that standards are of high technical quality and fair.

What is a standard?

A standard is a document that…

- Describes that test procedures in adequate detail that results can be reproduced from one lab to the next
- Is produced by a recognized standards organization
- May include pass-fail criteria

Example: Wet leakage current test from PV safety standard IEC 61730-2 / UL 1703

be provided by manufacturer.

c) Increase the voltage applied by the test equipment at a rate not exceeding 500 V/s to 500 V or the maximum system voltage for the module, whichever is greater. Maintain the voltage at this level for 2 min. Then determine the insulation resistance.

d) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up on the module.

e) Ensure that the used solution is well rinsed off the module before continuing the testing.

4.15.4 Requirements

– For modules with an area of less than 0,1 m^2 the insulation resistance shall not be less than 400 MΩ.

– For modules with an area larger than 0,1 m^2 the measured insulation resistance times the area of the module shall not be less than 40 MΩ·m^2.

Outline for Background Information

1. What are standards?
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3. Why were current standards derived from temperate environments?
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How are standards used?

A. Governments and organizations set requirements based on standards (vary with location and time)

PHOTOVOLTAIC PRODUCTS

California Energy Commission – CEC Requirements

Have your product ready to enter the California PV market

Excerpts from UL flier

Flat-plate non concentrating photovoltaic modules require high-quality testing data from independent laboratories to determine safety and to calculate the expected performance of the sy… Comn…

The th… rating… meter… Comn… eligib…

- Modules shall be certified to UL 1703, the Standard for Safety of Standard for Flat-Plate Photovoltaic Modules and Panels, by a Nationally Recognized Testing Laboratory (NRTL) for safety and reliability.
- Detailed performance data shall be reported and certified using the subsections of International Electrotechnical Commission (IEC) Standard 61215 or 61646, depending on the type of PV-system.

The factory measured maximum power of each production module, as specified in UL 1703, Section 44.1, and the lower bound of the manufacturer's stated tolerance range, under UL 1703, Section 48.2, shall be no less than 95 percent of the maximum power reported to the California Energy Commission.

The performance data and information in the table on page two shall be certified and provided to the California Energy Commission.

This data must be made available to the public. For multiple model numbers, data may be grouped together as described in the table.

How are standards used?

B. Manufacturers use them to demonstrate value to customers, and build confidence in their product durability


CanadianSolar
Make The Difference

QUARTECH

The Next Generation Module

CS6P-250 I 255 I 260P

*Black frame product can be provided upon request.

QUARTECH MODULE | THE NEXT GENERATION MODULE

Canadian Solar's new Quartech modules have raised the module efficiency to a new standard in the solar industry. It introduced innovative four busbar cell technology which demonstrated higher power output and higher system reliability. Our worldwide customers have embraced this next generation modules for their excellent performance, superior reliability and enhanced value.

PRODUCT | KEY BENEFITS

Higher Energy Yield

- Outstanding performance at low irradiance
- Maximum energy yield at low NOCT
- Improved energy production through reduced cell series resistance

Increased System Reliability

- Long term system reliability with IP67 junction box
- Enhanced system reliability in extreme temperature environment with special cell level stress release technology

Extra Value to Customers

- Positive power tolerance up to 5W
- Stronger 40mm robust frame to hold 5400 Pa load
- Anti-glare project evaluation
- Salt mist, ammonia and blowing sand resistance apply to seaside, farm and desert environment

QUARTECH MODULE | NEW TECHNOLOGY

- Reduces cell series resistance
- Reduces stress between cell interconnectors
- Improves module conversion efficiency
- Improves product reliability

PRODUCT & MANAGEMENT SYSTEM | CERTIFICATES*

IEC 61215 / IEC 61730: VDE / MCS/CE/JET/KEMCO/SII/CEC AU/INMETRO/CQC
UL 1703 / IEC 61215 performance: CEC listed (US) / FSEC (US Florida)
UL 1703: CSA | IEC 61701 ED2: VDE | IEC 62716: TUV | IEC60068-2-68: SGS
PV CYCLE (EU) | UNI9177 Reaction to Fire: Class 1

ISO9001:2008	Quality management system
ISO/TS16949:2009	The automotive industry quality management system
ISO14001:2004	Standards for environmental management system
QC080000:2012	The certificate for hazardous substances process management
OHSAS18001:2007	International standards for occupational health and safety

How are standards used?

B. Manufacturers use them to demonstrate value to customers, and build confidence in their product durability

Special-use environments: For example, salt mist corrosion IEC 61701

How are standards used?

C. Specify measurement or test procedures

➔ The same result means the same thing, worldwide

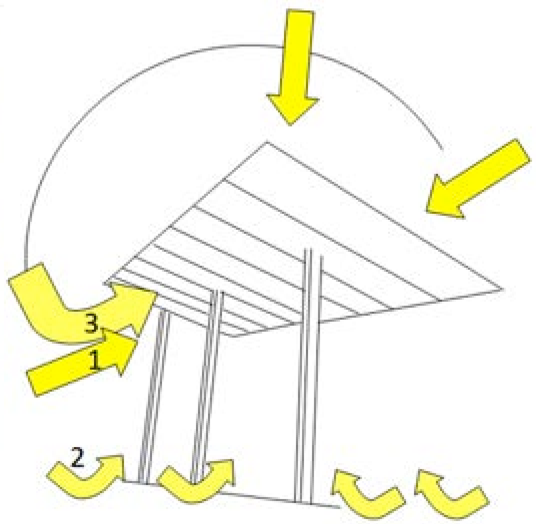
Example of success – performance data are reported according to IEC 61215

Are we underestimating the performance benefits of bifacial PV?

Mar 08, 2016 9:15 AM GMT PVTech

By Joris Libal and Radovan Kopecek

The bifacial PV system on Lake Constance, Germany.



Example of a place where standardization is needed: bi-facial modules.

Work in progress is proposed IEC 60904-1-2.

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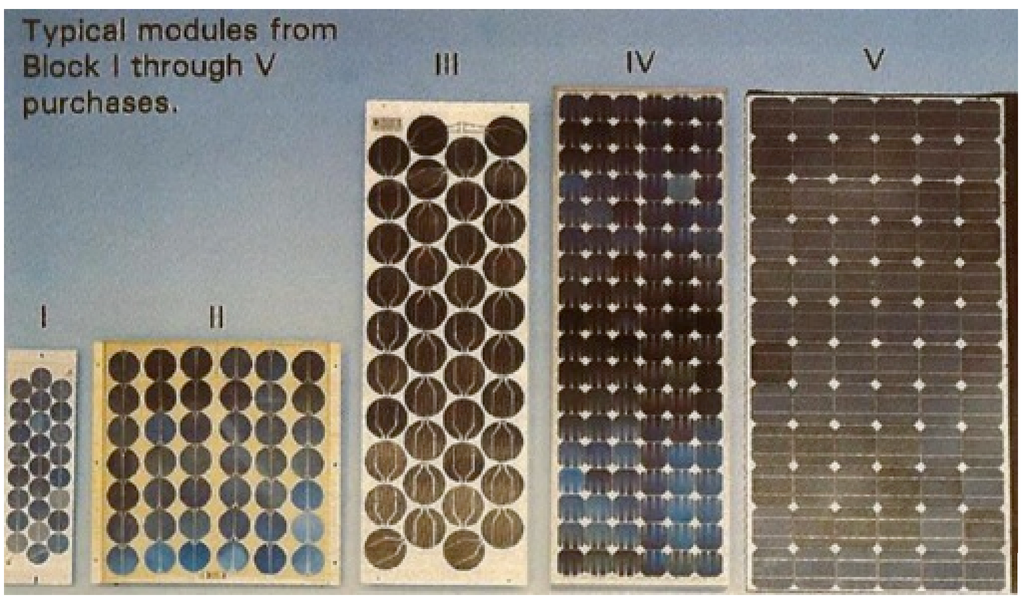
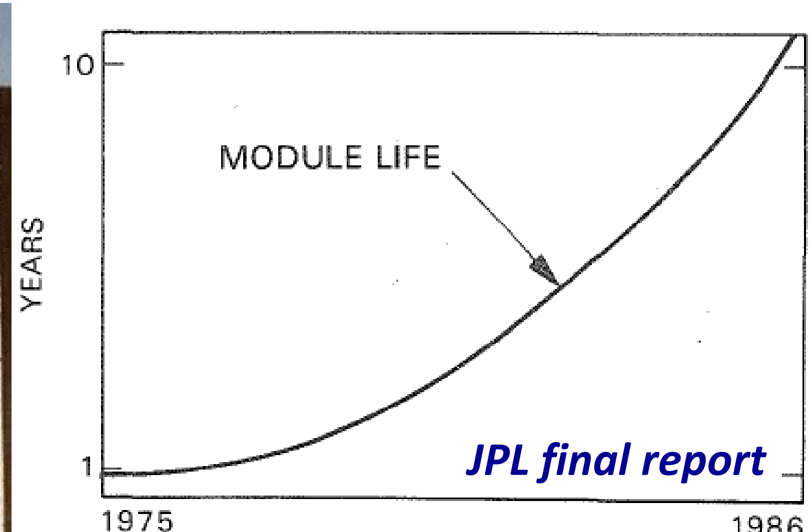
Why are current standards derived from temperate climates?

Roots of PV reliability studies are in Jet Propulsion Laboratory (JPL) series of module block buys (1975-1984)

- **JPL prepared accelerated test specifications**
- **Companies manufactured modules and modified design to pass tests**
- **Modules were deployed outdoors**
- **If there were field failures, tests were modified and the sequence repeated.**



Wohlgemuth, IEEE 43



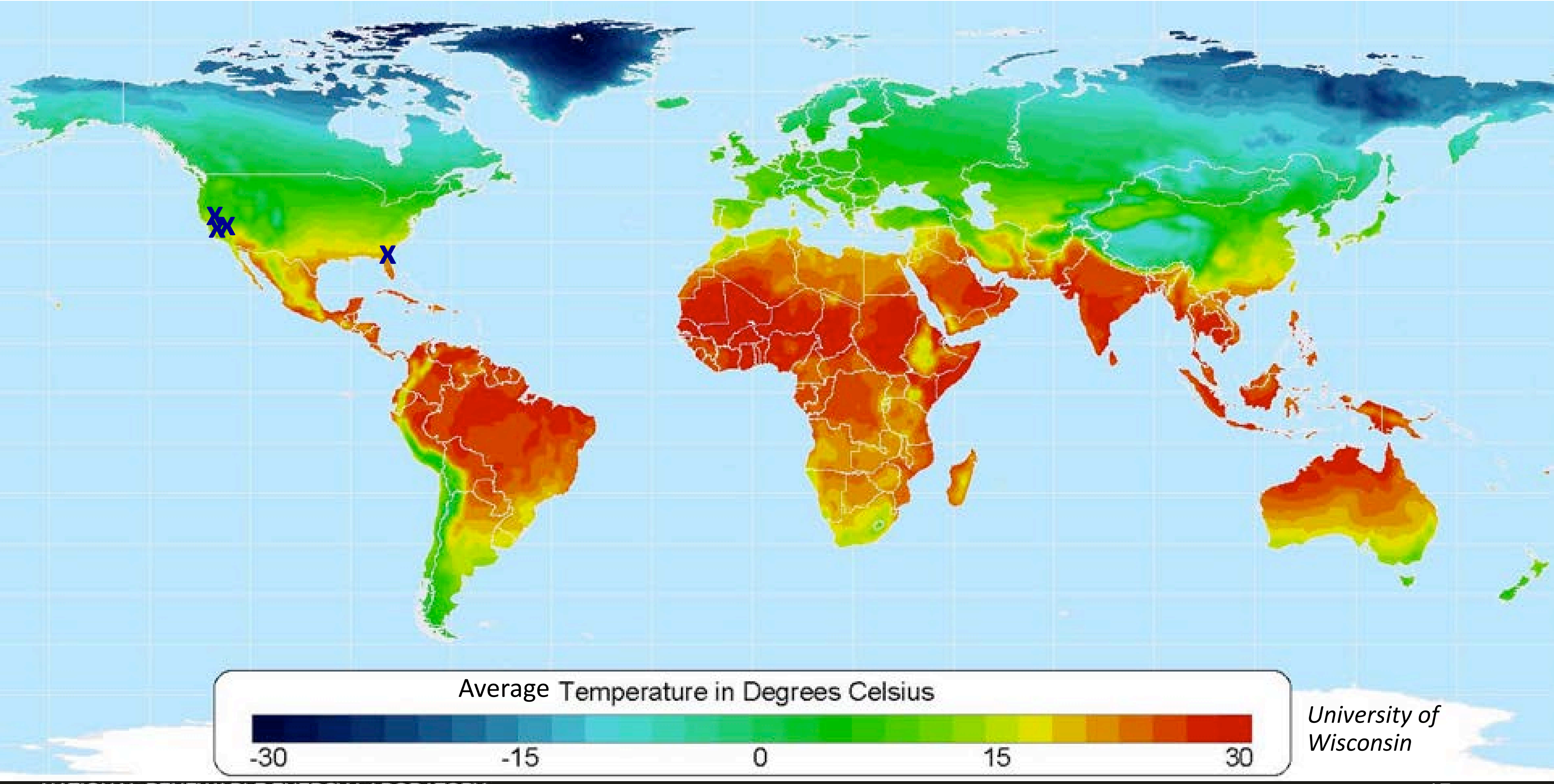
JPL final report

Why are current standards derived from temperate climates?

JPL Block IV sites (x's : Pasadena, Cape Canaveral, Goldstone, Oroville) are warm for United States, but not as hot as some locations where PV is now installed.

Block IV modules were mounted in open racks (cooler than rooftop-mounted)

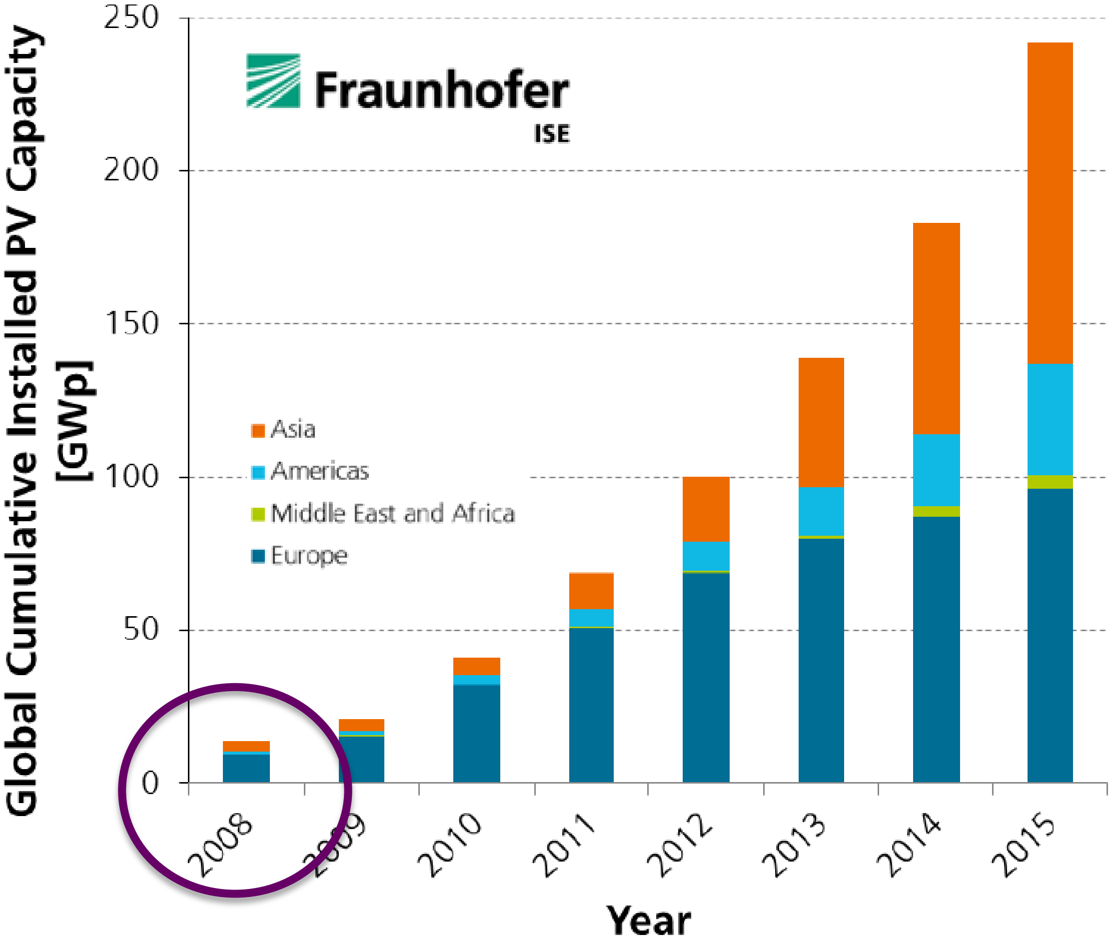
Similar efforts were undertaken in Europe from 1981-1991 (EU specifications 501 to 503)



University of Wisconsin

Why are current standards derived from temperate climates?

- **~10 years ago, most photovoltaic systems were installed in Europe.**
- **Most of the European systems were in Germany (cool climate).**
- **Installations in very hot climates have grown more recently.**



Outline for Background Information

1. What are standards?
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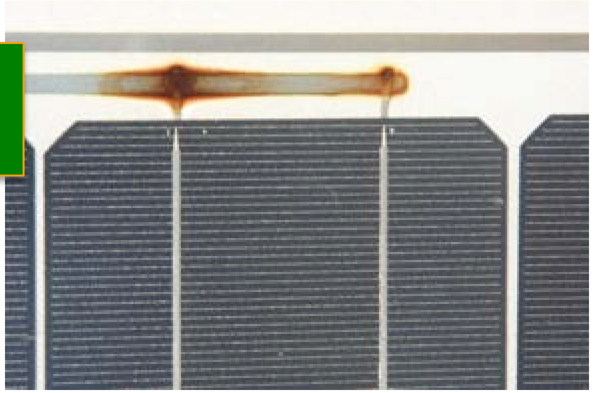
Limits of qualification tests

General methodology to develop tests:

Observe failure or degradation

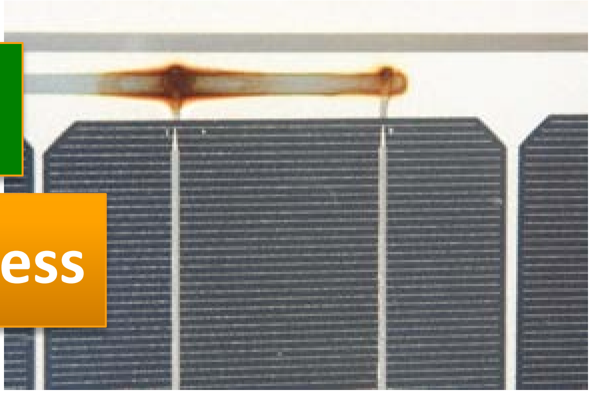


Limits of qualification tests

General methodology to develop tests:

Observe failure or degradation

Identify mechanism or responsible stress



Operation at high temperature?

High humidity?

Changes in temperature?

UV exposure?

Combination of several?

Wind or snow loading?

Something else?

