# Test-to-Failure for Long-Term Performance Assessment

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This presentation does not contain any proprietary or confidential information.

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# Photovoltaic Module Field Failure Database

https://www.nrel.gov/pv/performance_reliability/failure_database/

## Tell us about the module

*Module Manufacturer

*Module Model

Module Serial Number

Module Manufacture Date

*When Was Module Installed

Month January Year 2010

## *Tell us how it failed

First click on a category, then select the failure type.

- **Physical Damage (Cracks, Distortions)**
- **Visual Changes (Color), or corrosion**
- **Peeling/delamination**
- **Electrical Damage (Shorts, Burns)**
- **Performance Degradation**
- **Unknown/Other**

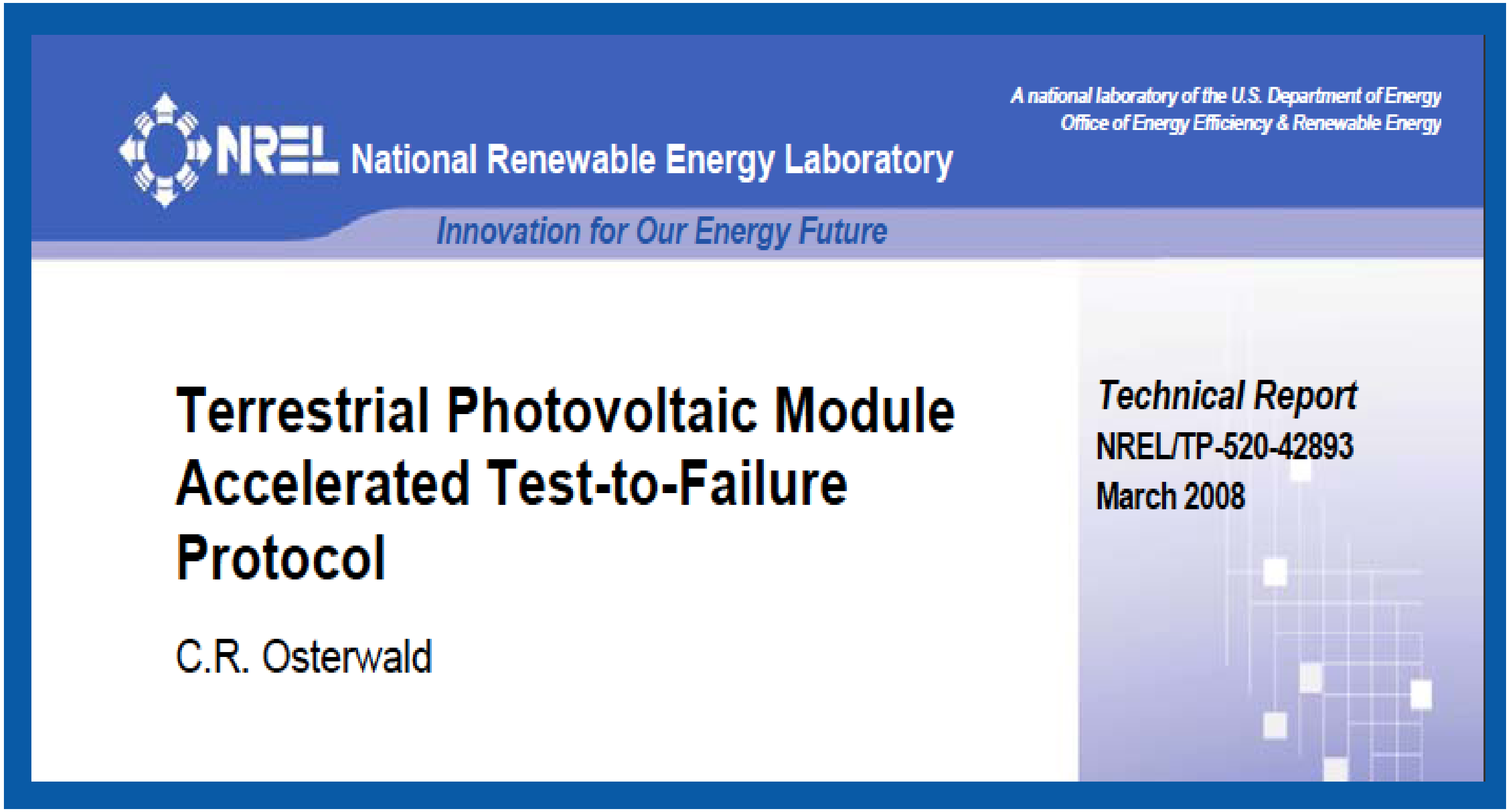
**Physical Damage (Cracks, Distortions)**

- junction box - cracking
- frame - corrosion
- area between or around cells or active light absorbing film
- backsheet or backing material
- wire leads - cracking insulation
- cells/ light absorbing region
- junction box - separating from module
- mounting bracket
- frame - bending/breaking
- front window
- connector - break/crack
- cells/ metallization
- wire leads - pulling out, weakly held in juncion box

# Overview

- Motivation for the Test-to-Failure protocol
- Test description
- Program description
- Results and discussion from application of the protocol
    - Thermal cycling with load
    - Damp heat with bias
    - Failure mechanisms
- Main results