Limits of qualification tests

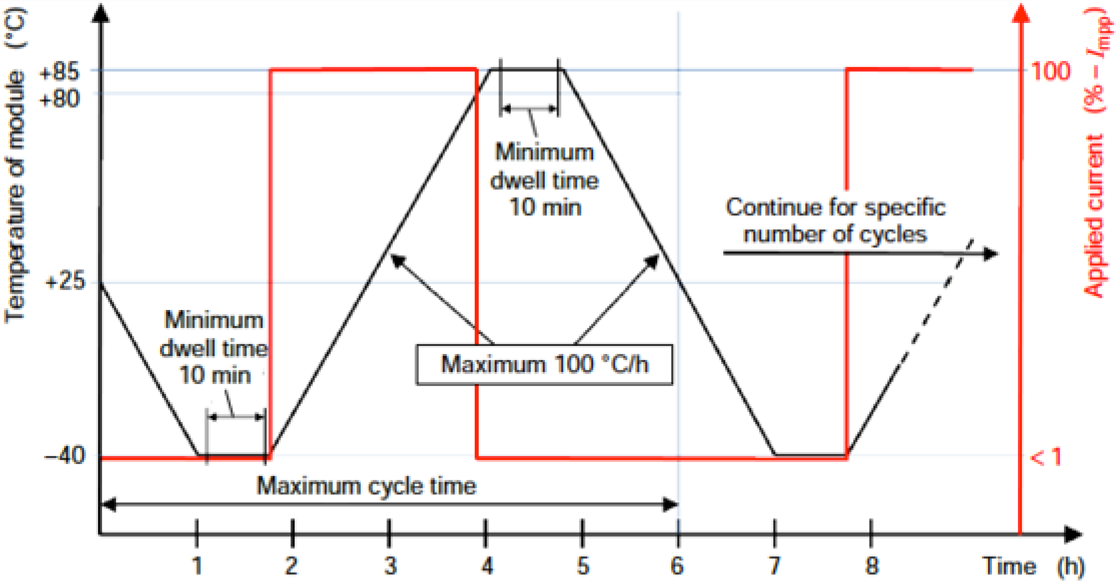
General methodology to develop tests:

Observe failure or degradation

Identify mechanism or responsible stress

Perform laboratory accelerated stress tests (AST's)

Thermal cycling test from IEC 61215-2



Limits of qualification tests

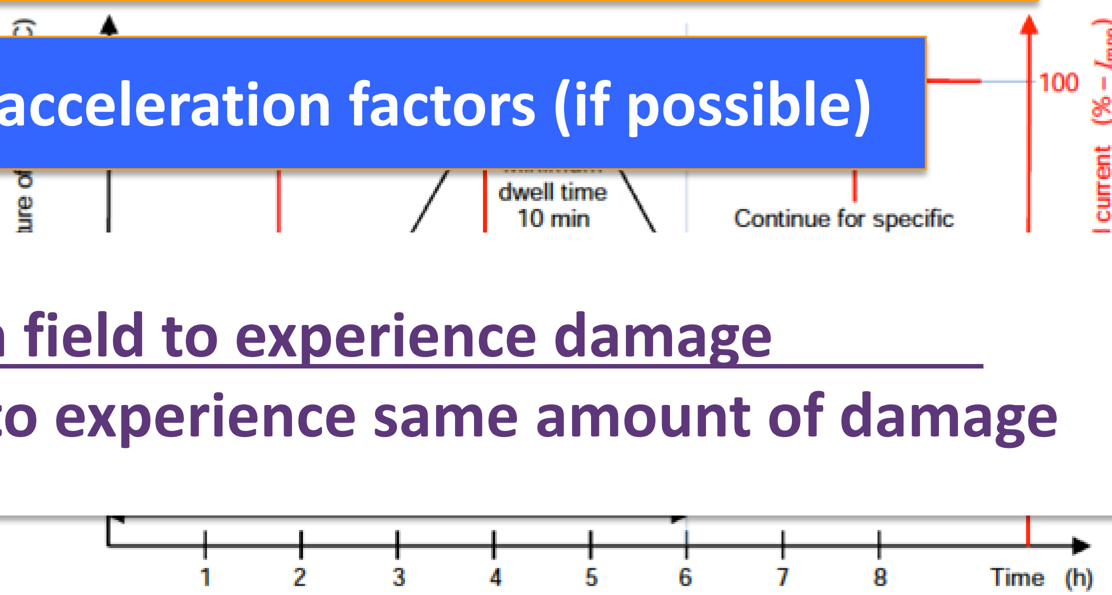
General methodology to develop tests:

Observe failure or degradation

Identify mechanism or responsible stress

Perform laboratory accelerated stress tests (AST's)

Estimate acceleration factors (if possible)



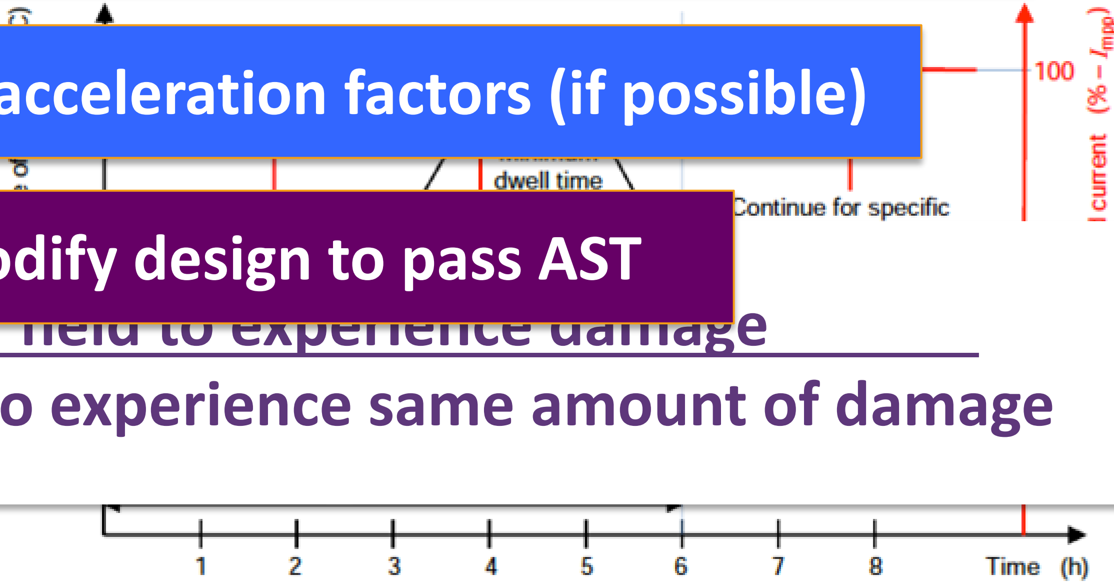
$$A = \frac{\text{time in field to experience damage}}{\text{time in test to experience same amount of damage}}$$

General methodology to develop tests:

- Observe failure or degradation
- Identify mechanism or responsible stress
- Perform laboratory accelerated stress tests (AST's)
- Estimate acceleration factors (if possible)
- Modify design to pass AST

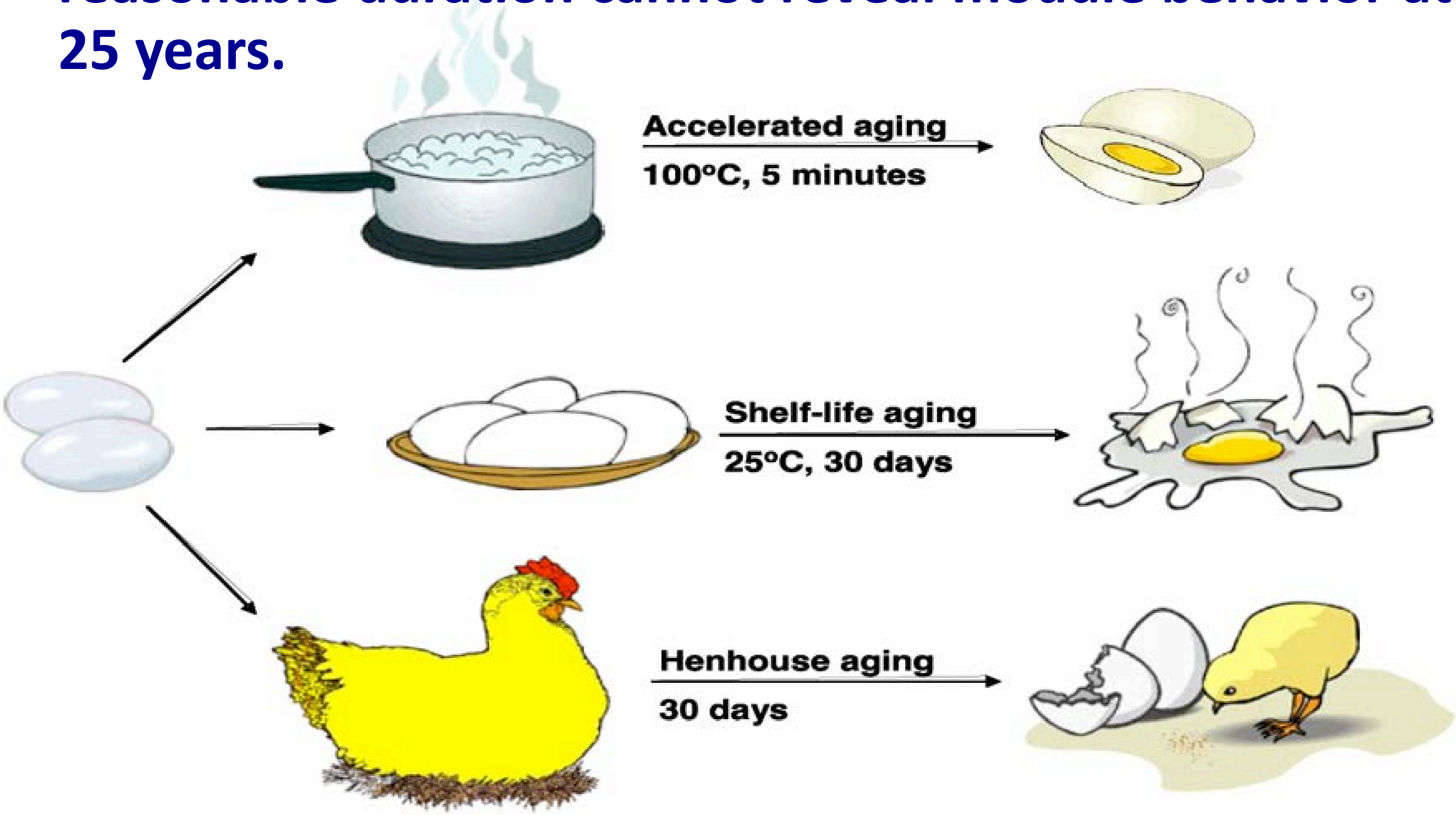
This cycle and development of associated standard typically takes several years.

$$\frac{\text{time in field to experience damage}}{\text{time in test to experience same amount of damage}}$$



Limits of qualification tests

- **Some processes are not easy to accelerate, i.e. a test of reasonable duration cannot reveal module behavior at 25 years.**



Accelerating 25 years into 3 months is like trying to hatch a chick in 6 hours!

Limits of qualification tests

- **Some processes are not easy to accelerate, i.e. a test of reasonable duration cannot reveal module behavior at 25 years.**
- **Uncertainty in acceleration factor (due to variations in field exposure, statistics / product variation, measurement uncertainty)**

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- **New or previously-unobserved mechanisms can occur**

Limits of qualification tests

- Some processes are not easy to accelerate, i.e. a test of reasonable duration cannot reveal module behavior at 25 years.
- Uncertainty in acceleration factor (due to variations in field exposure, statistics / product variation, measurement uncertainty)
- New or previously-unobserved mechanisms can occur

☐ Qualification tests should be considered “price of admission,” not a guarantee of service life (e.g. 25 years)

Conclusions

1. Standards are detailed test documents approved by national and international organizations.
2. Standards are used to set requirements and communicate product value.
3. Some formative reliability work was performed in temperate climates.
4. Hotter climates may benefit from modified accelerated tests.
5. Qualification tests should be considered “price of admission,” not a guarantee of service life

Next Item

1:00	Introduction to Problem	Ingrid Repins
1:30	Experimental Evidence	Dirk Jordan
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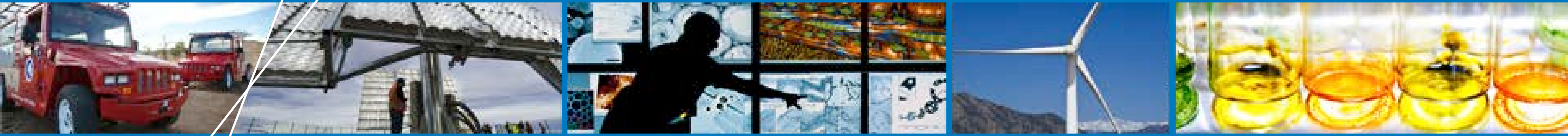
Hot Climates – Experimental Evidence



Solar Power International

Las Vegas, NV

Dirk Jordan, Tim Silverman, Sarah Kurtz

9/12/2016

Outline

- Degradation (rates) curves
- Degradation modes

Why degradation (rates, curves, modes) matter

Degradation

Economic

Technical

$$$

Energy output prediction
Warranty default
Significant impact on LCOE

Chamber tests

Correlation

Field tests

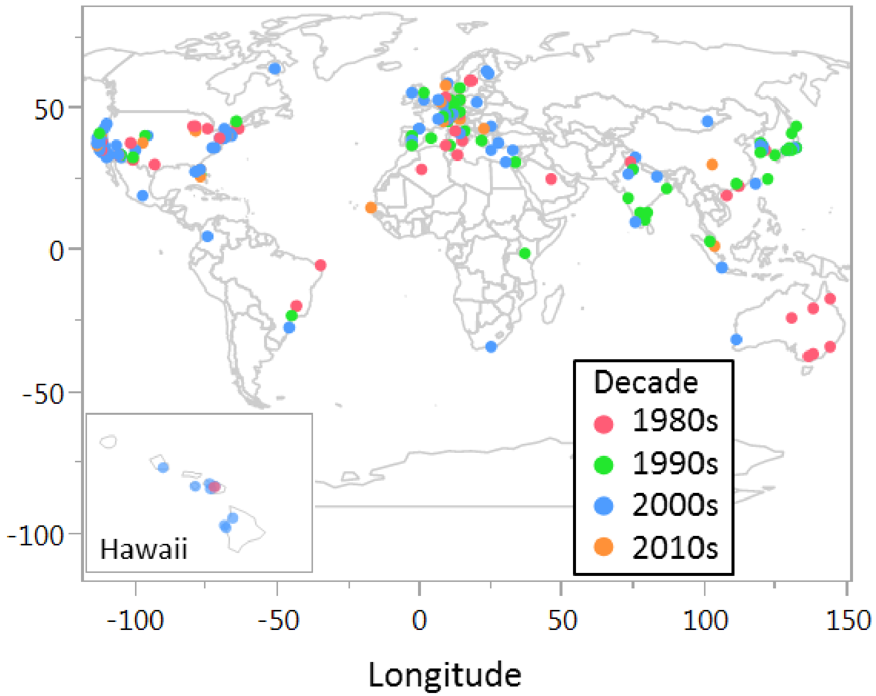
Low cost & Lifetime prediction

- Degradation (rates) curves

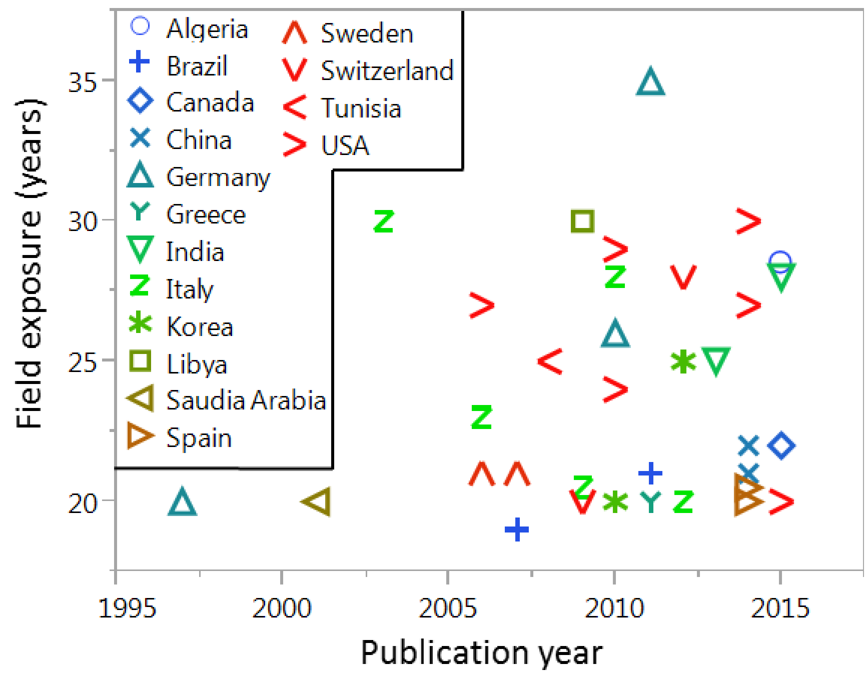
- Degradation modes

> 30 system studies of 20+ years field exposure

Geographic distribution of degradation rates (R_d)



Studies of systems > 20+ years in field

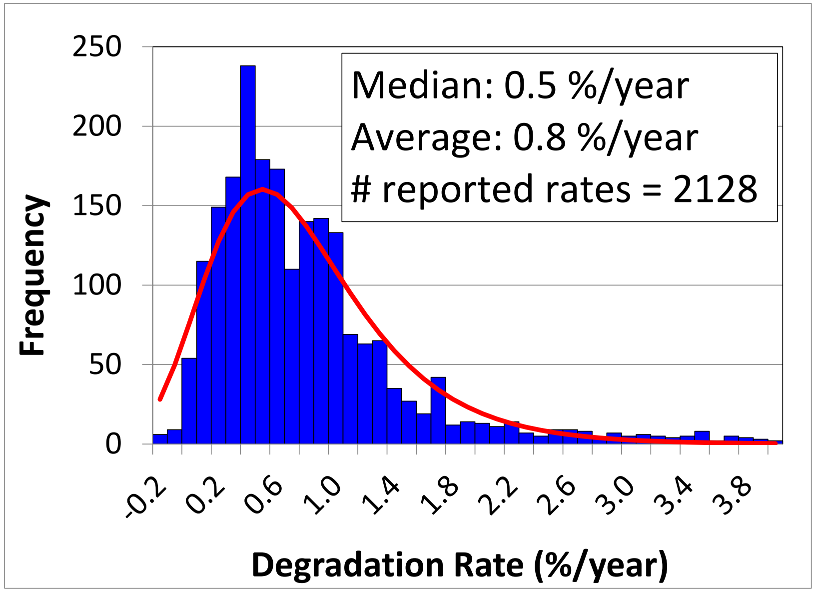


Increased interest in recent years in long-term performance & degradation

Sampling bias is present – representative of the population?

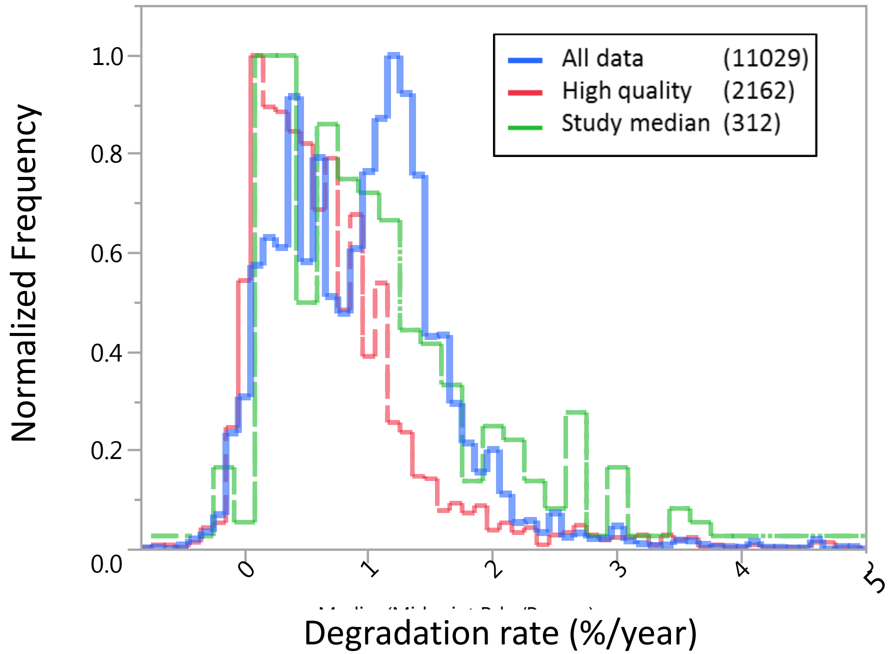
Literature survey

2011



Jordan et al., "Degradation Rates – An Analytical Review", Progress in PV, 2011

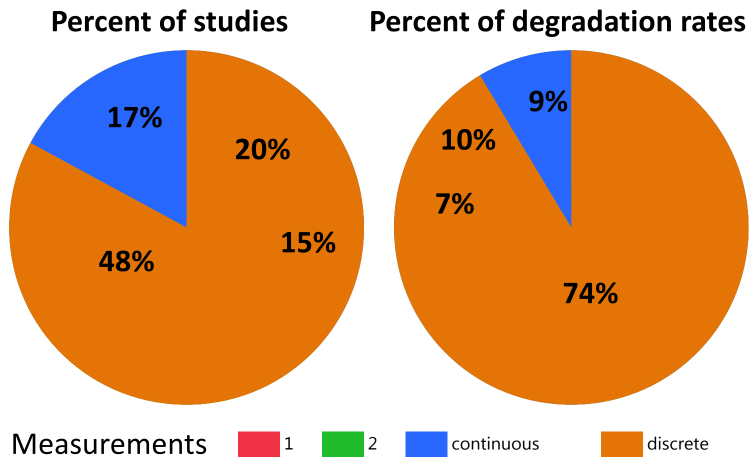
2016



Jordan et al., "Compendium of photovoltaic degradation rates", Progress in PV, 2016

- Few studies with > 1000 modules
- Aggregated distribution is dominated by particular module, system, mounting, method etc.
- Counteract overrepresentation → analyze in different ways
- Median per study & system → second peak disappears
- High quality data (multiple measurements, calibrations etc.) → second peak disappears

Majority of R_d are determined by single measurement.



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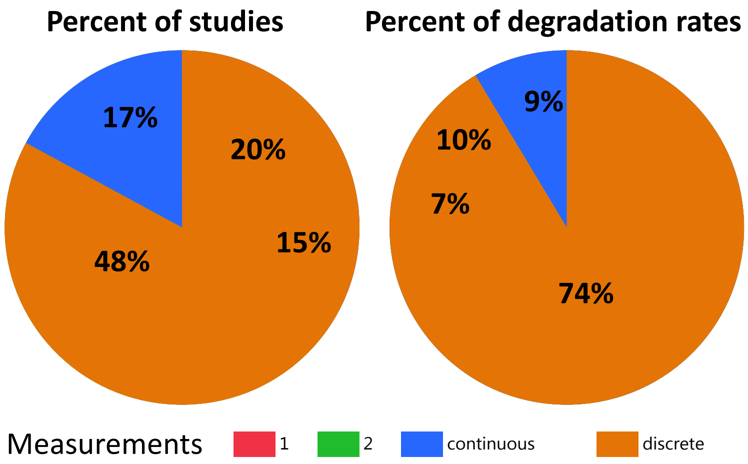
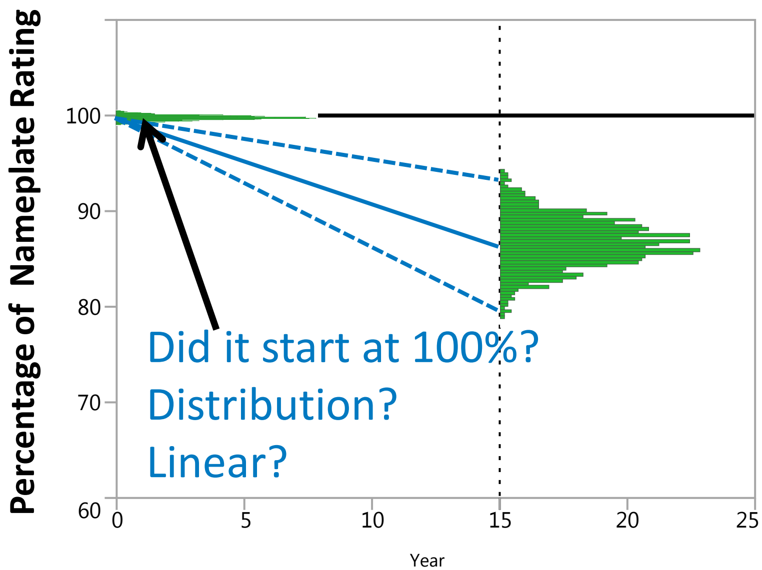


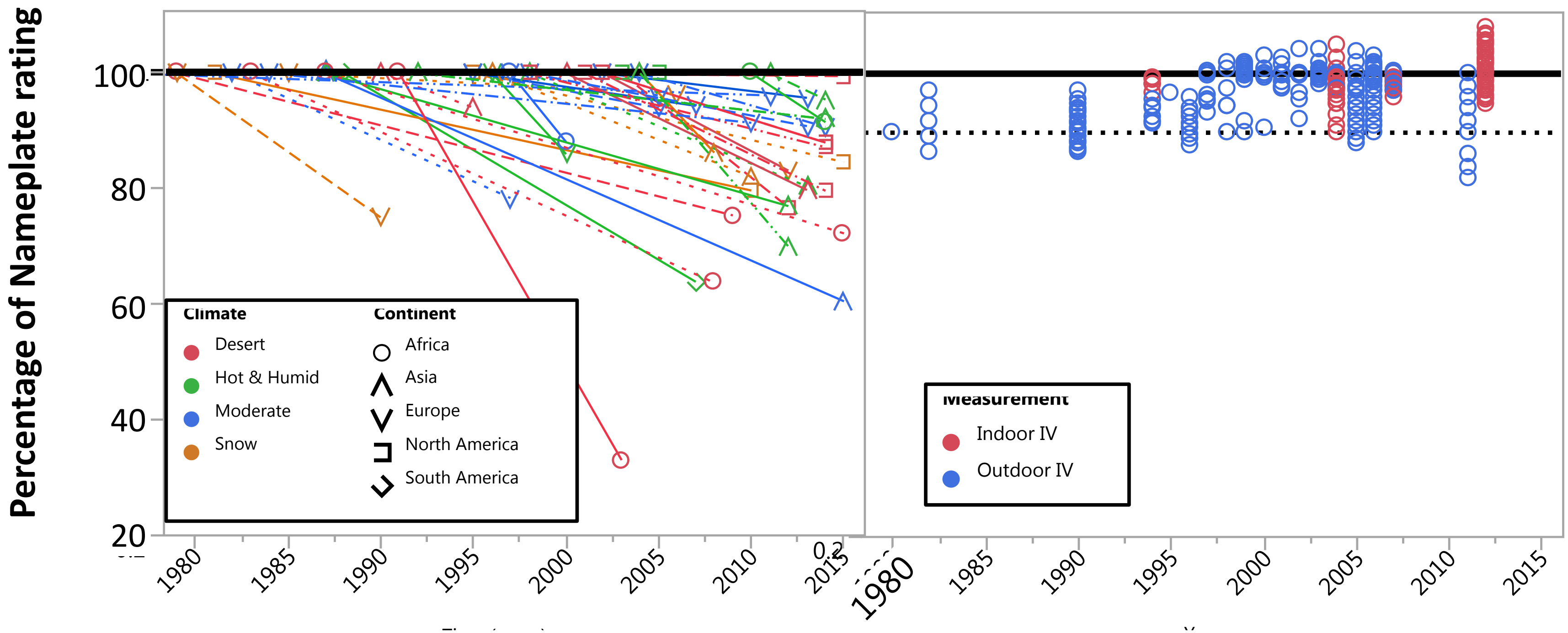
How are R_d determined with 1 measurement?



R_D using nameplate rating may have significant error.

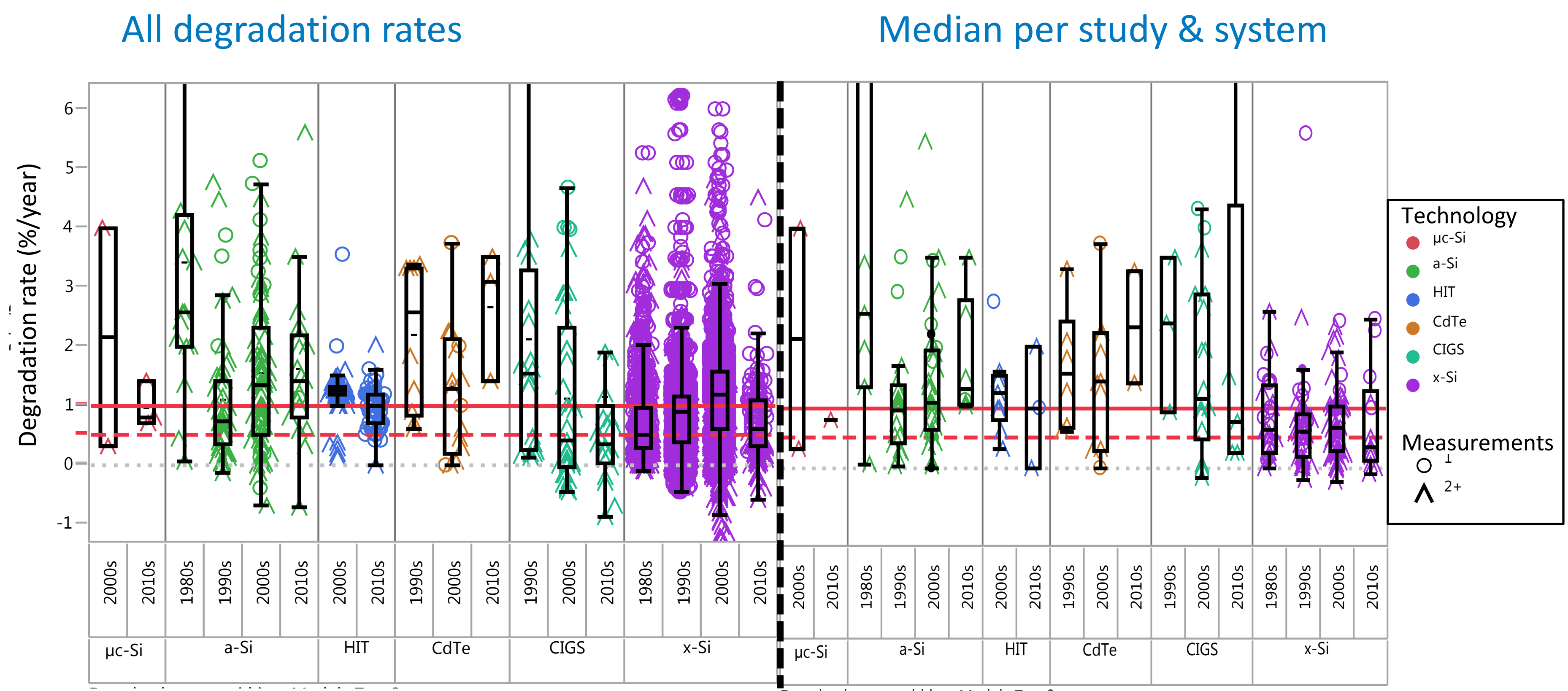
Studies using nameplate rating

Historical deviation from nameplate rating



- Indoor IV seem closer to nameplate rating (though limited data)
- Outdoor seem farther away trending towards nameplate rating. Outdoor data may include light-induced degradation (LID)

Reducing sampling bias x-Si → median 0.5 - 0.6, mean 0.8 %/year



Significant difference between all R_d & median per study & system

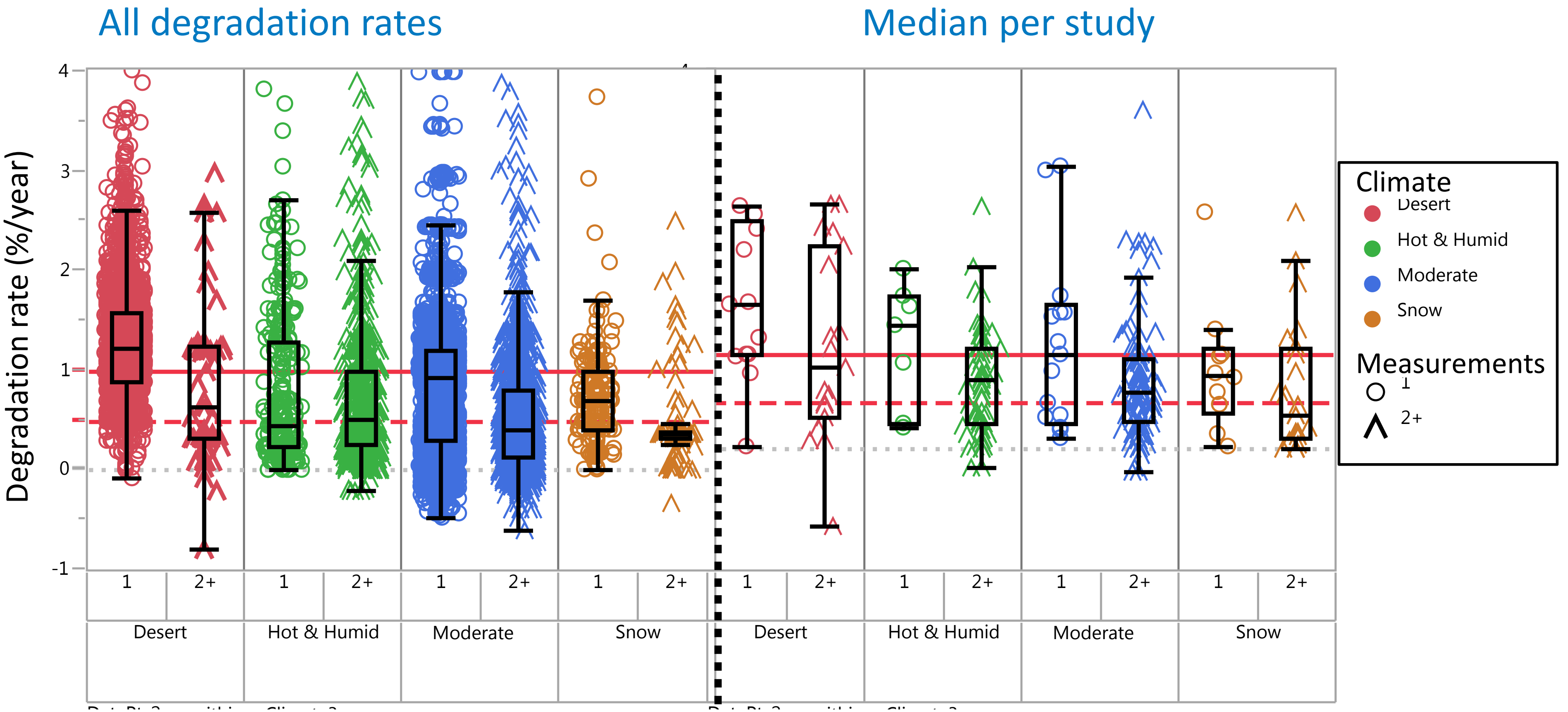
a-Si R_d > 1 %/year

Hetero interface (HIT) R_d similar to a-Si than x-Si

CIGS around 0.5 %/year

Hotter climates may show higher R_d

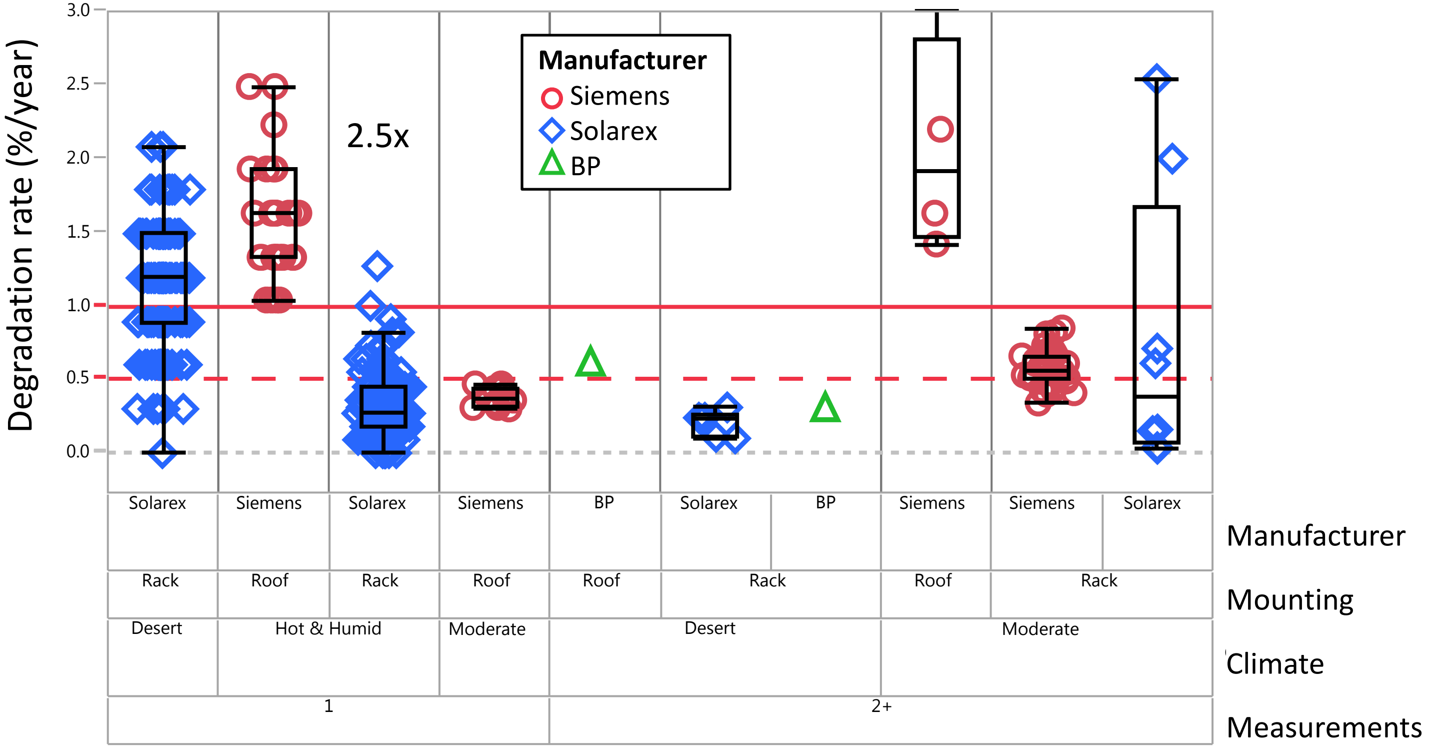
Climate category: simplified Köppen-Geiger



1-measurement studies show statistically significant higher rates

Hotter climates may show slightly higher R_d

Some modules more susceptible to hotter climates & mounting.



Solarex:

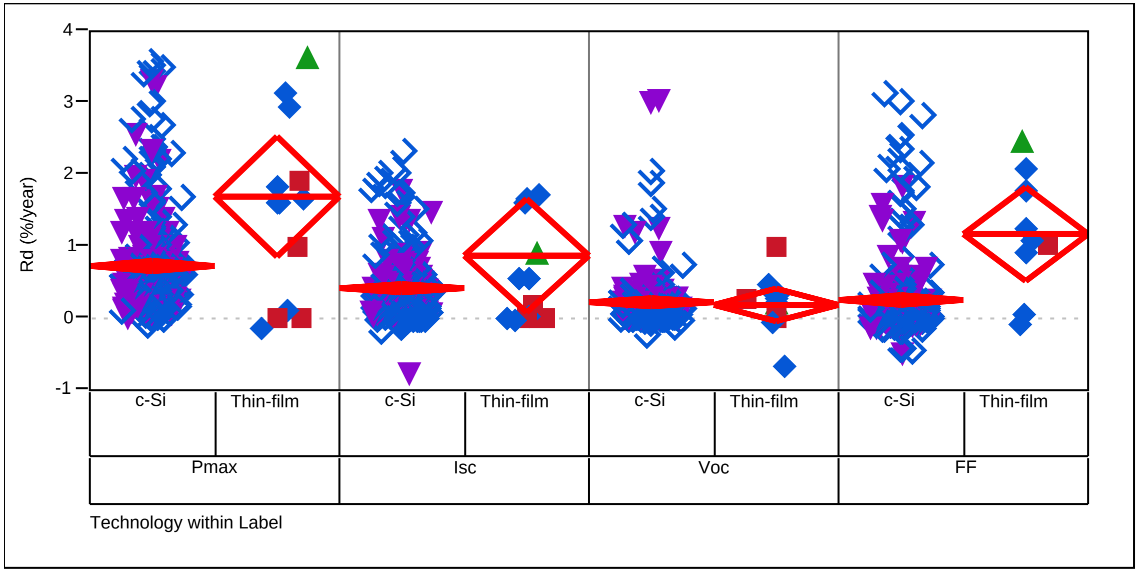
- Show low median R_d across climates
- Desert (1-measurement) shows higher R_d → 1-axis tracker & 2.5x concentration

Siemens:

- Roof mounting shows higher R_d even for moderate climate
- Hot & Humid shows higher R_d than Solarex

Some manufacturers differentiate degradation by climate

Hot & Humid Climate



Thin-film show high FF R_d in humid climates

First Solar

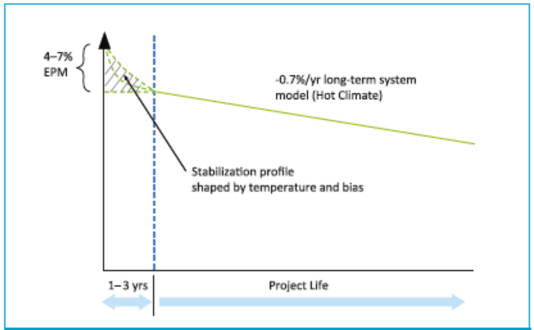


Figure 5. First Solar CdTe PV system degradation profile.