# Background



A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

**Terrestrial Photovoltaic Module Accelerated Test-to-Failure Protocol**

C.R. Osterwald

*Technical Report*
NREL/TP-520-42893
March 2008

# Background

Field Reliability Experience

Qualification Test

Test-to-Failure

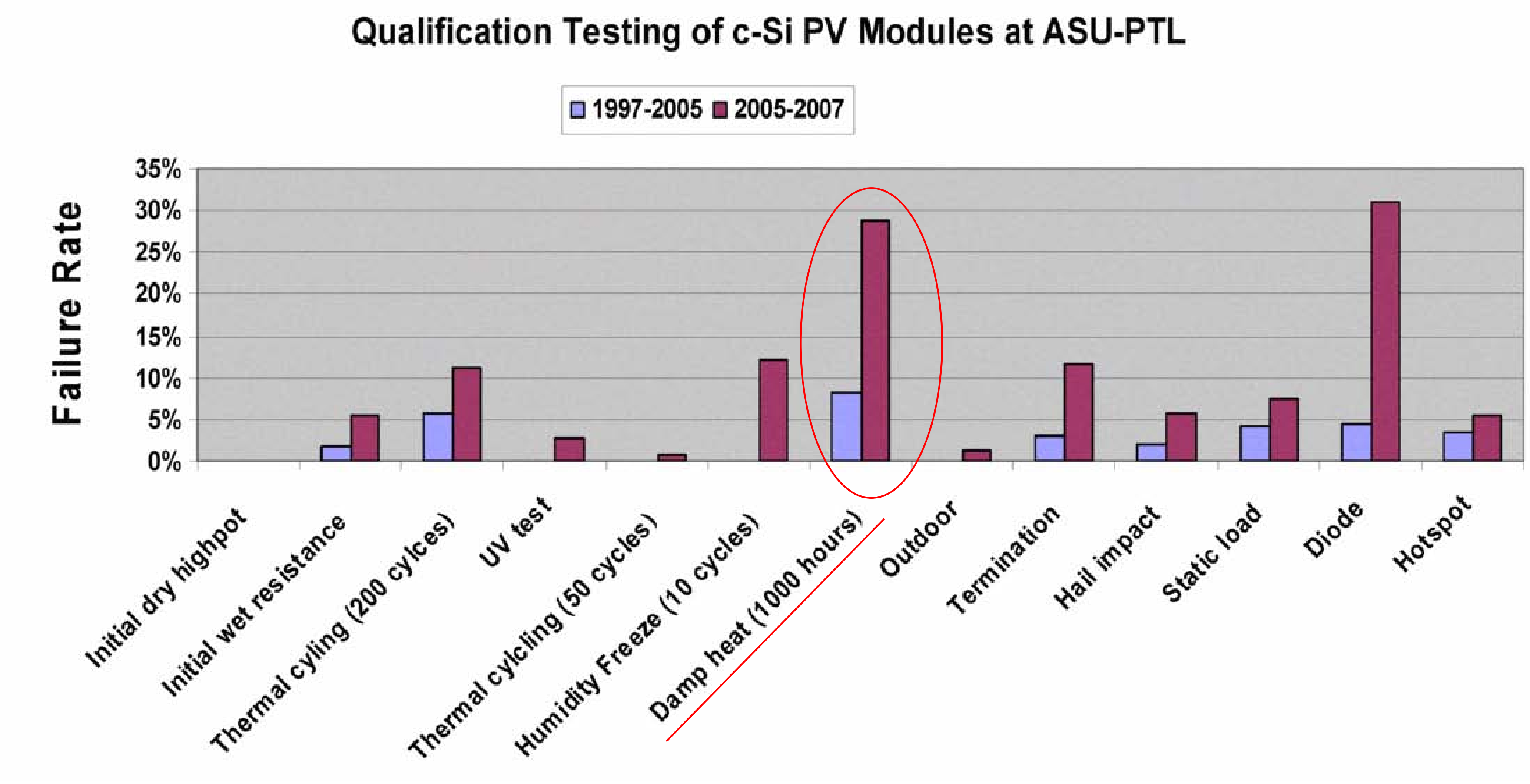
Lifetime Prediction

# Motivation

- Test new module technologies on a comparative basis in a highly accelerated manner
- Perform due diligence between various module technologies before large capital outlays for PV power plants are committed
- Characterize potential performance and reliability problems for high voltages systems
  - 600 V systems in USA
  - 1000 V, 1500 V  systems in EU
- Accelerate the onset of failure so that failure mechanisms can be analyzed, compared to field failures, and then addressed

# Failure rate of c-Si modules through IEC 61215 qualification testing at ASU-PTL for 1997-2005 and 2005-2007

## Damp heat a key environmental stress challenge




Courtesy G. TamizhMani et. al.  TUV-PTL

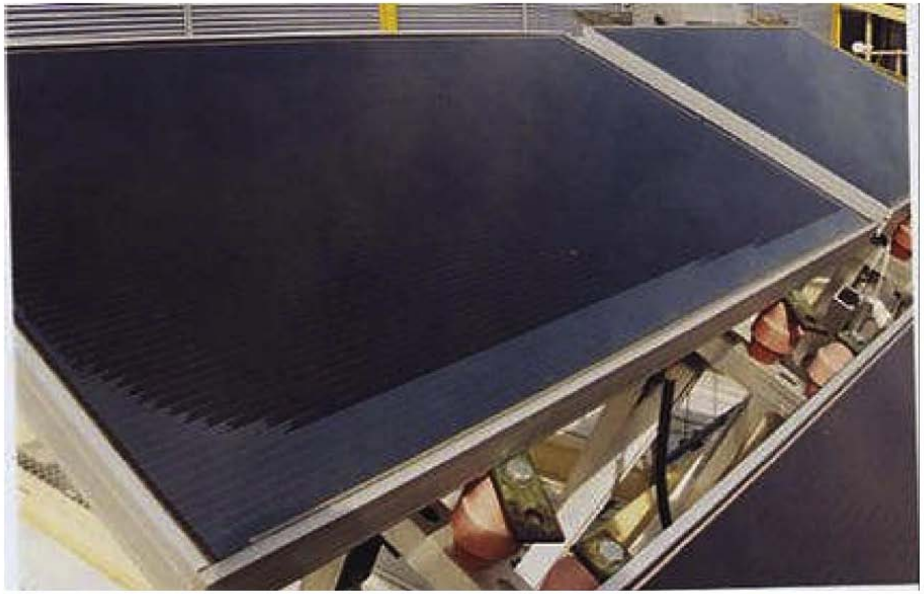
# Qualification testing at EU JRC Institute for Energy/ Ispra

Distribution of major defects of commercial modules provoked per Qualification Tests performed between 1990 and 2006

| Type of module failure | Tests type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | OE | HSP | UVE | Total irrad. tests | TC50 | HUF | TC200 | DAH | Total envir. tests |
| *Modules which failed the IEC 61215* | | | | | | | | | |
| Visual defect | 0 | 1 | 1 | 2 | 3 | 3 | 7 | 3 | 16 |
| Power loss | 1 | 0 | 3 | 4 | 2 | 2 | 7 | 3 | 14 |
| Visual defect and power loss | 0 | 0 | 0 | 0 | 2 | 0 | 5 | 1 | 8 |