First Solar recommendation:
-0.7%/year for hot climate
-0.5%/year for all other climates

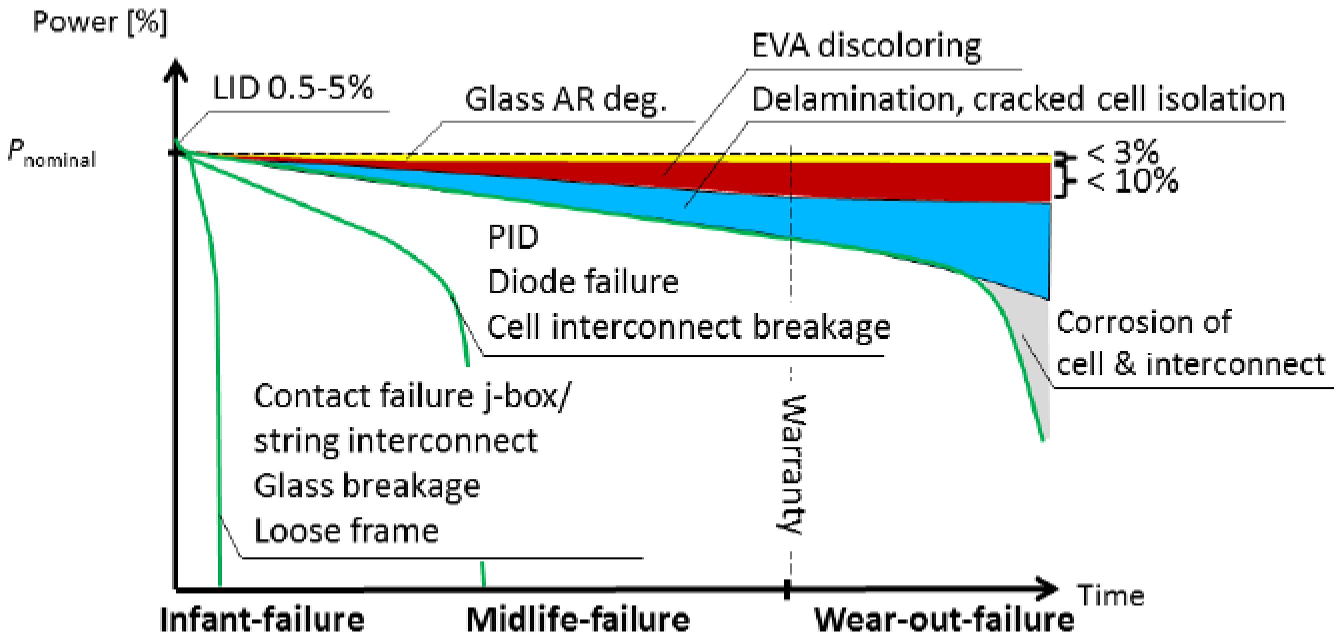
Different long-term performance recommendation based on climate

Strevel et al., 17th edition Journal Photovoltaics International, 2012

- Degradation (rates) curves
- Degradation modes

Timeline of PV module degradation modes

Early life and wear-out phase



Difficulties:

1. Outdoor data tend to be noisy

2. Modules often show multiple degradation modes present at the same time.

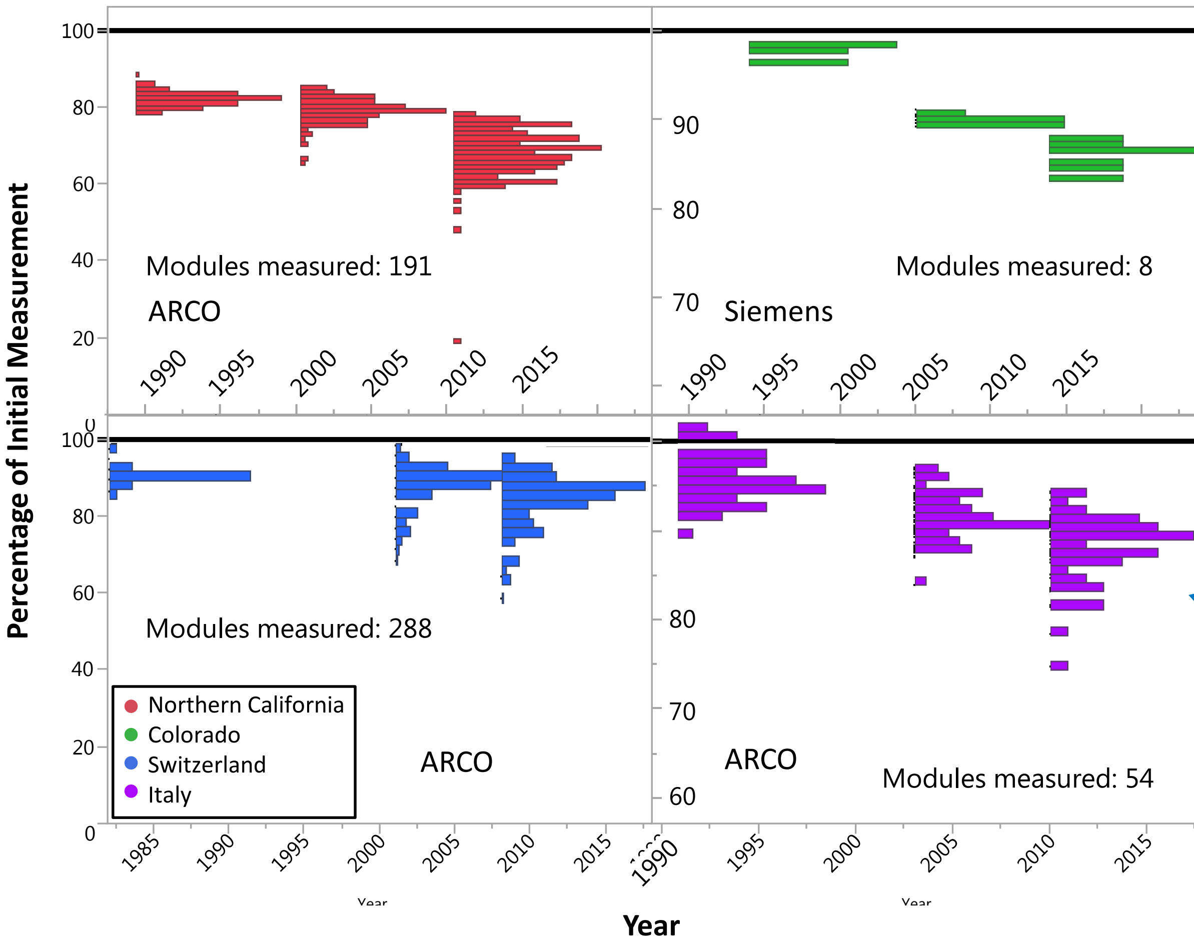
Köntges et al., IEA PVPS Task 13, 2014

Appears linear for most modules, worst modules non-linear

Studies that measured sample modules several times in 20+ years

20 years

30 years

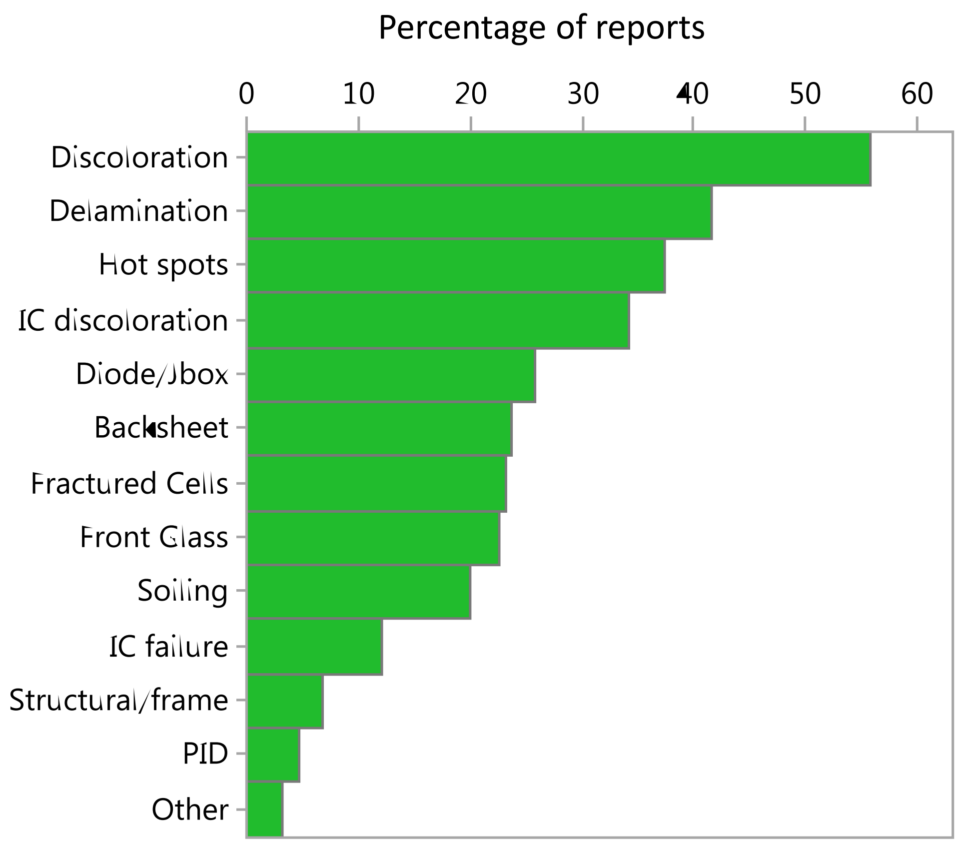


1st measurement taken after 11 years

Distribution skews towards low end → worse performing modules show some non-linearity

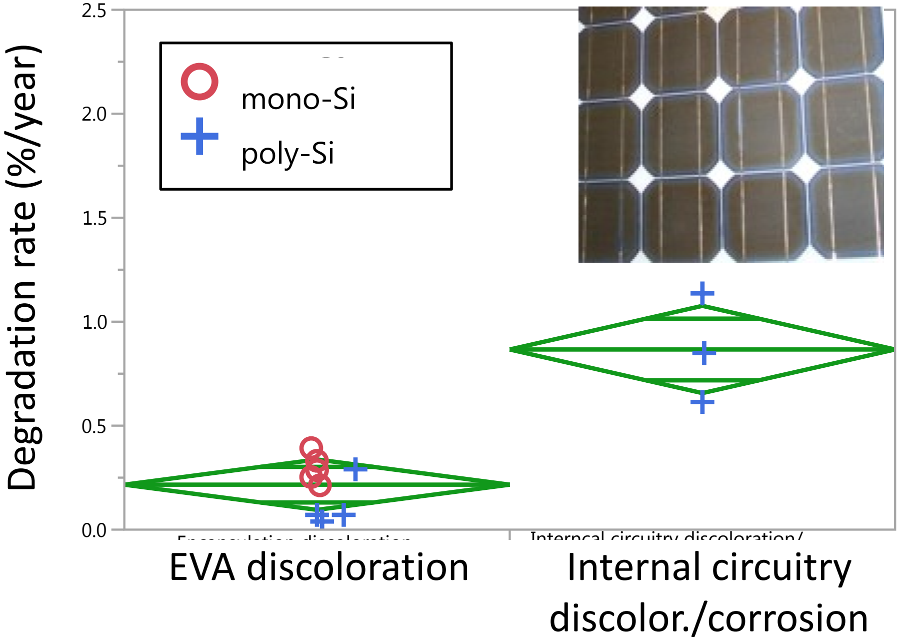
Central tendency & better modules → fairly linear

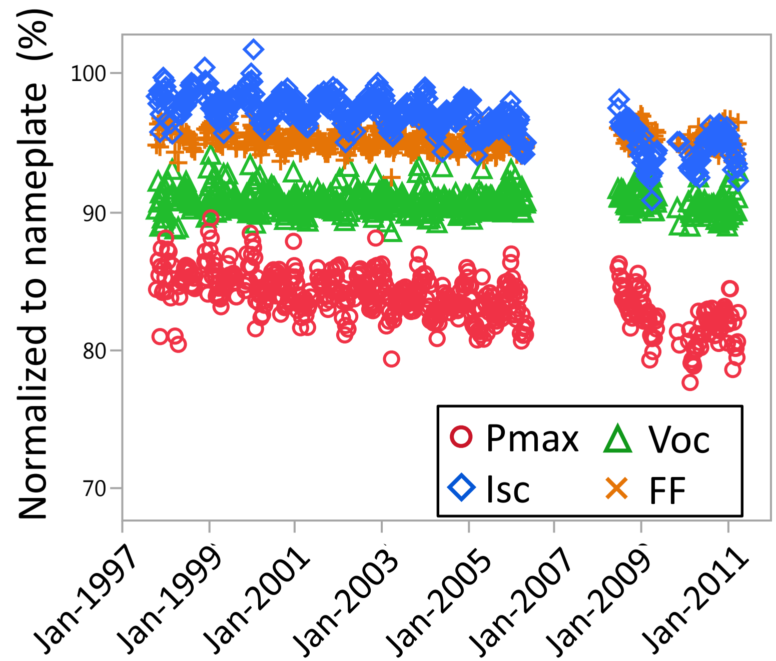
Literature degradation modes



… but is that the most important effect?

Encapsulation discoloration associated with small power loss



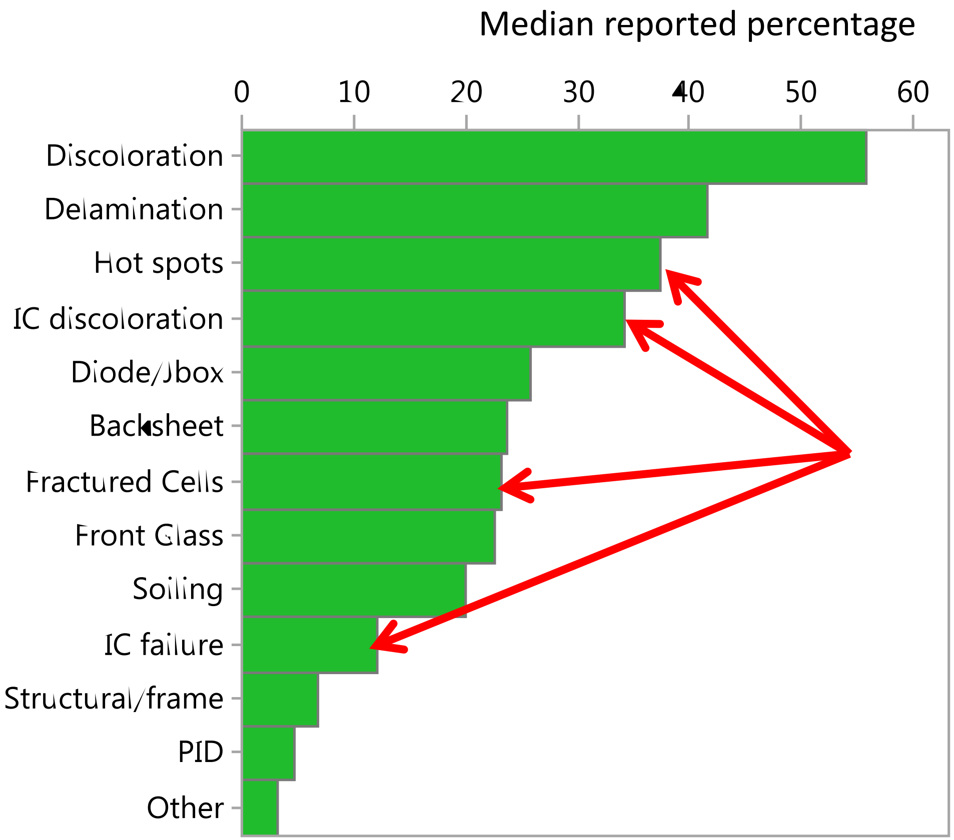


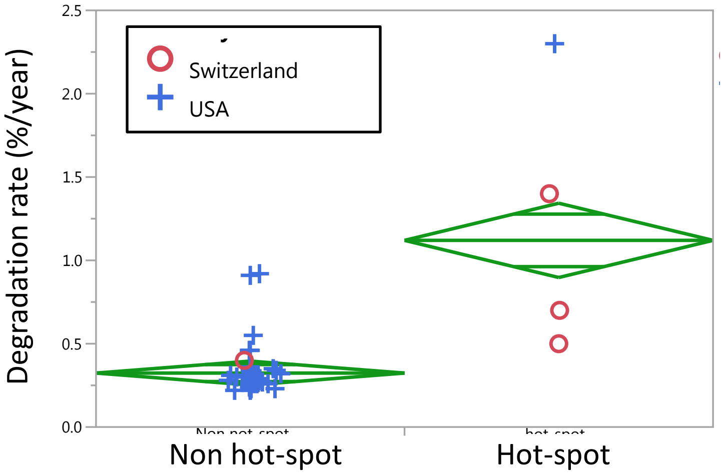
Jordan, et al., 35th PVSC, Honolulu, HI, USA, 2010.

Encapsulant discoloration associated with lower power loss in direct comparison.

Encapsulant discoloration shows linear decline below 0.5 %/year, dominated by Isc losses.

Modules with hot-spots exhibit higher power loss





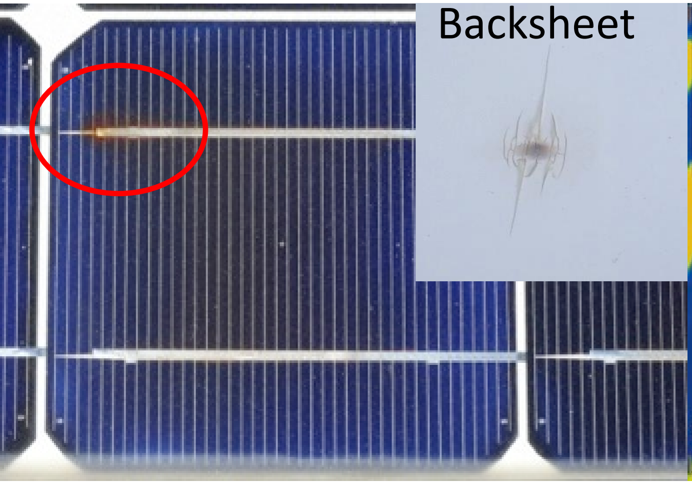
Hot-spots can have several causes such as cracked cells or solder bond failure.

Modules with hot-spots in 1-1 comparison studies showed higher power loss than modules without.

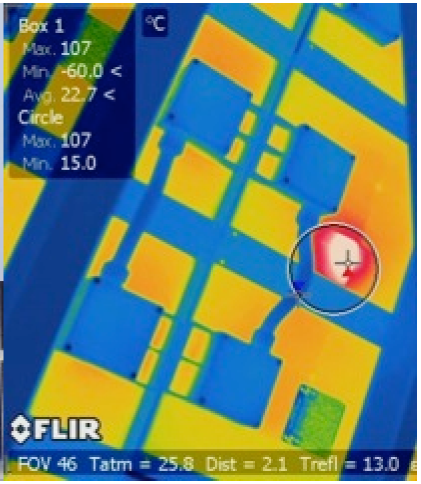
Single solder bond failure causing hot-spot

Solder bond on cell busbar causing hot-spot in 22 year old mono-Si system

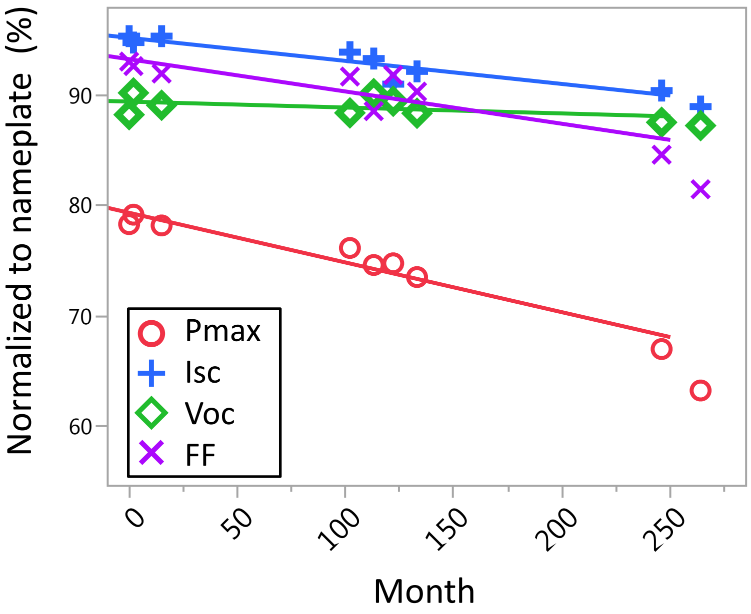
String IV measurements



Visual image of affected cell



IR image of the back



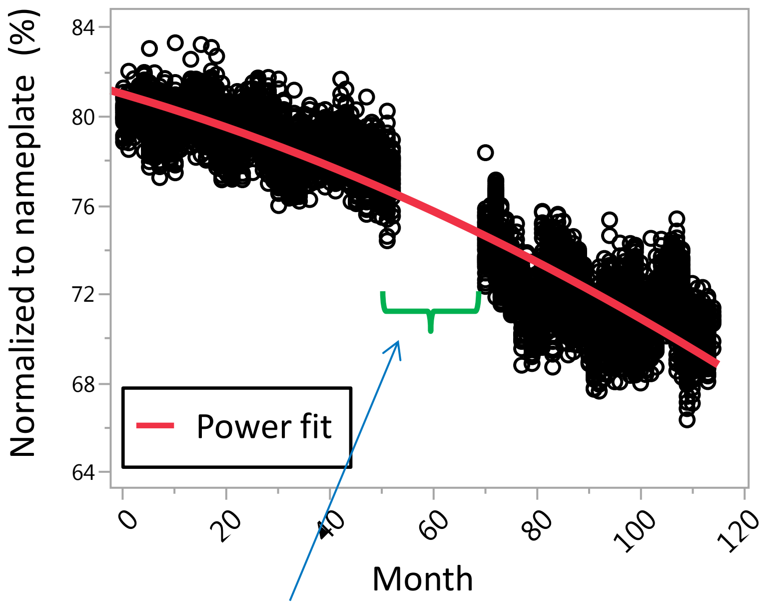
Siemens M55 model
Module was replaced
Only replacement out of 280 modules

The first 20 years decline appears to be around 0.5 %/year.

More rapid decline associated with FF loss.

Multiple solder bond fatigues causing non-linearities

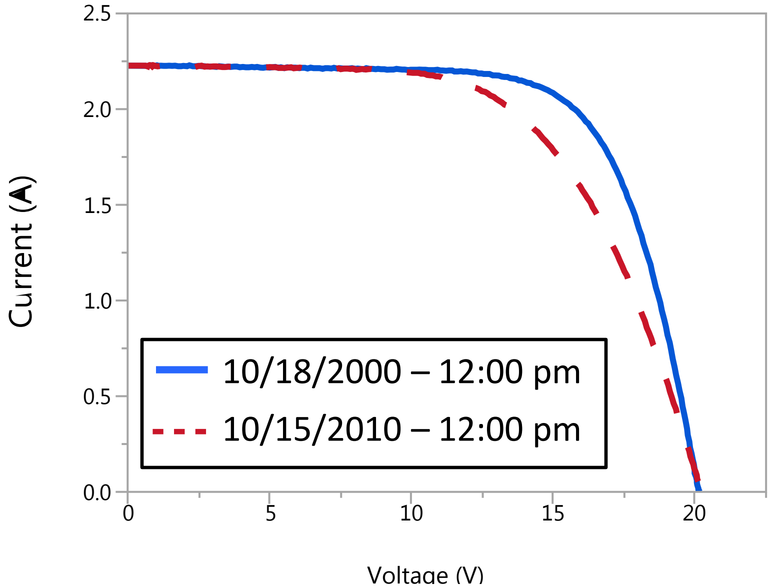
Continuous Pmax data



Module exposed outside but problems with data acquisition

Temperature correction to 48C

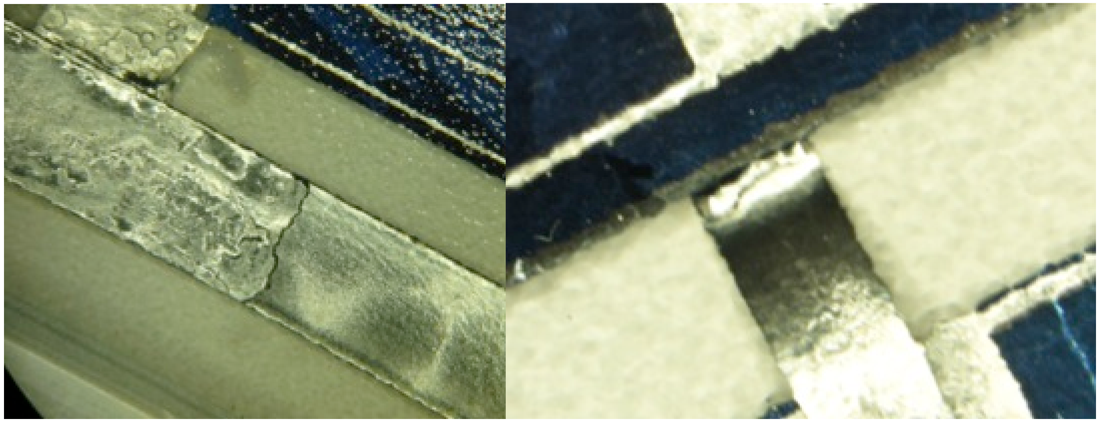
I-V curves



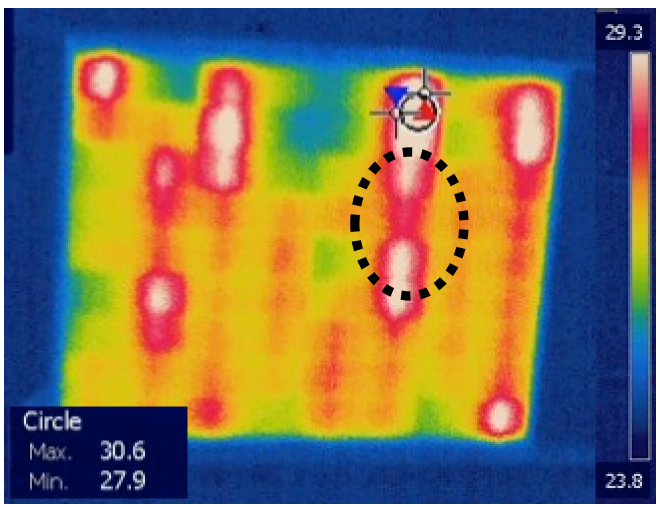
Non-linearity due to solder bonds can be seen in thermal cycling testing.*

*Herrmann, et al., 37th PVSC, Seattle, USA, 2011.

Solder bond fatigue – non-linear

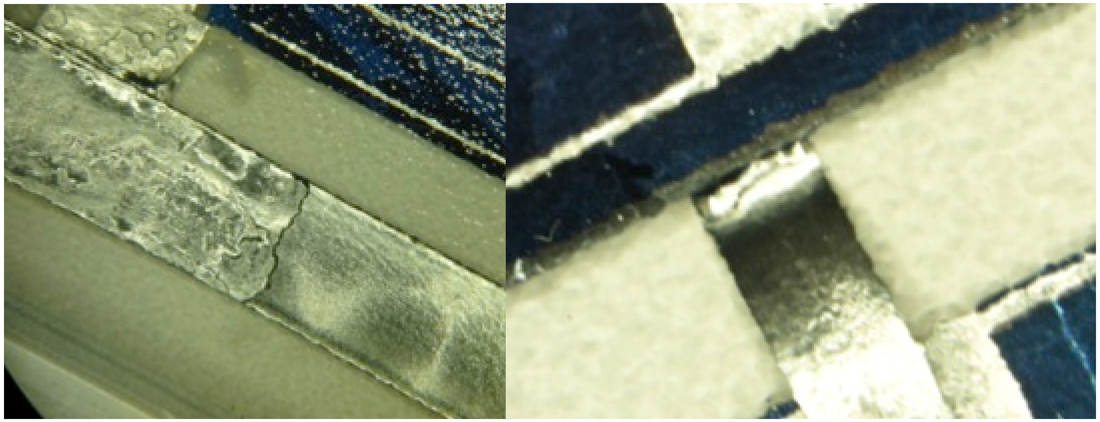


Cracks in interconnect ribbons but haven't failed yet.

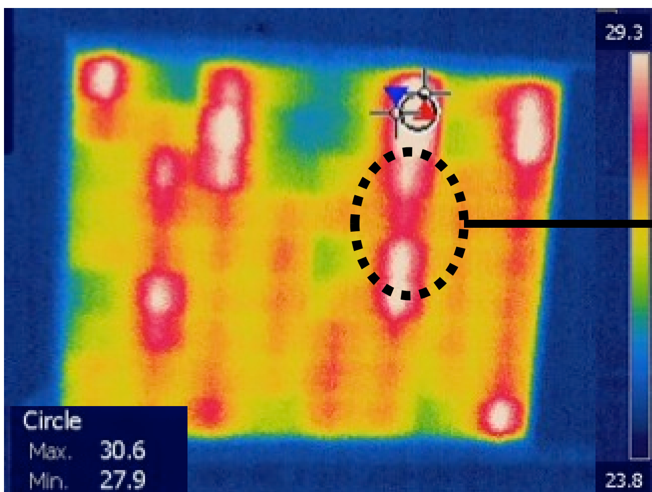


IR image shows hot-spots along cell interconnect ribbons

Solder bond fatigue – non-linear



Cracks in interconnect ribbons but haven't failed yet.

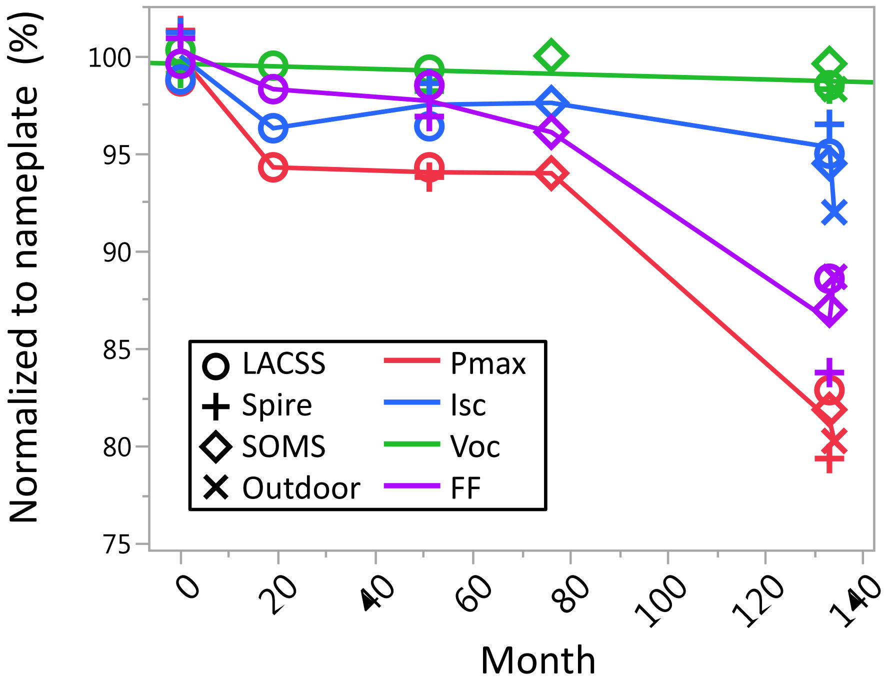


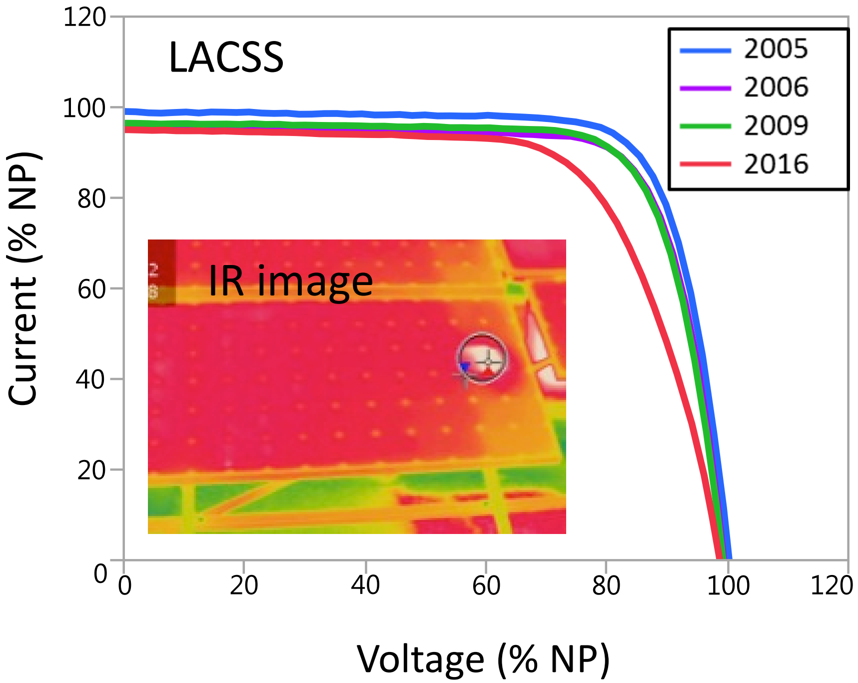
IR image shows hot-spots along cell interconnect ribbons

EL shows change of connectivity when pressure is applied

Cracked cell causing non-linearity

I-V measurements





LACSS: large area solar simulator
Spire: indoor flash tester
SOMS: standard outdoor measurement system
Outdoor: Daystar field measurements

- Module was stable for several years
- Now we see more precipitous decline associated with FF losses, Rs increase

Risk priority number can quantify risk

Failure Mode & Effect Analysis (FMEA) uses risk priority number

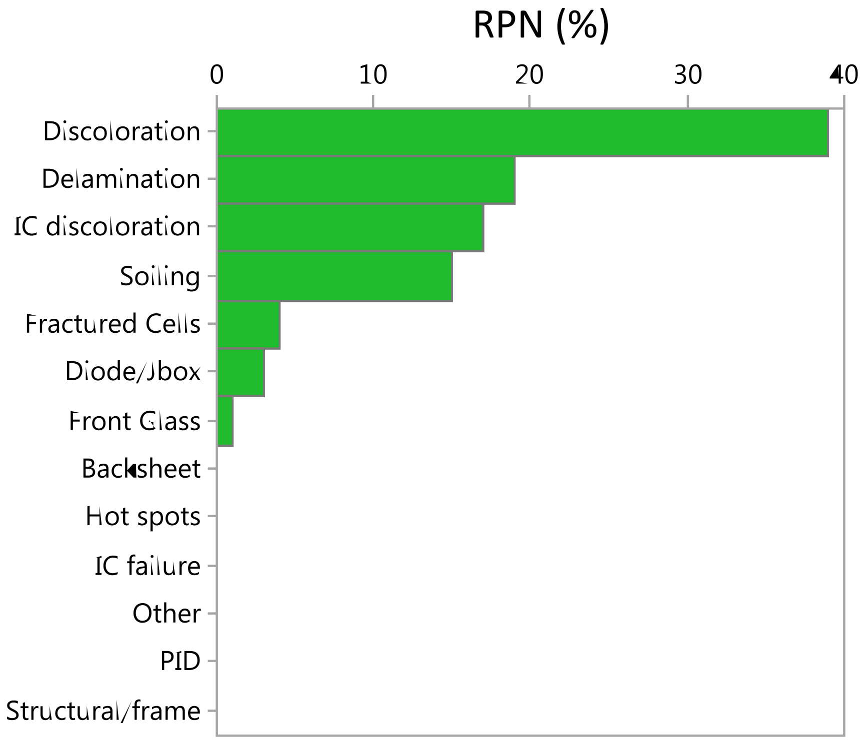
Risk priority number (RPN) = Occurrence * Severity * Detectability

= Number of reports*Number of affected modules * Severity * ~~Detectability~~

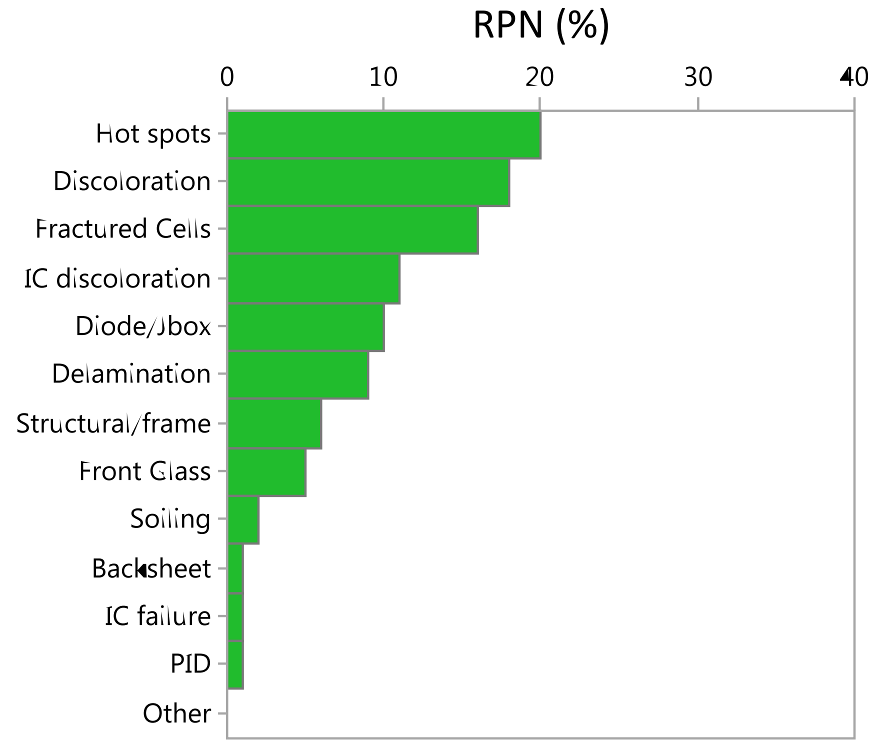
Severity	Rating
Major impact on power & unsafe	5
Major impact on power	4
Significant impact on power	3
Slight deterioration of performance	2
No effect on performance	1

Hot spots & fractured cells have become more important recently

Older installations – before 2000



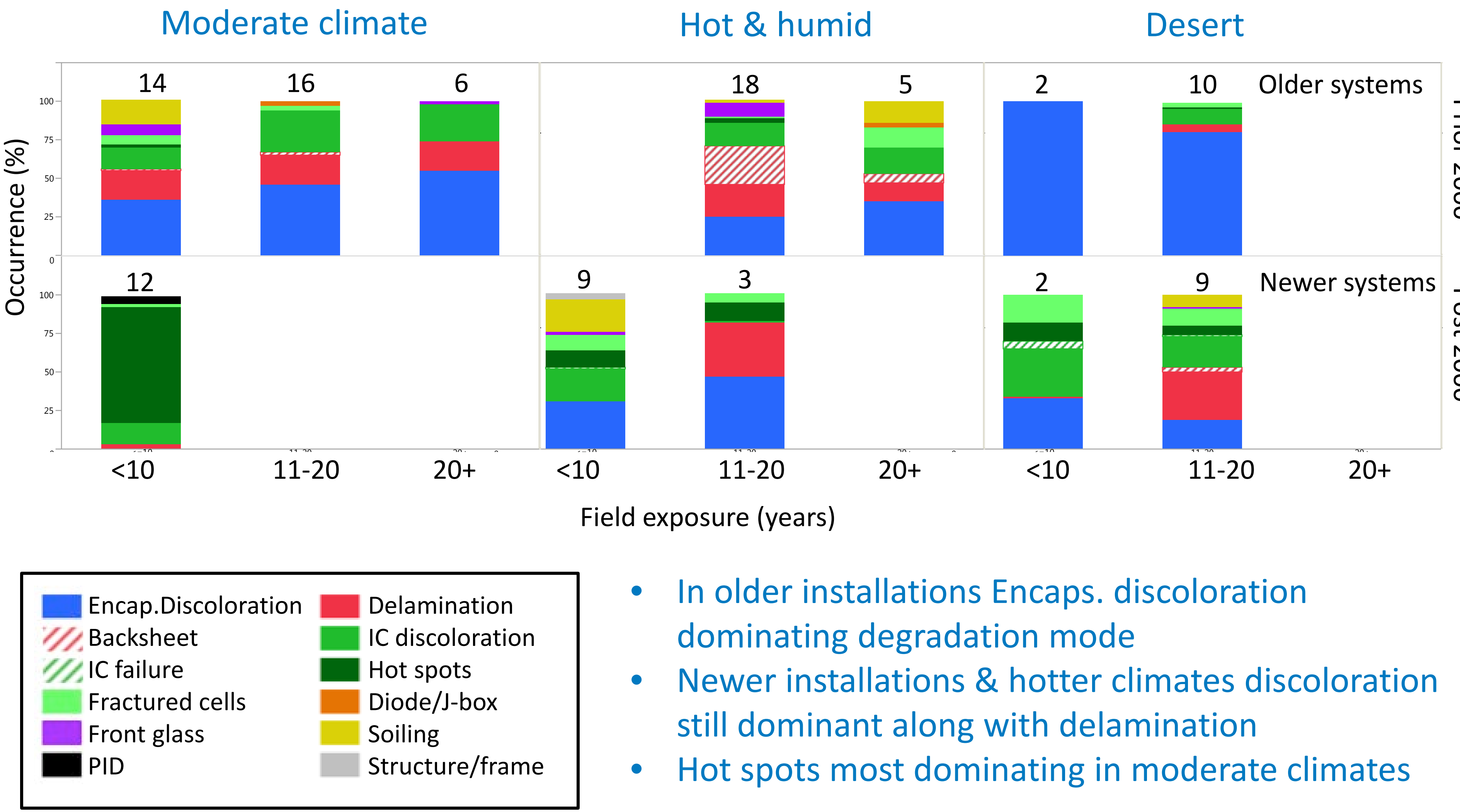
Newer installations – after 2000



Older installations most important factor was discoloration because large number of modules affected by it

Newer installations most important factors are hot spots & fractured cells. Modules affected are rather small but more publications reporting it.