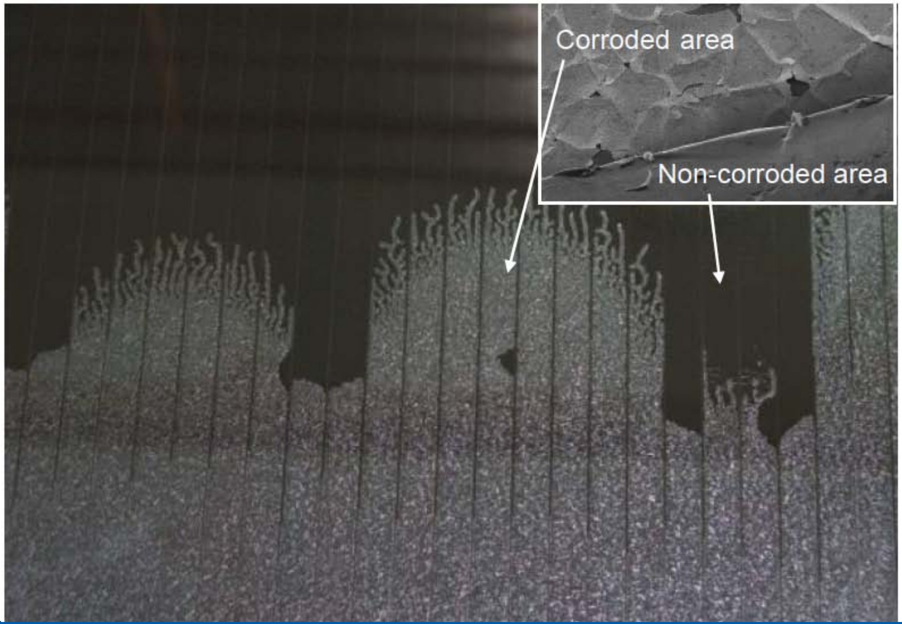
A. Skoczek, JRC IE/Ispra

# Effects of Damp Heat *with System Bias*



J. H. Wohlgemuth et al. *"LONG TERM RELIABILITY OF PHOTOVOLTAIC MODULES"*, WPSEC-4 (2006) p. 2050

- a-Si
- \- 600 V
- 12 months in the field




Stefan Krauter, Jürgen Arp, Sven Lehmann, Paul Grunow
PI Photovoltaik-Institut Berlin AG

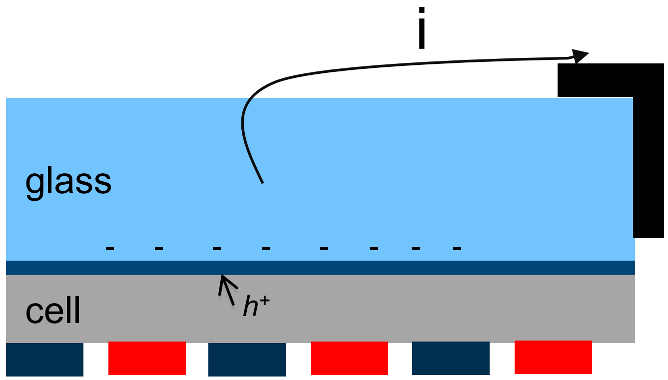
Electrochemical corrosion from sodium ions with water at the TCO/glass interface causes de-lamination of the TCO

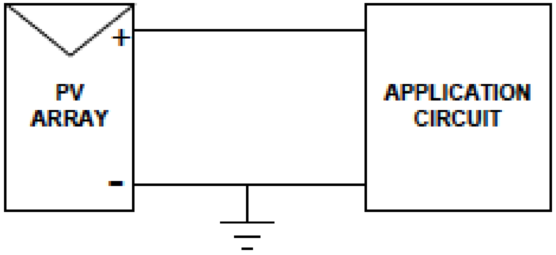
key drivers are:

- negative cell polarity vs. ground
- moisture ingression
- temperature
- Na content in glass

# Damp heat - *with system bias*

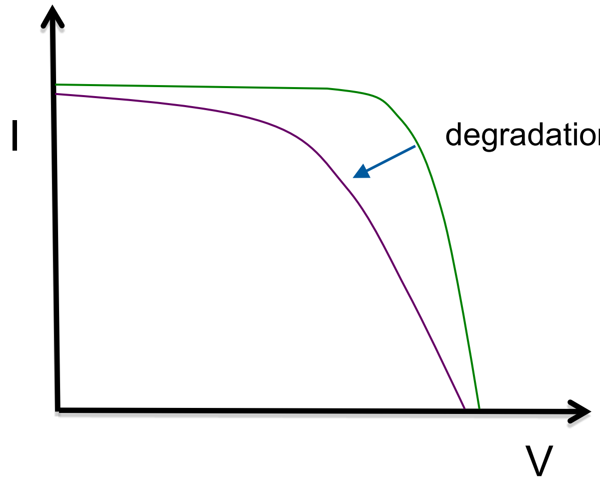
SunPower 2005 press release, reports 'surface polarization' in solar cells



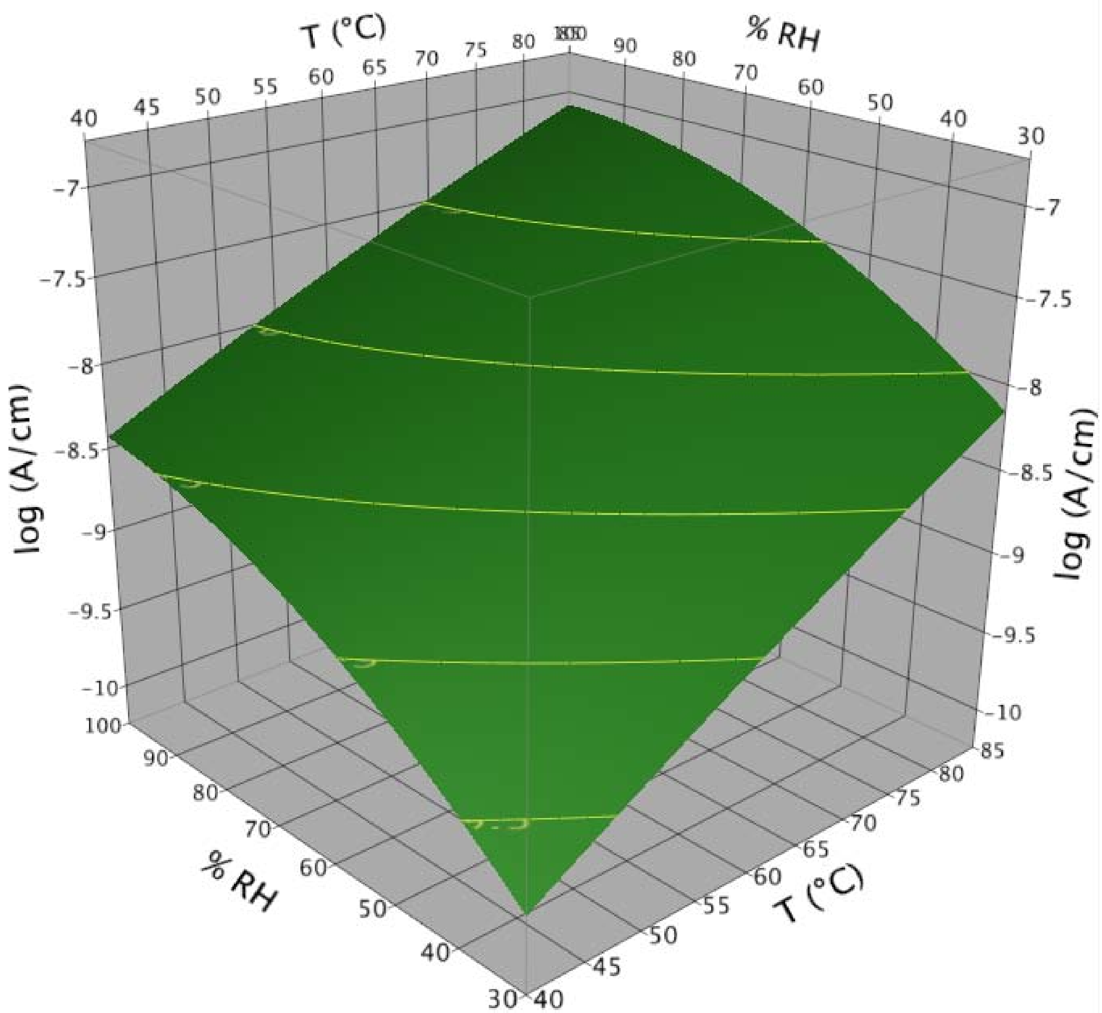

- Positive bias string leads to leakage current through glass to ground, leaving negative charge on cell surface, degrading effectiveness of the $n^+$ front surface field of the $n^+/n$ structure