Hot climates show discoloration, delamination & hot spots



- In older installations Encaps. discoloration dominating degradation mode
- Newer installations & hotter climates discoloration still dominant along with delamination
- Hot spots most dominating in moderate climates

Summary

- Increased R_d in hotter climates & mounting configurations for some products but maybe not all products.
- x-Si has median in 0.5 – 0.6 %/year range, mean in 0.8 %/year range
- Discoloration is the most commonly observed failure mode but is associated with less power loss. It is still common in newer systems an hotter climates.
- In contrast, hot-spots are not as frequently observed but show greater power losses, more prevalent in newer systems.

Acknowledgments

Thank you for your attention

NREL reliability group

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Golden, CO 80401, USA
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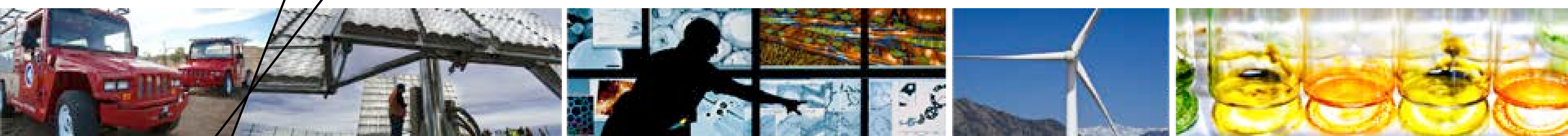
This work was supported by the U.S. Department of
Energy under Contract No. DE-AC36-08-GO28308
with the National Renewable Energy Laboratory

Why the highest temperatures are the most stressful to PV modules during thermal cycling



Nick Bosco
National Renewable Energy Laboratory
Golden Colorado USA

Motivation

Observations of higher rates of degradation due to series resistance increases in hotter climates

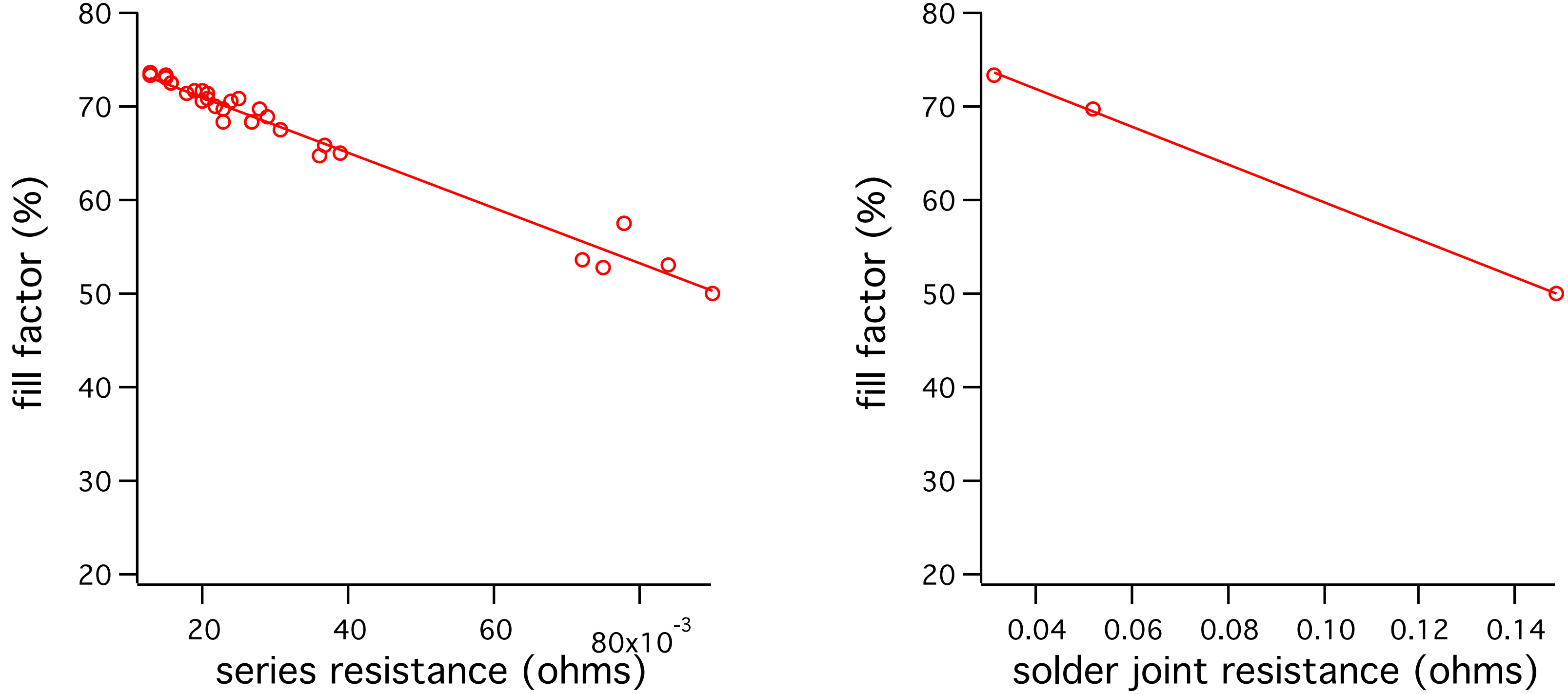
Climatic Zone	Pmax(%/year)	Isc(%/year)	Voc(%/year)	FF(%/year)

All-India Survey of Photovoltaic Module Degradation: 2013
Rajiv Dubey, Shashwata Chattopadhyay, Vivek Kuthanazhi,
Jim Joseph John, B. M. Arora, Anil Kottantharayil, K. L. Narasimhan, Chetan S. Solanki, Vaman Kuber and Juzer Vasi
National Centre for Photovoltaic Research and Education Indian Institute of Technology Bombay
Powai, Mumbai 400076, India
and
Arun Kumar and O. S. Sastry
Solar Energy Centre
National Institute of Solar Energy Gwalpahari, Gurgaon, Haryana 122003, India

motivation

Observations of higher rates of degradation due to series resistance increases in hotter climates

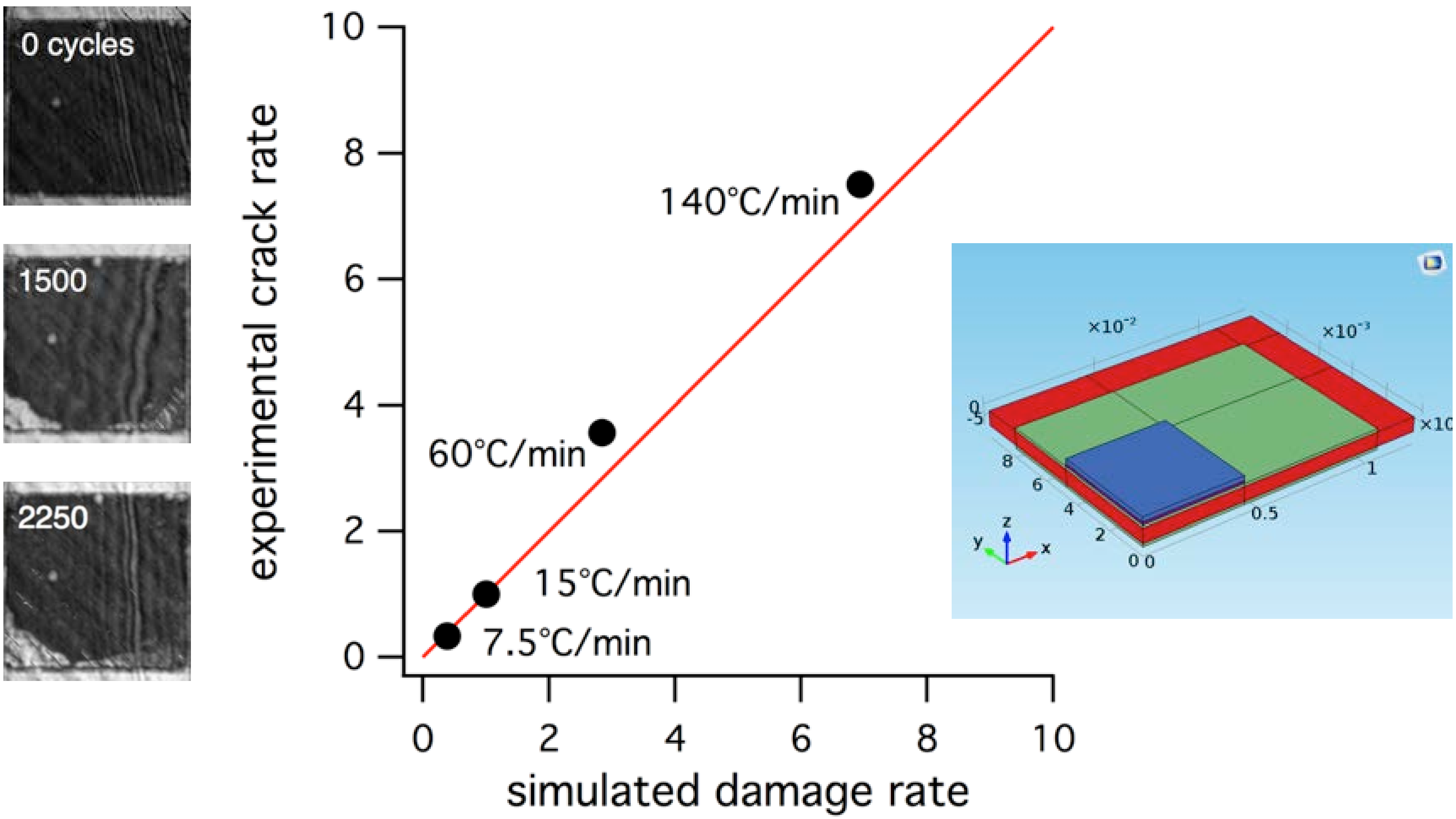
Individual cell level measurements on module deployed in Phoenix for 18 years



Data courtesy of:
Abhishiktha Tummala and Govindasamy Tamizhmani
Photovoltaic Reliability Laboratory
Arizona State University

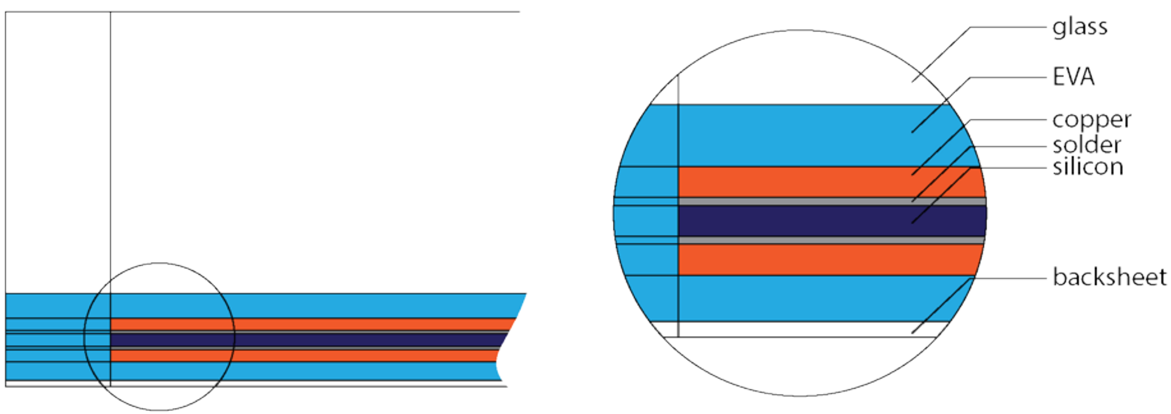
Approach

FEM is in excellent agreement with thermal cycling experiments of PbSn solder bond fatigue.



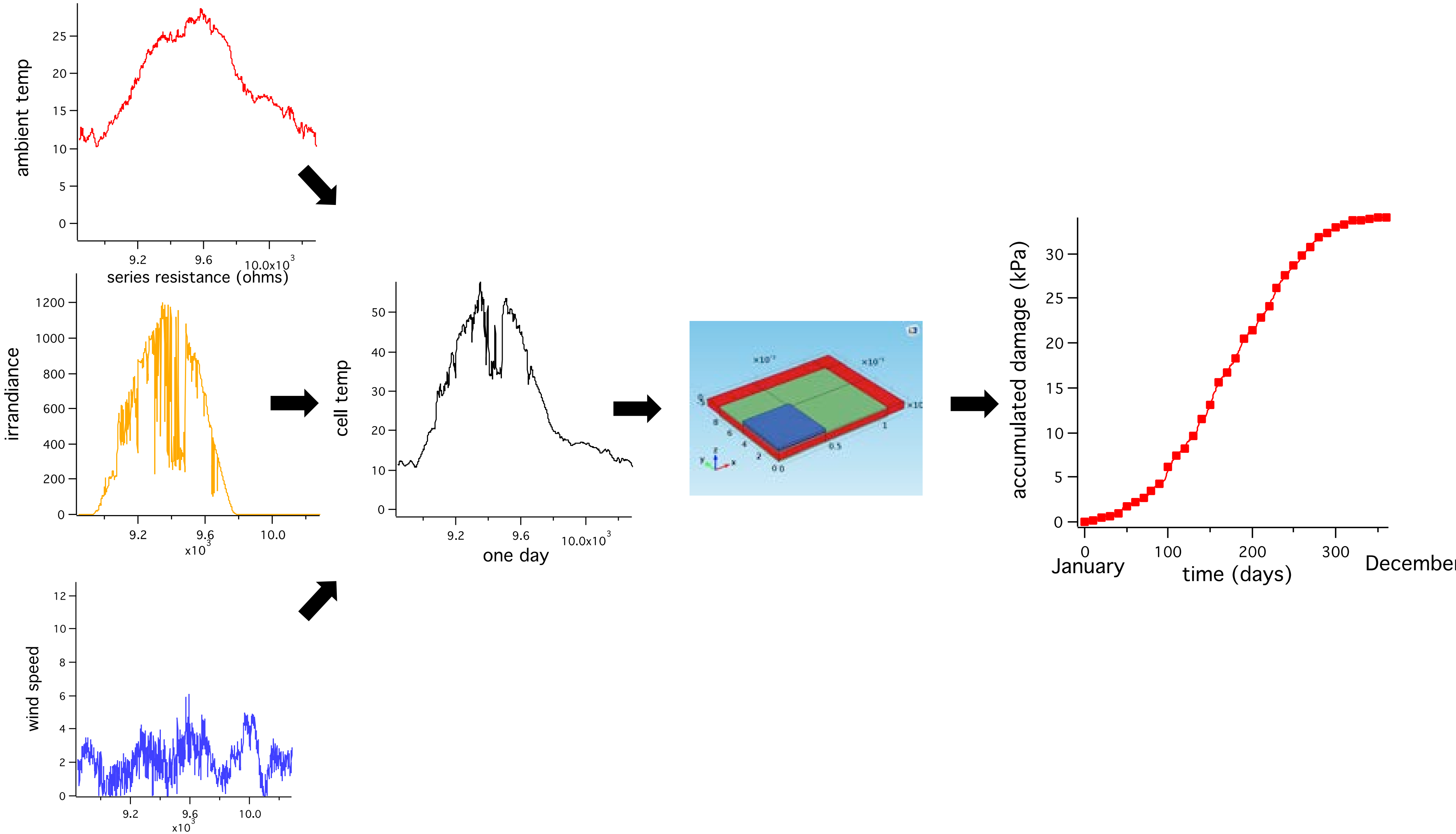
FEM

2D FEM of PbSn solder joint for flat plate PV module.



Approach

Flow of weather data through to accumulated solder damage



Cities

Seven cities examined

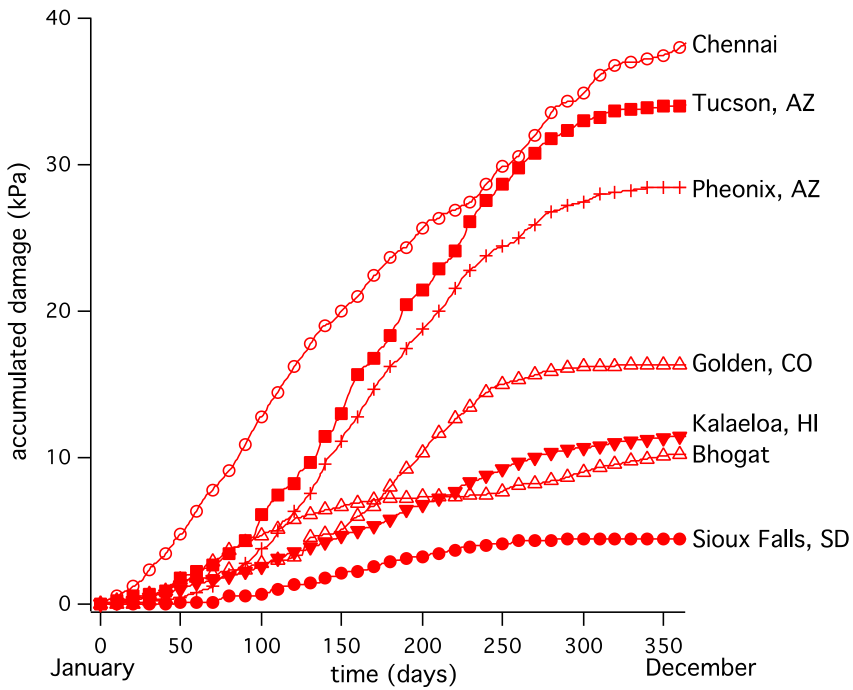
city	climate	mean monthly max temp (C)
Phoenix	Hot and Dry	38
Chennai	Hot and Humid	37
Tucson	Hot and Dry	36
Bhogat	Hot and Humid	35
Kalaeloa	Hot and Humid	31
Golden	Temperate	27
Sioux Falls	Cold	23

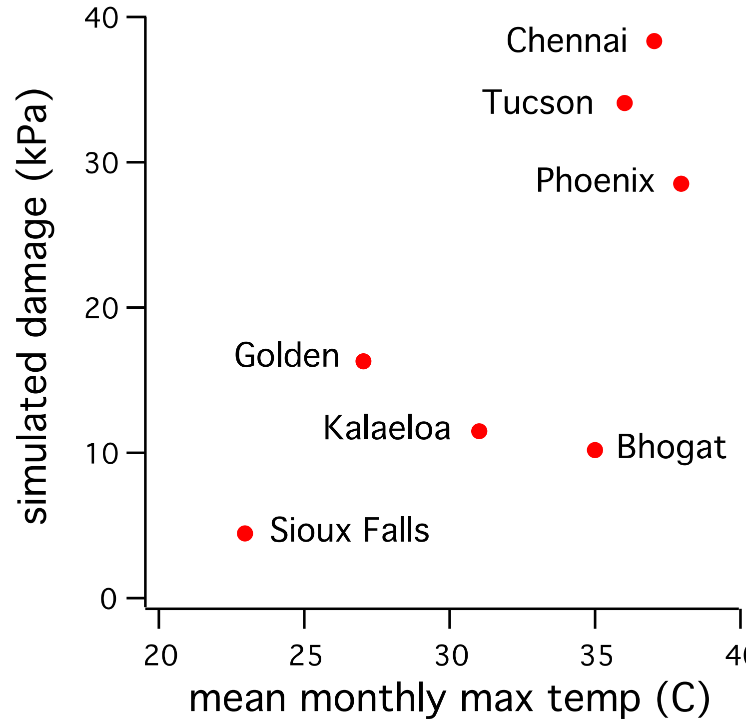
Definition of climates

climate	mean monthly max temp (C)	mean relative humidity (%)
hot and Dry	>30	<55
hot and humid	>30	>55
	>25	>75
temperate	25-30	<75
cold	<25	All values
composite	when 6 months or more do not fall within any of the above categories	

Results

Accumulated solder fatigue damage





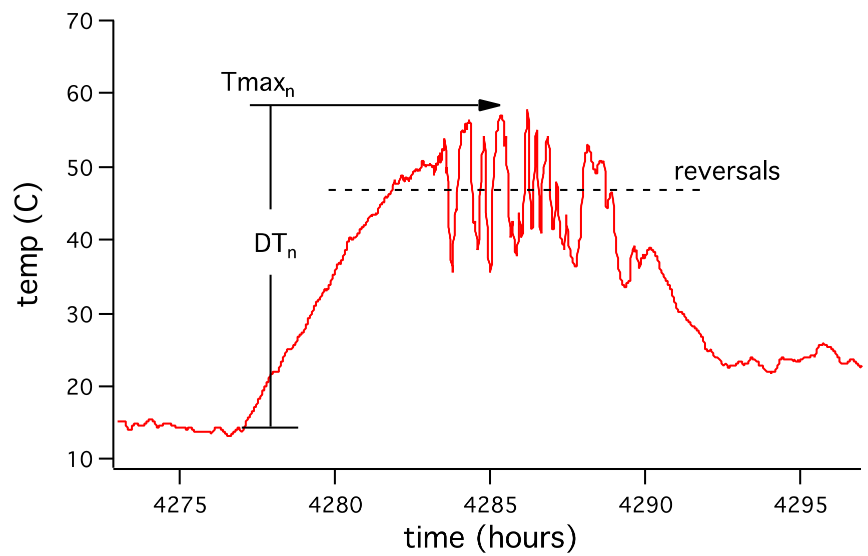
FEM simulation of solder damage accumulation over one year's exposure

Comparison of solder damage with mean monthly max temp

Analysis

We wanted to create a simple equation that could predict the FEM calculated damage.