- Minority carriers (holes) recombine at front surface, leading to degraded cell performance



# Effects of Damp Heat *with System Bias*

Leakage current vs temperature (T) and relative humidity (RH) per unit length of module frame (500 V bias) in a c-Si mini module with EVA-Tedlar construction




- Leakage current vary by orders of magnitude with modest changes in temperature and humidity
- Electrolytic corrosion directly related to the coulombs transferred

Adapted from G. Mon et al, (JPL), 18th IEEE PVSC (1985)

# Test-to-Failure Protocol

- Thermal cycling to accelerate diurnal solar thermal loading of the extreme conditions seen in high desert
- Damp heat with system bias to accelerate hydrolytic and corrosive action of hot humid environments

# The organization of the modules within the accelerated lifetime test sequences in the Test-to-Failure protocol.

| Sequence | A. Control | | B. Damp Heat with Bias 85°C/85%RH | | C. Thermal Cycling with load -40°C/85°C | | D. Alternating Seq. B/C DH/TC | |
|---|---|---|---|---|---|---|---|---|
| | A1 | A2 | B1 | B2 | C1 | C2 | D1 | D2 |
| | 5 kW hrs/m$^2$ light soak | | | | | | | |
| Round 1 | | | DH+ | DH- | TC | TC | DH+ | DH - |
| Round 2 | | | DH+ | DH- | TC | TC | TC | TC |
| Round 3 | | | DH+ | DH- | TC | TC | DH+ | DH - |
| Round 4 | | | DH+ | DH- | TC | TC | TC | TC |
| … | | | | | | | | |
| Round 15 | | | DH+ | DH- | TC | TC | DH+ | DH - |

- DH refers to 1000 hrs 85°C 85% relative humidity, IEC 61215 Ed. 2 sec. 10.13
- DH+(-) indicates +(-) voltage bias of 600 V or module's rated system voltage (whichever is greater) on shorted module leads with respect to grounded frame
- TC refers to 200 cycles between -40°C and 85°C, IEC 61215 Sec. 10.11 ($I_{mp}$ applied when T> 25°C)
- Alt. DH/TC refers to a sequence of alternating 1000 Hrs. DH and TC 200 stress cycles described above

# Test-to-Failure Program Description

***I***

Group 1 Pilot run with 1 c-Si model, now entering 5th round

Group 2 3 models c-Si, now entering 2nd round

Group 3 3 models c-Si, 1 now entering first round

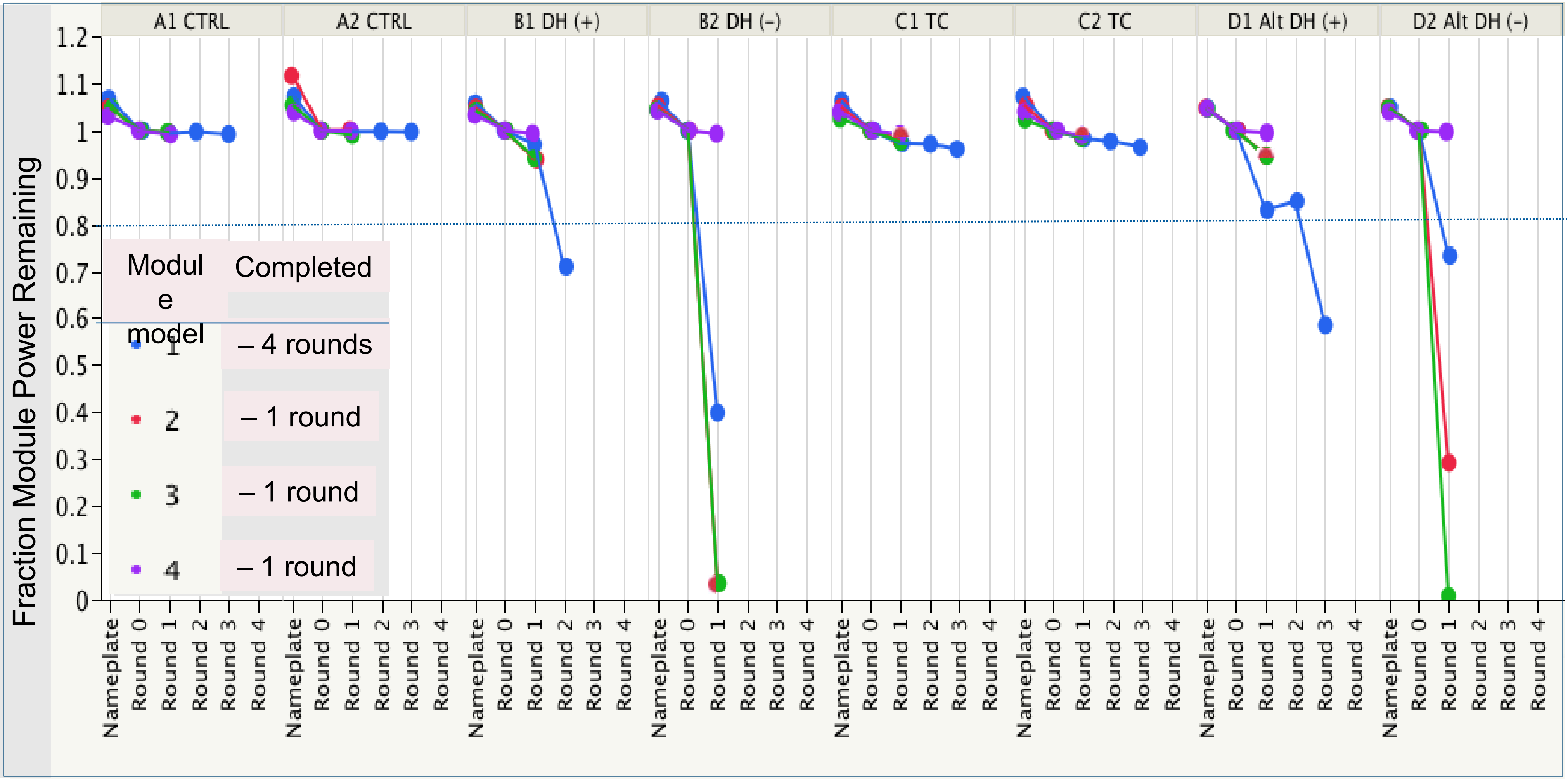
***II*** Outdoor parallel tests

***III*** Experiments varying factors and levels, and consideration of other stress factors to study degradation rates, determine, any necessary modifications to the test to failure program, and develop relationships for service lifetime

***IV*** Thin film tests

# Performance Results

Fraction module power remaining vs. measurement round
by test sequence & module model



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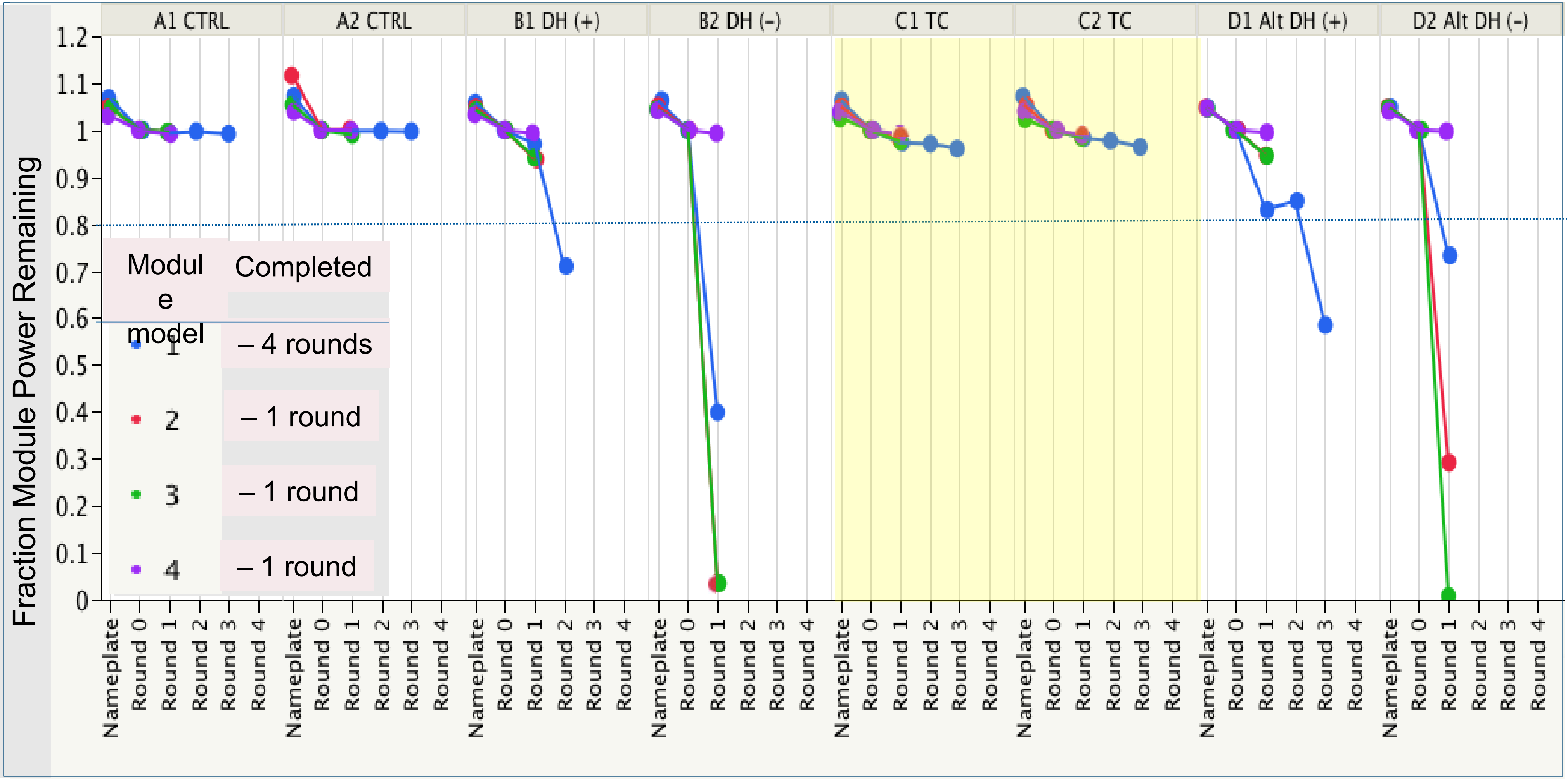

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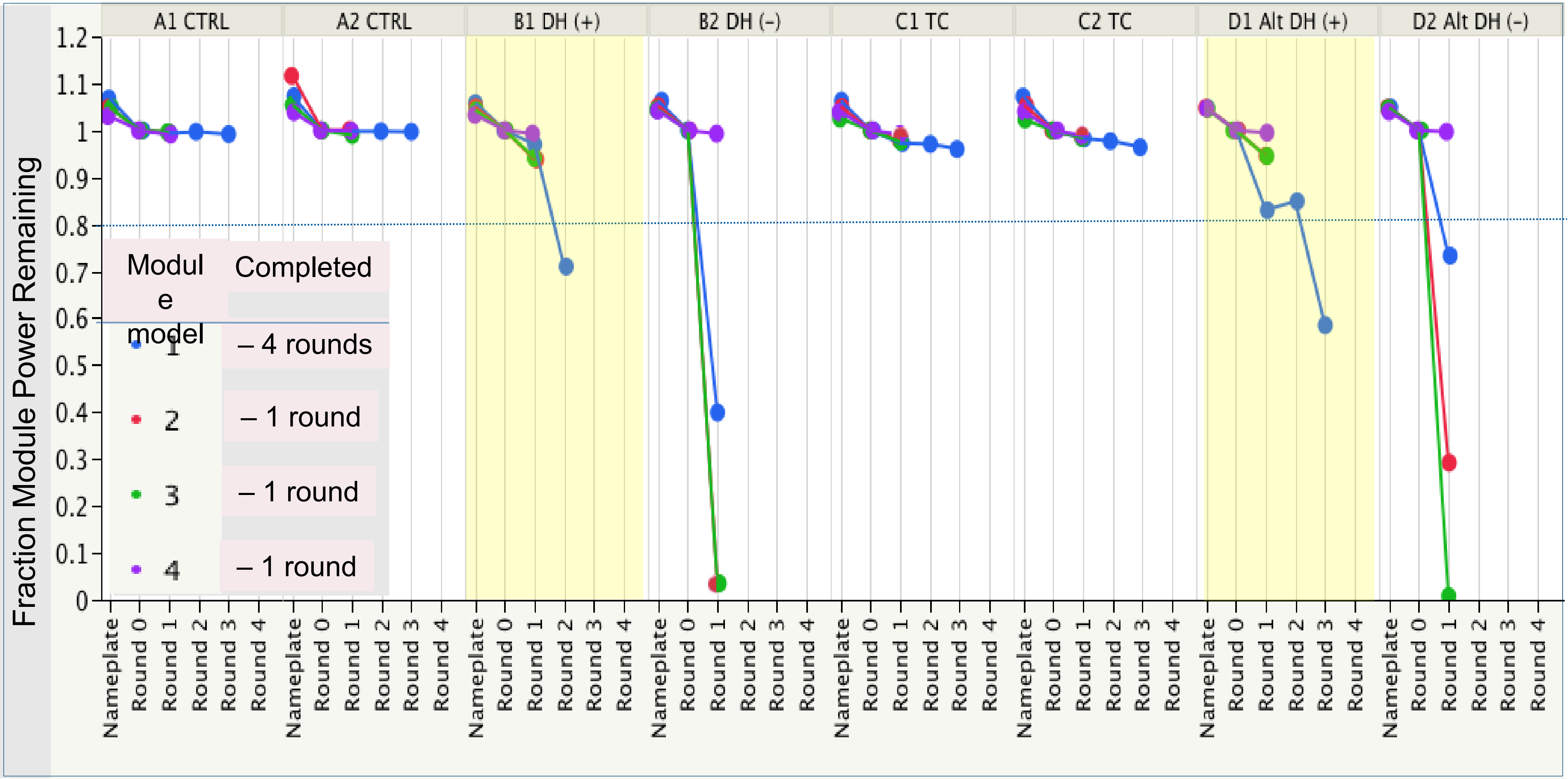