This equation also gives us an insight about which weather characteristics contribute to solder fatigue damage.



$$D = K \cdot rev(T_m)^a \cdot DT^n \cdot \exp\left(\frac{E_a}{kT_{\max}}\right)$$

city	T_{max}, mean daily max cell temp (C)	ΔT, mean daily max cell temp change (C)	*r(57)*, number of temp reversals across 57 ˚C
Chennai	59	35.5	2228
Phoenix	53.4	34.7	1264
Tucson	53.2	37	1474
Kalaeloa	51.2	30.7	142
Bhogat	49.7	27.9	174
Golden	37.6	33.4	466
Sioux Falls	25.8	23.5	0

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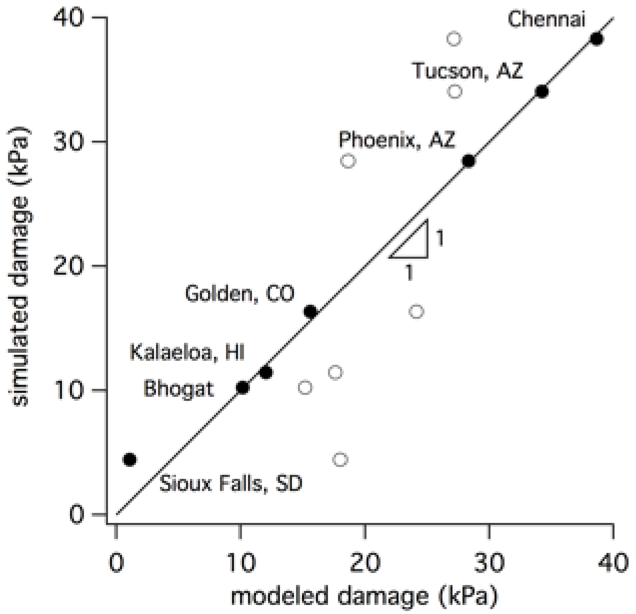

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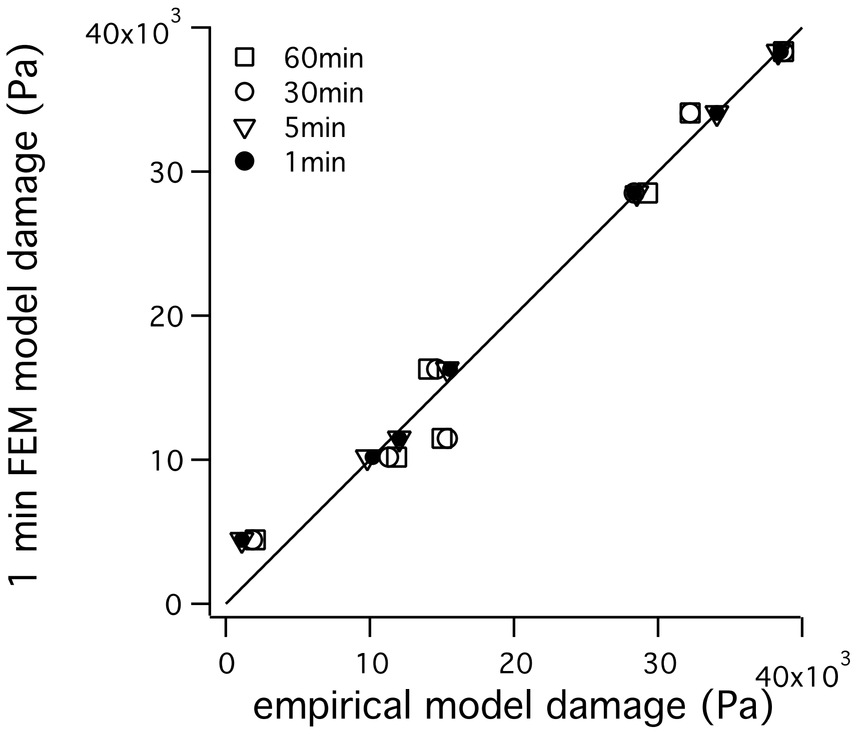
Golden	37.6	33.4	466
Sioux Falls	25.8	23.5	0

Analysis

- Weather data down to 30 minute resolution is still acceptable for empirical model input.

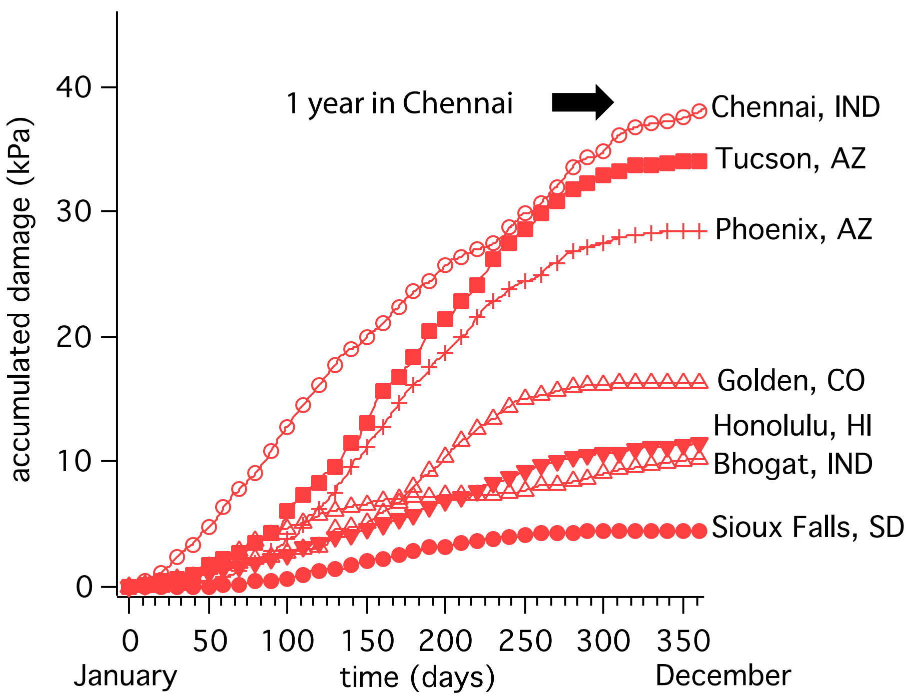


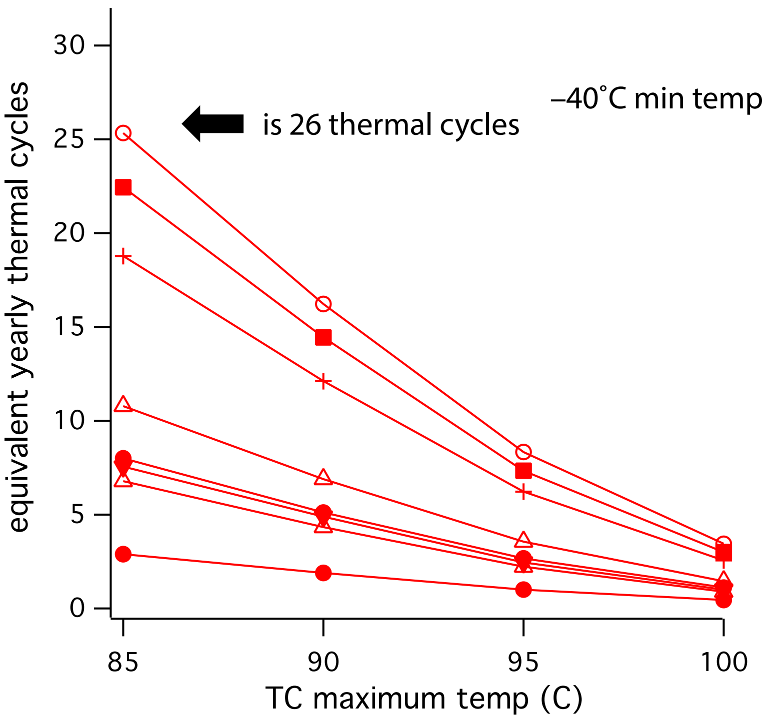
$$D = K \cdot rev(T_m)^a \cdot DT^n \cdot \exp\left(\frac{E_a}{kT_{max}}\right)$$

interval (min)	K	T_m (C)	E_a (eV)	a	n
1	239.9	56.4	0.12	0.33	1.9
5	249.9	56.9	"	"	"
30	344.1	55.8	"	"	"
60	405.6	54.8	"	"	"

Analysis

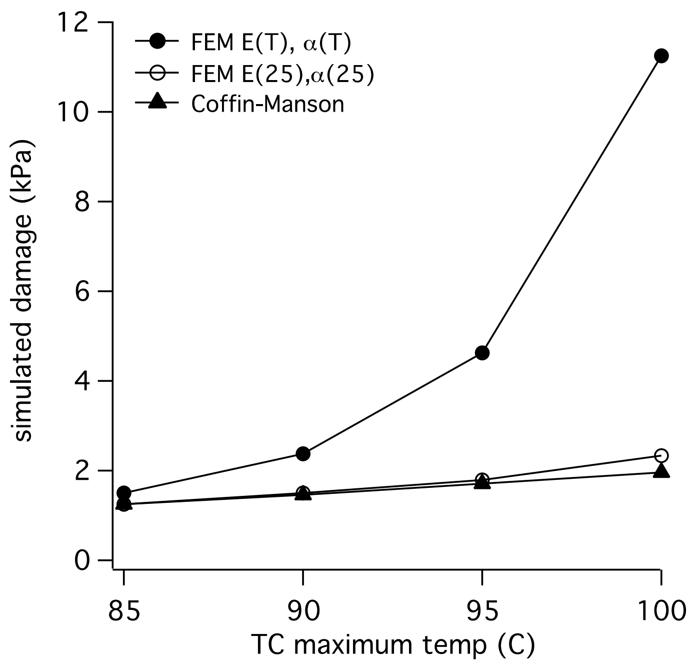
Thermal cycle equivalency to service conditions

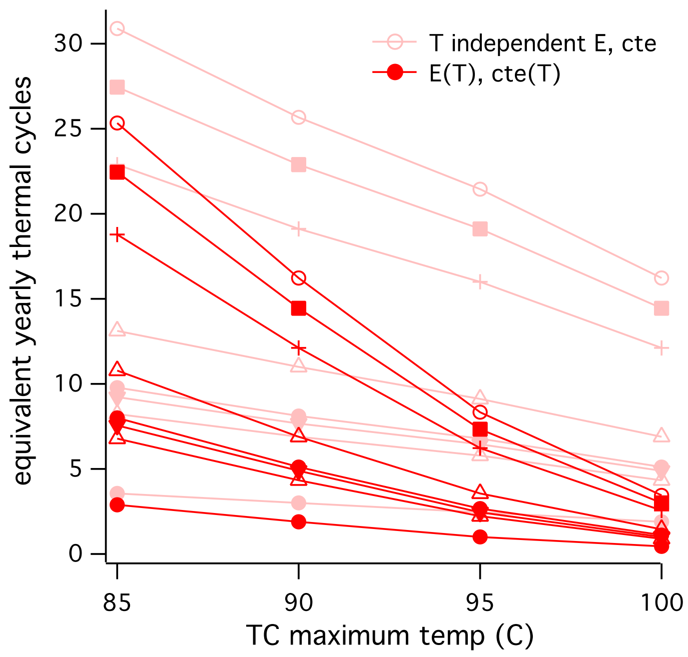




Analysis

Effect of encapsulant





Conclusions

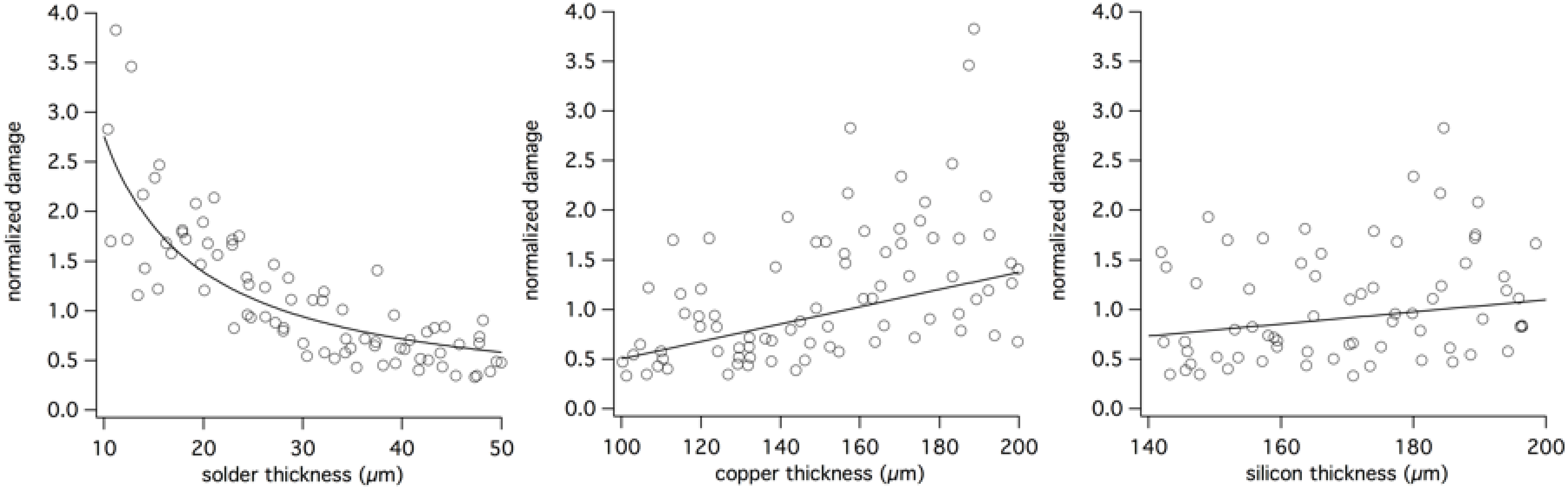
- Solder fatigue does accumulate faster in hotter climates.
- BUT, we must also know the daily temperature change and number of "reversals".
- Climate zone alone does not tell the entire story.
- The developed empirical model should be used to compare the relative potential for solder fatigue damage in specific locations.

Acknowledgment

This research is based upon work supported in part under the Solar Energy Research Institute for India and the U.S. (SERIIUS) funded jointly by the U.S. Department of Energy subcontract DE AC36-08G028308 (Office of Science, Office of Basic Energy Sciences, and Energy Efficiency and Renewable Energy, Solar Energy Technology Program, with support from International Affairs) and the Government of India subcontract IUSSTF/JCERDC-SERIIUS/2012 dated 22nd Nov. 2012.

Analysis

The Influence of PV Module Materials and Design on Solder Joint Thermal Fatigue



Bosco, N., Silverman, T., Kurtz, S., "The Influence of PV Module Materials and Design on Solder Joint Thermal Fatigue Durability", Journal of Photovoltaics, to be published

Safety Aspects for Modules Deployed in Hot Use Environments

Overview

Why the Concern?

The IEC qualification and safety standards (IEC 61215 series and IEC 61730 series) lay down requirements for PV modules suitable for long-term operation in general open air climates as defined in IEC 60721-2-1: 2002, Edition 1. IEC 60721-2-1: 2002, Edition 1 defines “climates” by the temperature and humidity levels experienced at the location. For general open air this means an absolute maximum temperature of +45 °C versus world-wide levels recorded as high as + 65 °C.

So the testing in IEC 61215 and 61730 covers only a portion of the temperature range that PV modules are likely to encounter during operation in all terrestrial climate zones.

Specific Concern – Polymers

Polymers

Thermal degradation of polymers is “molecular deterioration as a result of overheating”. At high temperatures the components of the long chain backbone of the polymer can begin to separate (molecular scission) and react with one another to change the properties of the polymer.

It is part of a larger group of degradation mechanisms for polymers that can occur from a variety of causes such as:

- Heat (thermal degradation and thermal oxidative degradation when in the presence of oxygen).
- Light (photodegradation).
- Oxygen (oxidative degradation).
- Weathering(generally UV degradation).

Zeus Industrial Products, *Thermal Degradation of Plastics*, whitepaper ,
http://www.appstate.edu/~clementsjs/polymerproperties/zeus_thermal_degradation.pdf, downloaded Sept. 1, 2016

What it Means for Modules

Insulation Systems – IEC 60664-1

5.3.2 Stresses

5.3.2.1 General

The stresses applied to solid insulation are divided into

– short-term, and
– long-term.

Short-Term Stresses - IEC 60664-1

5.3.2.2 Short-term stresses and their effects

5.3.2.2.1 Frequency of the voltage

The electric strength is greatly influenced by the frequency of the applied voltage. Dielectric heating and the probability of thermal instability increase approximately in proportion to the

Frequency (…) Increasing the frequency will reduce the electric strength of most insulating materials. Not applicable to modules (DC)

Short-Term Stresses - IEC 60664-1

5.3.2.2.2 Heating

Heating can cause

- mechanical distortion due to the release of locked-in stress,
- softening of thermoplastics at comparatively low temperature-rise above ambient, for example temperatures above 60 °C,
- embrittlement of some materials due to loss of plasticiser,
- softening of some cross-linked materials particularly if the glass transition temperature of the material is exceeded,
- increased dielectric losses leading to thermal instability and failure.
- High temperature gradients, for example during short-circuits, may cause mechanical failure.

Short-Term Stresses - IEC 60664-1

5.3.2.2.3 Mechanical shock

In the case of inadequate impact strength, mechanical shock may cause insulation failure.

Failure from mechanical shock could also occur due to reduced impact strength of materials:

- due to material becoming brittle when the temperature falls below its glass transition temperature;
- after prolonged exposure to high temperature that has caused loss of plasticiser or degradation of the base polymer.

Long-Term Stresses - IEC 60664-1

5.3.2.3 Long-term stresses and their effects

5.3.2.3.1 Partial discharges (PD) (not addressed) ☺

5.3.2.3.2 Heating

Heating causes degradation of the insulation, for example, by volatilization, oxidation or other long-term chemical changes. However, failure is often due to mechanical reasons, for example embrittlement, leading to cracking and electric breakdown.

This process is continuous and cannot be simulated by short-time testing since several thousand hours testing time would be required (see IEC 60216).

Long-Term Stresses - IEC 60664-1

5.3.2.3.3 Mechanical stresses

Mechanical stresses caused by vibration or shock during operation, storage or transportation may cause delamination, cracking or breaking-up of the insulating material.

5.3.2.3.4 Humidity

The presence of water vapour can influence the insulation resistance and the discharge extinction voltage, aggravate the effect of surface contamination, produce corrosion and dimensional changes. For some materials, high humidity will significantly reduce the electric strength. Low humidity can be unfavourable in some circumstances, for example by increasing the retention of electrostatic charge and by decreasing the mechanical strength of some materials, such as polyamide.

Long-Term Stresses - IEC 60664-1

5.3.2.4 Other stresses

Many other stresses can damage insulation (…)

Examples of such stresses include

- radiation, both ultraviolet and ionizing,
- stress-crazing or stress-cracking caused by exposure to solvents or active chemicals,
- he effect of migration of plasticizers,
- the effect of bacteria, moulds or fungi,
- mechanical creep.

The effect of these stresses is of less importance or they will apply less often but require consideration in particular cases.

Long-Term Stresses - IEC 60664-1

5.3.3 Requirements

5.3.3.1 General

Solid insulation of basic, supplementary and reinforced insulation shall be capable of durably withstanding electrical and mechanical stresses as well as thermal and environmental influences which may occur during the anticipated life of the equipment.

IEC 61730-1 Edition 2 – Some definitions

3.4.6

insulation <electrical>

part of an electrotechnical product which separates conducting parts at different electric potentials during operation or insulates such parts from the surroundings.

3.4.8 Insulation concepts

3.4.8.1

basic insulation

insulation of hazardous live parts which provides basic protection against electric shock

Note 1 to entry: The concept does not apply to insulation used exclusively for functional purposes.

[SOURCE: IEC 60050-826:2004, 826-12-14, modified: added: “against electric shock”]

IEC 61730-1 Edition 2 – Some definitions

3.4.8.2

double insulation

insulation comprising both basic insulation and supplementary insulation

[SOURCE: IEC 60050-826:2004, 826-12-16]

3.4.8.3

functional insulation

insulation that is necessary for the proper functioning of the equipment

Note 1 to entry: Functional insulation by definition does not protect against electric shock. It may, however,

reduce the likelihood of ignition and fire.

[SOURCE: IEC 60050-195:1998, 195-02-41]

IEC 61730-1 Edition 2 – Some definitions

3.4.8.4

reinforced insulation

insulation of hazardous live parts which provides a degree of protection against electric shock equivalent to double insulation

Note 1 to entry: Reinforced insulation may comprise several layers that cannot be tested singly as basic insulation or supplementary insulation.

[SOURCE: IEC 60050-826:2004, 826-12-17]

3.4.8.5

supplementary insulation

independent insulation applied in addition to basic insulation for fault protection, e.g. in order to reduce the risk of electric shock in the event of a failure of the basic insulation

[SOURCE: IEC 60050-826:2004, 826-12-15, modified: added example]

IEC 61730-1 Edition 2 – Some definitions

3.4.8.6

solid insulation

insulating material consisting entirely of a solid

Note 1 to entry: Solid insulating material interposed between two conductive parts or between conductive parts and outer accessible parts or surfaces with no interfaces and therefore there is no creepage pathway.

[SOURCE: IEC 60050-212:2010, 212-11-02]

3.4.10

relied upon insulation

insulation system providing the sole protection against electric shock in final application

Note 1 to entry: A polymeric backsheet or frontsheet can consist of relied upon insulation plus additional layers that, e.g., protect the polymeric materials from UV light.

IEC 61730-1 Edition 2 – Some definitions

3.5.5 Temperatures

3.5.5.1

ambient temperature

average temperature of air or another medium in the vicinity of the equipment

Note 1 to entry: During the measurement of the ambient temperature the measuring instrument/probe should be shielded from draughts and radiant heating.

[SOURCE: IEC 60050-826:2004, 826-10-03]

3.5.5.2

environmental temperature

air temperature defined in degrees Celsius for the geographic installation location as measured and documented by meteorological services for this geographic location

IEC 61730-1 Edition 2 – Some definitions

3.5.5.3

relative temperature index

RTI

temperature index of an insulating material or system obtained from the time which corresponds to the known temperature index of a reference material or system when both are subjected to the same ageing and diagnostic procedures in a comparative test

3.5.5.4

relative thermal endurance index RTE numerical value of the Celsius temperature expressed in degrees Celsius at which the estimated time to endpoint of an insulating material is the same as the estimated time to endpoint of a control material at a temperature equal to its assessed thermal endurance

IEC 61730-1 Edition 2 – Some definitions

3.5.5.5

temperature index

TI

numerical value of the Celsius temperature expressed in degrees Celsius characterizing the thermal capability of an insulating material or an insulation system

IEC 61730-1 Edition 2 – Temperatures Clearly Addressed

All PV modules shall be suitable for operation in outdoor non-weather protected locations, exposed to direct and indirect (albedo) solar radiation, in an environmental temperature range of at least –40 °C to +40 °C and up to 100 % relative humidity as well as rain. PV modules shall be designed to withstand the electrical, mechanical, thermal and environmental (temperature, mechanical load, humidity, UV/weather, pollution, etc.) stresses occurring in their intended use and present no danger to the user or the environment.

Compliance is verified by evaluation of materials, components and PV module construction as well as tests specified in IEC 61730-2.

NOTE 1 The environmental temperature is typically measured 1 m above ground. PV modules deployed closer to the ground may experience higher ambient temperatures than this quoted environmental temperature.

Proposal of Guidelines for Modules Deployed in Hot Use Environments

Overview

New Work Item Proposal (NWIP)

INTERNATIONAL·ELECTROTECHNICAL·COMMISSION¶

GUIDELINES·FOR·QUALIFYING·PV·MODULES,·COMPONENTS·AND·MATERIALS· FOR·OPERATION·AT·HIGHER·TEMPERATURES¶

The IEC qualification and safety standards (IEC 61215 series and IEC 61730 series) lay down requirements for PV modules suitable for long-term operation in general open air climates as defined in IEC 60721-2-1: 2002, Edition 1. IEC 60721-2-1: 2002, Edition 1 defines “climates” by the temperature and humidity levels experienced at the location. For general open air this means an absolute maximum temperature of +45 °C versus world-wide levels recorded as high as + 65 °C. So the testing in IEC 61215 and 61730 covers only a portion of the temperature range that PV modules are likely to encounter during operation in all terrestrial climate zones. This guideline will consider what additional testing may be required to qualify a PV module for operation at higher temperatures than those defined by general open air climates.

Modules operating in an open rack configuration have unrestricted cooling while those in other types of mounting systems (for example on a roof top) may have restricted cooling and operate at considerably higher temperatures. This guideline will also consider what additional testing maybe necessary to qualify a PV module for operation with restricted cooling.

Overall this guideline will address the test temperature requirements in IEC 61215, IEC 61730, IEC 62790 and IEC 62852.

GUIDELINES FOR QUALIFYING PV MODULES, COMPONENTS AND MATERIALS FOR OPERATION AT HIGHER TEMPERATURES

Scope

This Technical Specification provides guidance on how to modify the testing in IEC 61215, IEC 61730, IEC 62790 and IEC 62852 (herein called the reference standards) to account for the fact that the PV modules may be installed in places where the ambient temperatures exceed those defined in the referenced standards or installed in mounting systems that restrict cooling (for example on roof-tops) so that the operating temperature exceeds that assumed in the referenced standards.

This Technical Specification will provide guidance on:

- How to determine the maximum operating temperatures that the module and components will experience in particular ambient conditions and mounting systems.
- How to modify the testing specified in the reference standards in order to qualify the product (module or component) for operation at temperatures higher than specified in those standards.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures - Definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836, IEC 61730-1 and the following apply:

Maximum Ambient Temperature ($T_{MAX\ AMB}$): The highest ambient temperature routinely observed at a particular location (See Clause 4.1)

Maximum PV Module Operating Temperature (T_{CON}): The maximum reference temperature expected for a PV module as calculated in the Temperature Test (MST 21) from IEC 61730-2.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures - Selection

4.1 Selecting the maximum ambient temperature

IEC 60721-2-1 defines "climates" by the temperature and humidity levels experienced at the location. For general open air this means an absolute maximum temperature of +45 °C. There are of course many areas of the world where this is exceeded on a routine basis. For PV performance or qualification it is not so much the highest temperature expected during a module's lifetime, but rather the highest ambient temperature routinely observed at a particular location that is important. The selection of this maximum ambient temperature is up to the user of the PV modules based on the weather data available for the site or sites where the modules will be deployed.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures - Selection

Once a maximum ambient temperature ($T_{MAX\ AMB}$) has been selected it can be used in conjunction with the Temperature Test (MST 21 from IEC 61730-2) to determine the maximum reference temperatures for the PV module. Clause 4.2 provides guidance on how to determine this temperature for an open rack mounted module. Clause 4.3 provides guidance on how to modify the Temperature Test for all mounting systems with restricted airflow including roof mounted modules.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures - Selection

4.2 Maximum module reference temperature for open rack mounting

For open rack mounted PV modules, according to IEC 61730-1 the normalized measured maximum PV module operating temperature can be assumed to be 90 °C or that measured during the temperature test (IEC 61730-2, MST 21), if it is less. These temperatures are based on exposure at an ambient temperature of 40 °C. Once a maximum ambient temperature has been selected (See Clause 4.1) the difference between this new $T_{MAX\ AMB}$ and 40°C is added to either 90 °C or the temperature measured during the Temperature Test (MST 21) to achieve the new Maximum PV Module Operating Temperature (T_{CON}). This is then the value used for the testing as defined in Clauses 5 to 8.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures - Selection

Maximum module reference temperature for other mounting methods with restricted air flow

For any mounting system besides open rack that has restricted air flow reducing the cooling, the Temperature Test (MST 21) shall be performed with the module mounted in the same way as it will be in the application. If there is more than one possible mounting configuration, the one leading to the highest measured module temperature shall be used. The procedure of MST 21 is then followed, resulting in a value for the measured module temperature (T_{OBS}) at a particular measured environmental temperature (T_{ENV}). The new Maximum PV Module Operating Temperature (T_{CON}) is then calculated for the maximum ambient temperature selected in Section 4.1 according to the formula:

$$T_{CON} = T_{OBS} + (T_{MAX\ AMB} - T_{ENV})$$

This new value of the Maximum PV Module Operating Temperature (T_{CON}) is the value used for the testing defined in Clauses 5 to 8.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61215 Test Modifications

The following changes shall be made to the test procedures in IEC 61215-2

5.1 Hot-spot endurance test (MQT 09)

In Section 4.9.5.2.h (for wafer based products), in Section 4.9.5.3.2.i (for monolithically integrated (MLI) thin film technologies Case S), in Section 4.9.5.3.4.h and Section 4.9.5.3.4.m (for MLI Case SP with inaccessible cell circuit and internal reverse bias protection), and in Section 4.9.5.3.5.j (for MLI Case SP with inaccessible cell circuit and no reverse bias protection) the temperature of the exposure shall be changed from (50 ± 10) °C to (T_{CON} – 10 °C ± 5) °C.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61215 Test Modifications

5.2 UV preconditioning test (MQT 10)

In Section 4.10.3.b change from “Make sure that the module temperature sensors read (60 ± 5) °C” to “Make sure that the module temperature sensors read (T_{CON} – 10 °C ± 5) °C”.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61215 Test Modifications

- Thermal cycling test (MQT 11)

In Section 4.11 the upper limit of the temperature cycling shall be increased from 85 ± 2 °C to T_{CON} ± 2 °C. In Figure 9 the value of the upper temperature limit changes from 85 °C to T_{CON} and the value at 80 °C changes to T_{CON} - 5°C.

In Section 4.11.3.c the upper limit of continuous current flow shall be changed from 80 °C to T_{CON} - 5°C and the temperature at which the current flow shall be reduced to less than 1% of the measured STC peak power current shall be changed from 80 °C to T_{CON} - 5°C.

Section 4.11.3.d shall be changed from “subject the module(s) to cycling between measured module temperatures of (–40 ± 2) °C and (+85 ± 2) °C” to subject the module(s) to cycling between measured module temperatures of (–40 ± 2) °C and (T_{CON} ± 2) °C”.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61215 Test Modifications

- Bypass diode testing (MQT 18)

In Section 4.18.1.2.a the apparatus shall be capable of heating the module to a temperature of (T_{CON} ± 5) °C rather than just to (90 ± 5) °C.

In Section 4.18.1.3.h add "Using the same procedure, measure V_{D5} at (T_{CON} ± 2) °C".

In Section 4.18.1.3.i add V_{D5} to the least squares fit data.

In Section 4.18.1.3.j change the instructions to "heat the module to (T_{CON} -10 ± 5) °C" instead of to (75 ± 5) °C.

In Section 4.18.1.3.k obtain T_J from V_D at T_{amb} = (T_{CON} -10) °C rather than at 75 °C.

In Section 4.18.1.3.l maintain the module temperature at (T_{CON} -10 ± 5) °C instead of at (75 ± 5) °C.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61730 Test Modifications

Most of the tests called out in IEC 61730-1 are found in IEC 61730-2 and will be covered in that section (6.2). One test that is required in IEC 61730-1 that does not appear in IEC 61730-2 is the RTE (RTI) or TI test required in Section 5.5.2.3.3. For safety qualification under this guideline, the RTE (RTI) or TI test shall be performed at T_{CON}.

A second test that does not appear in IEC 61730-2 is the Endurance to Weathering Stress in Section 5.5.2.2. The conditions for these tests are given in IEC 62788-7-2. For operation at higher temperatures, that is for any T_{CON} > 90 °C, the weathering exposures shall be performed at the highest temperature recommended in IEC 62788-7-2.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61730 Test Modifications

The following changes shall be made to the test procedures in IEC 61730-2:

6.2.1 Temperature Test (MST 21)

See Section 4.2 or 4.3 of this TS for the instructions on applying MST 21 for higher temperature operations.

6.2.2 Hot Spot Endurance Test (MST 22)

This test is equivalent to MQT 09 in IEC 61215-2, so follow the directions given in Section 5.1 of this TS for MQT 09.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61730 Test Modifications

6.2.3 Bypass diode thermal test (MST 25)

This test is equivalent to MQT 18 in IEC 61215-2, so follow the directions given in Section 5.4 of this TS for MQT 18.

6.2.4 Materials creep test (MST 37)

In Section 10.26.3.c change "subject the PV module to 105 °C ± 5 °C" to "subject the PV module to 105 °C ± 5 °C or T_{CON} ± 5 °C, whichever is higher.

In Section 10.26.3.c change the test temperature for modules designed for open rack mount only from 90 °C ± 3 °C to 90 °C ± 3 °C or T_{CON} ± 3 °C, whichever is higher.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 61730 Test Modifications

6.2.5 Thermal cycling test (MST 51)

This test is equivalent to MQT 11 in IEC 61215-2, so follow the directions given in Section 5.3 of this TS for MQT 11.

6.2.6 UV test (MST 54)

This test is equivalent to MQT 10 in IEC 61215-2, so follow the directions given in Section 5.2 of this TS for MQT 10.

6.2.7 Dry heat conditioning (MST 56)

In Section 10.33.3.c change "subject the PV module to 105 °C ± 5 °C" to "subject the PV module to 105 °C ± 5 °C or T_{CON} ± 5 °C, whichever is higher. In Section 10.33.3.c change the test temperature for modules designed for open rack mount only from 90 °C ± 3 °C to 90 °C ± 3 °C or T_{CON} ± 3 °C, whichever is higher.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 62790 for Junction Boxes

The general requirement (Section 4.1 of IEC 62790) includes a requirement for junction boxes to be suitable for durable use outside in an ambient temperature area from –40 °C to + 85 °C. In Section 4.11 of IEC 62790 it says junction boxes shall withstand the upper and lower values of temperature range as given in Section 4.1 or as specified by the manufacturer, if lower than the minimum value or higher than the maximum value as defined in 4.1. In most cases junction boxes are not defined for a specific module type, but are sold for use in any module type. Therefore it is recommended that junction boxes be evaluated for use in the hottest climates with restricted air flow. So the method of Section 4.3 of this TS shall be used to determine the Maximum Operating Temperature observed within the junction box, which is then designated (T_{CONBOX}).

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 62790 for Junction Boxes Test Modifications

7.1 Thermal cycle test

7.2 Weather Resistance Test

7.3 Ball pressure test

7.4 Resistance against ageing

7.5 Bypass diode thermal test

7.6 Test Schedule

7.7 Annex B - Qualification of conformal coatings for protection against pollution

7.8 Section 5.5.2.3.3 of IEC 61730-1 (RTI)

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 62852 for Connectors Test Modifications

The general requirement (Section 5.1) includes a requirement for connectors to be suitable for durable outdoor use in an ambient temperature area from –40 °C to +85 °C. Section 5.12 IEC 62852 says connectors shall withstand the upper and lower values of temperature range as specified by the manufacturer.

So PV connector manufacturers should assess the ambient temperature for which they want to qualify their connectors and then use Sections 4.2 and/or 4.3 of this standard to determine the Maximum PV Connector Operating Temperature (T_{CONC}). The following changes shall be made to the test procedures in IEC 62852:

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – IEC 62852 for Connectors Test Modifications

8.1 Change of temperature

In Section 6.3.11 the upper specified ambient temperature shall change from 85 °C ± 2 °C to T_{CONC} ± 2 °C.

8.2 Test Schedule

In Table 10 the line E2 for Change in Temperature the Upper temperature shall change from 85 °C to T_{CONC}.

In Table 12 the line G1 for Weather resistance the Black standard temperature shall change from 65 °C to T_{CONC} - 10 °C.

8.3 Section 5.5.2.3.3 of IEC 61730-1 (RTI)

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – Marking Requirements

For PV modules the Markings and Documentation Section (Section 5) of IEC 61215-1 shall be followed with the additional requirement that the Maximum PV Module Operating Temperature (T_{CON}) used in the qualification (if it is different from 90 °C) be listed on the Name Plate and given in the documentation.

For Junction Boxes the Marking and identification Section (Section 4.2) of IEC 62790 shall be followed with the additional requirement that the Maximum PV Junction Box Operating Temperature (T_{CONBOX}) used for the qualification (if different from an ambient of 85 °C) be provided as required in line 4.2.1.i.

For PV Connectors the Marking and identification Section (Section 5.2) of IEC 62852 shall be followed with the additional requirement that the Maximum PV Connector Operating Temperature (T_{CONC}) used for the qualification (if different from an ambient of 85 °C) be provided as required in line 5.2.1.h.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – Reporting Requirements

For PV modules in addition to the reporting requirements of IEC 61215-1 and IEC 61730-1, the test report shall include the maximum ambient temperature ($T_{MAX\ AMB}$) and the mounting system used in the temperature test (MST 21) as well as the Maximum PV Module Operating Temperature (T_{CON}) determined by the temperature test and used for the qualification and safety tests.. All test results should indicate at what temperature the tests were performed.

For Junction Boxes in addition to the reporting requirements of IEC 62790 the test report shall include the maximum ambient temperature (TMAX AMB) and the mounting system used in the temperature test (MST 21) as well as the Maximum PV Junction Box Operating Temperature (TCONBOX) determined by the temperature test and used for the junction box testing in IEC 62790. All test results should indicate at what temperature the tests were performed.

Guidelines for Qualifying PV Modules, Components and Materials for Operation at Higher Temperatures – Reporting Requirements

For PV Connectors in addition to the reporting requirements of IEC 62852 the test report shall include the maximum ambient temperature ($T_{MAX\ AMB}$) and the mounting system used in the temperature test (MST 21) as well as the Maximum PV Connector Operating Temperature (T_{CONC}) determined by the temperature test and used for the connector testing in IEC 62852. All test results should indicate at what temperature the tests were performed.

Thank You

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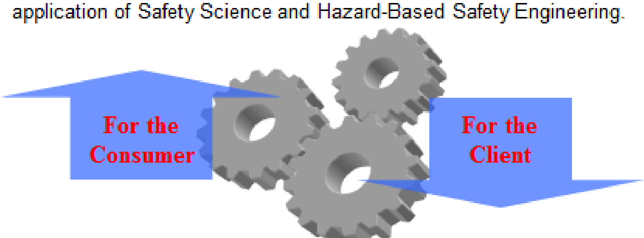

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