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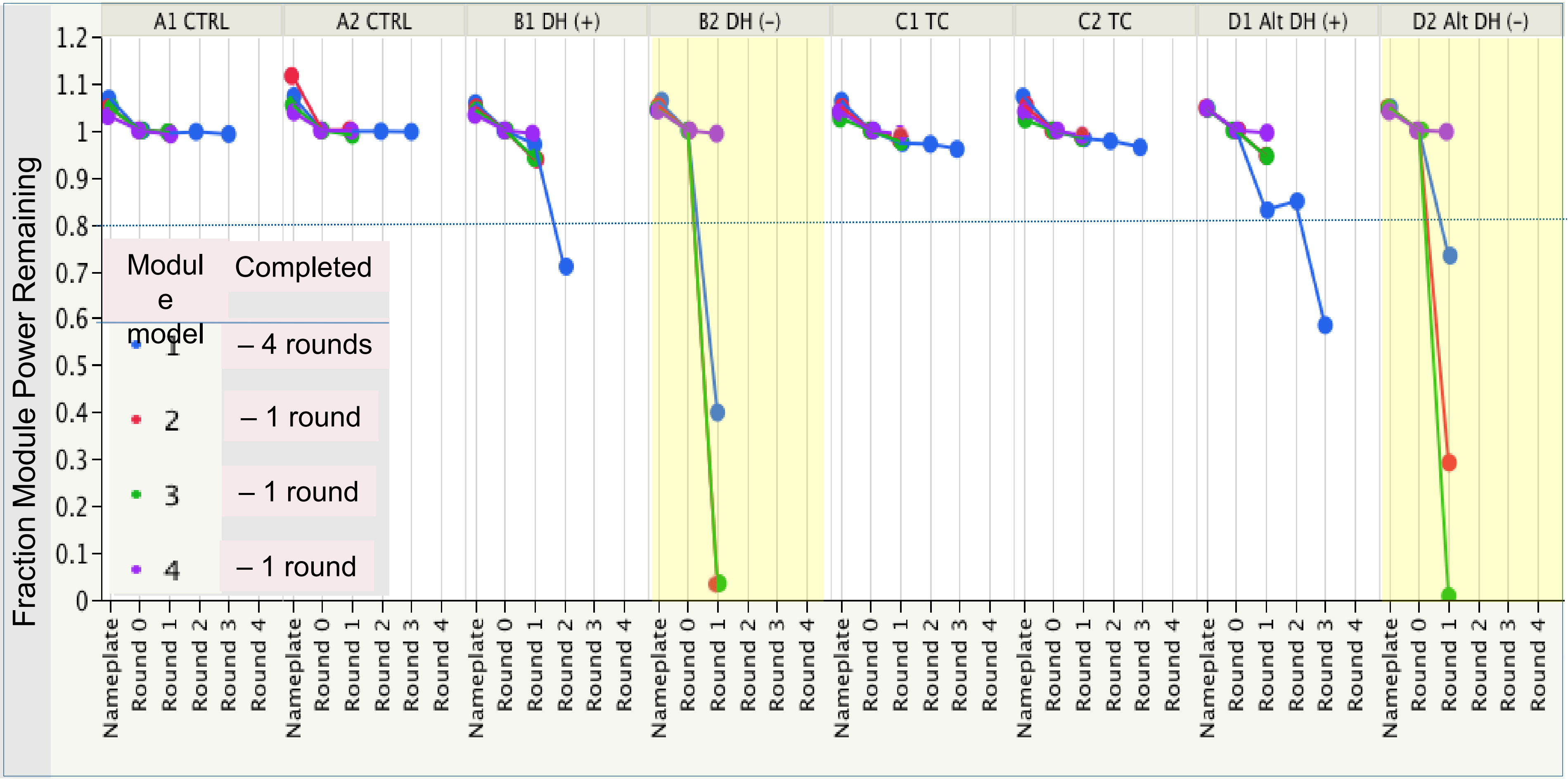


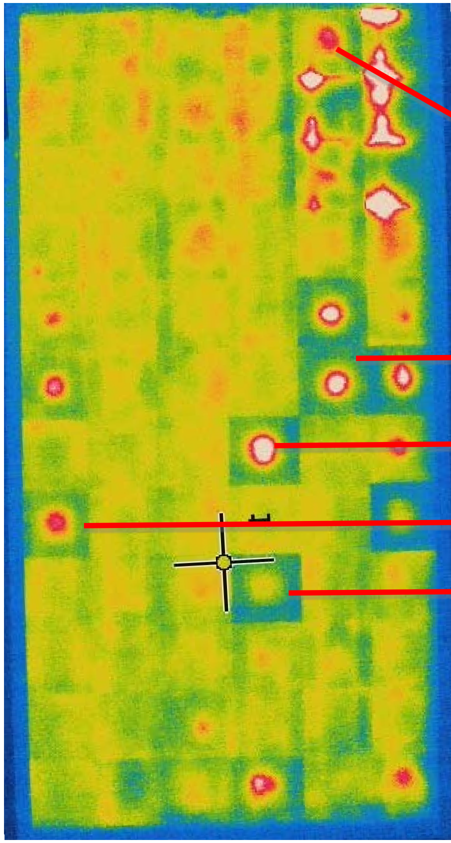
# Failure analysis, DH (+)

Ag gridline corrosion visible

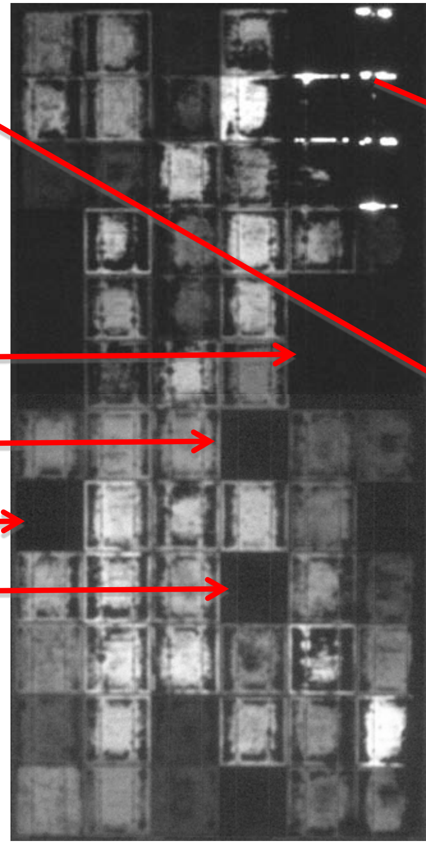
Series resistance increase according to dark I-V curve fitting

| | 0 hrs | 1000 Hrs | 2000 Hrs |
|---|---|---|---|
| $r_s$ ($\Omega$ cm$^2$) | 0.83 | 1.02 | 1.22 |

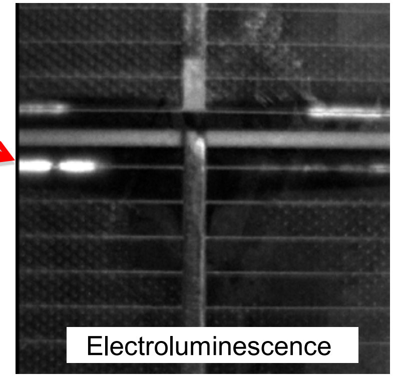
# Failure analysis, DH (-)



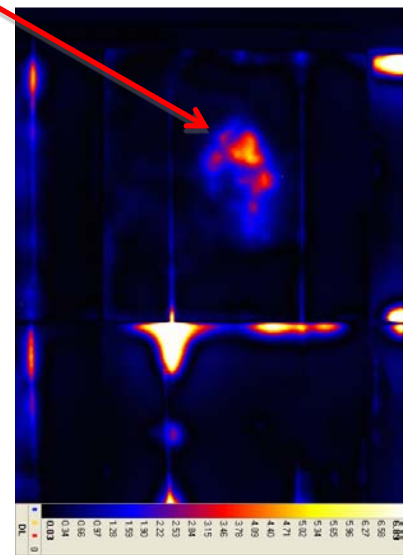
Thermal image



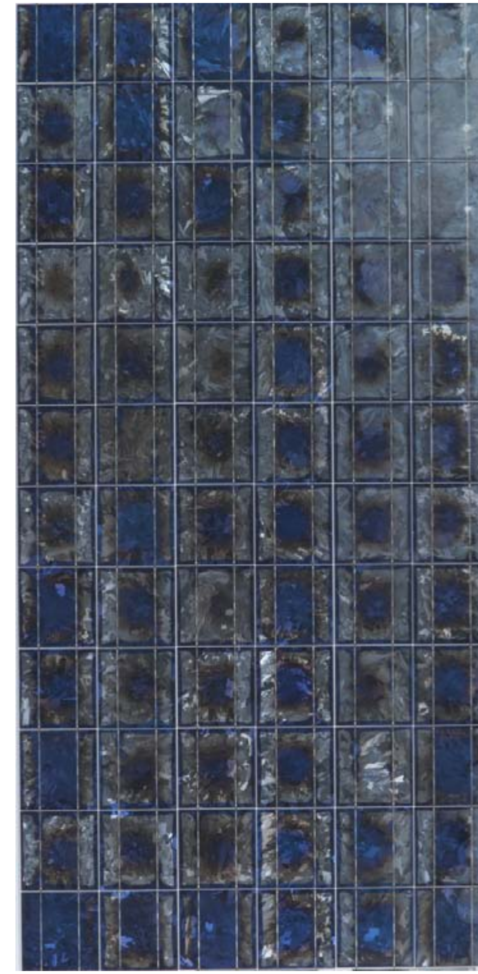
Electroluminescence



Electroluminescence

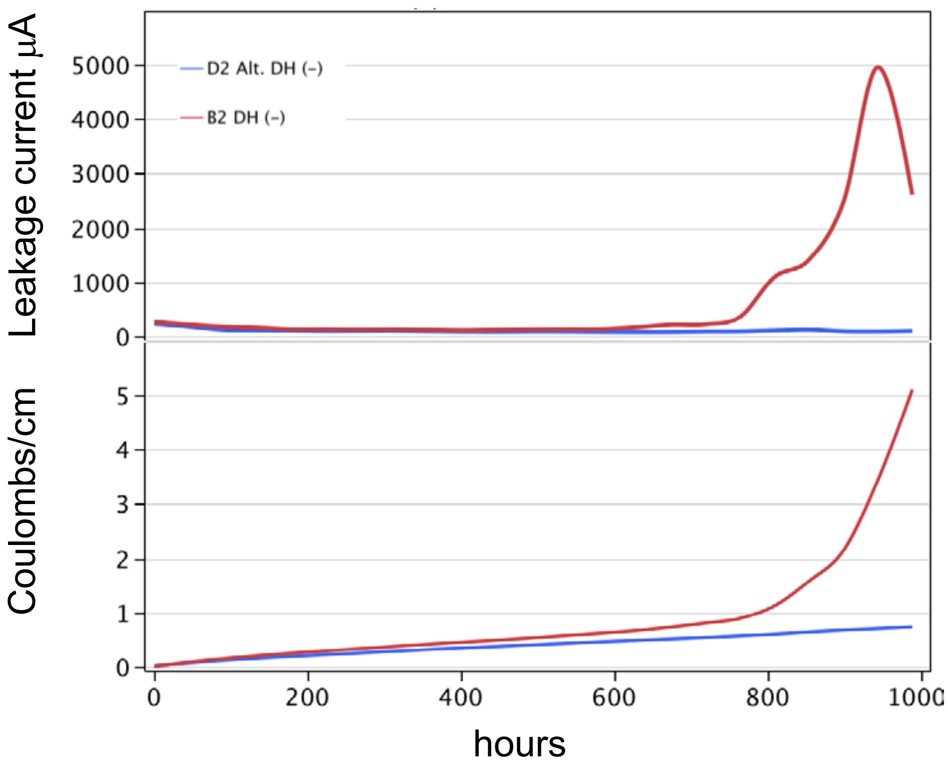


Lock-in thermography



- Shunting, often in the middle of the cells; cell dependent, suggests ionic motion
- Degradation of the Ag-Si interface, series resistance
- Decomposition of silicon nitride with water to ammonia and hydrous silica

# Monitoring corrosive damage by counting Coulombs



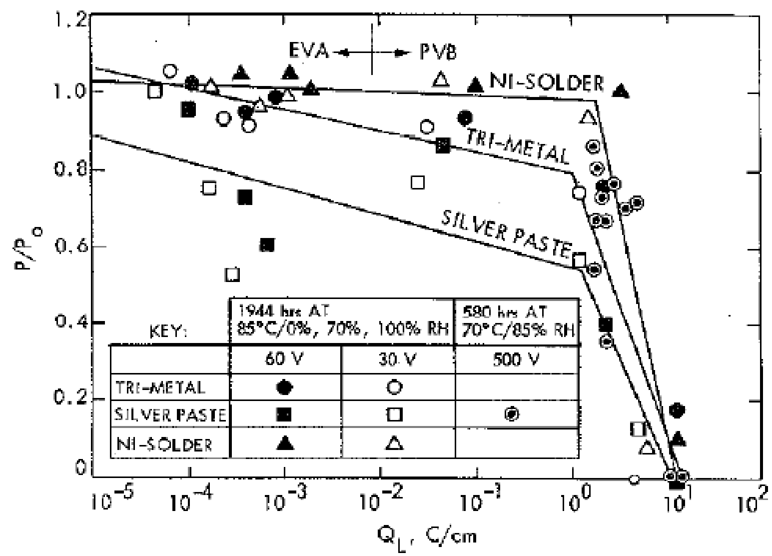




Figure 3. Power Output Reduction Versus Accumulated Unit Charge Transfer for C-Si Cells

G. Mon and R. G. Ross, (JPL), 18th IEEE PVSC (1985)

- > 20% power degradation in less than 1 Coulomb per cm of module edge

# Main Results

1) Crystalline silicon modules are holding up well so far in thermal cycling
2) Modules in damp heat with positive bias to active layer show varying degrees of Ag metallization oxidation and hydrolytic degradation of backsheet—the extent is related to leakage current
3) Modules in damp heat with negative bias to active layer show varying degradation rates attributable to cell shunting and Si-Ag interface degradation, the extent appears related to leakage current

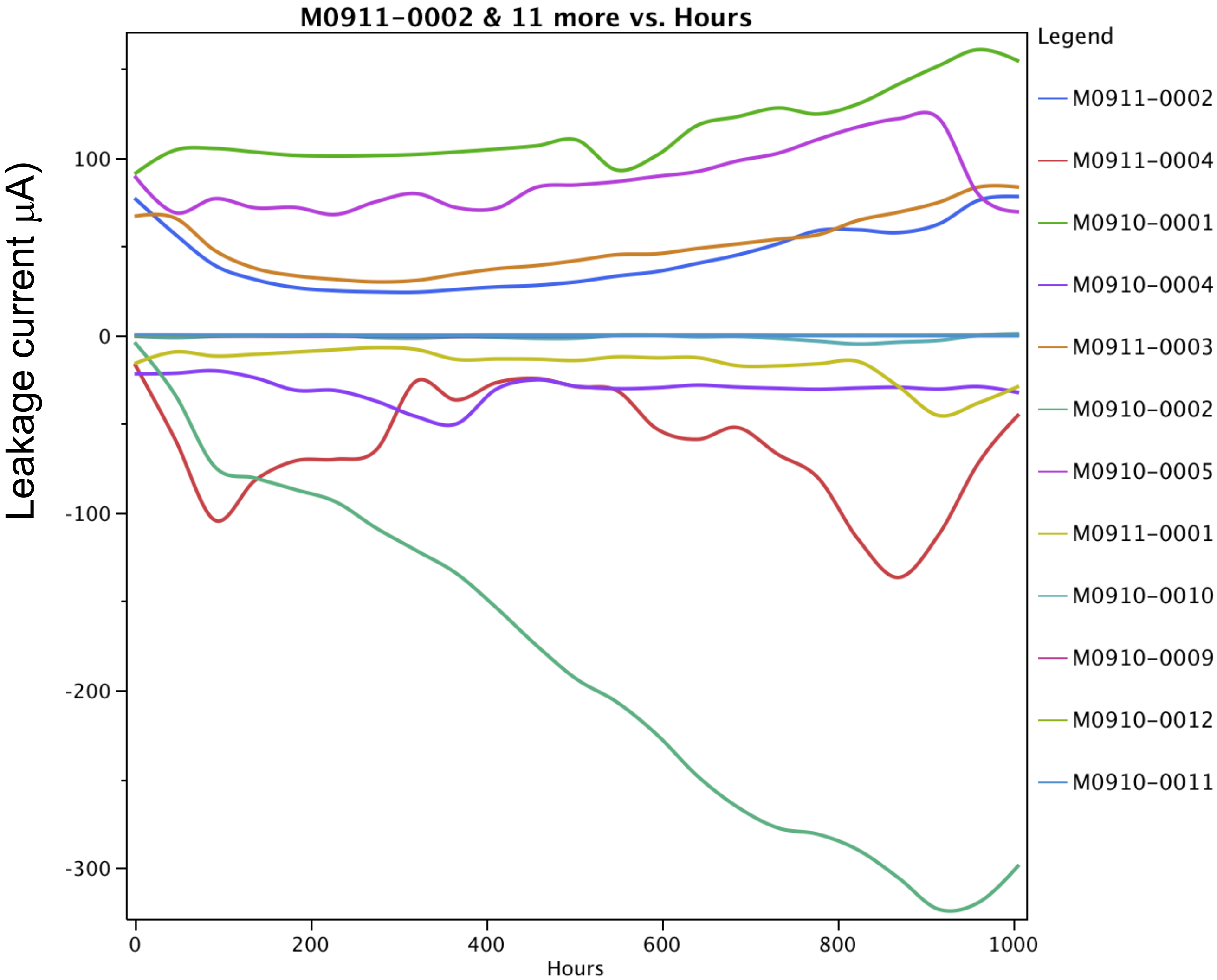
## Lessons from the past, from thin films*

1) The degradation depends on the direction of the internal electric fields; modules biased positively relative to a grounded frame show less damage (thin film, p-base Si)
2) Modules that lack a frame and use mounting points bonded to the backsheet glass show no damage.
3) Water vapor enhances the corrosion if it can enter the module through the edges, and by increasing the conductivity of the front glass surface.
4) Damage rates can be slowed if leakage currents that are caused by voltage potentials between the frame and the internal circuitry are reduced.

* Adapted from C.R. Osterwald, T.J. McMahon, and and J.A. del Cueto, **Electrochemical Corrosion of SnO2:F Transparent Conducting Layers in Thin Film Photovoltaic Modules,** Solar Energy Materials and Solar Cells, 2003 Vol.79 (No.1)

Thank you for your attention !

# Monitoring of module leakage current, ± 600 V




Worst case field monitored leakage current of modules:

NREL, 1 μA

FSEC, 8 μA

85°C DH, 85% RH is yielding generally 10x, up to 100x worst case field leakage currents