NREL
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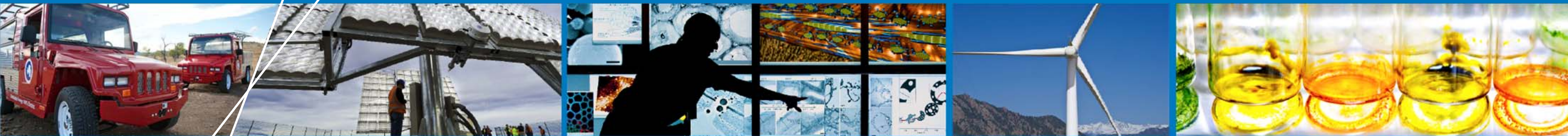
Initial results of IEC 62804 *draft* round robin testing



Peter Hacke and Kent Terwilliger
NREL, USA
Simon Koch, Thomas Weber, and Juliane Berghold
PI-Berlin, DE
Stephan Hoffmann and Michael Koehl
Fraunhofer ISE, DE
Sascha Dietrich and Matthias Ebert
Fraunhofer CSP, DE
Gerhard Mathiak
TÜV Rheinland, DE

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Abstract

Two out of three planned crystalline silicon module designs were distributed in five replicas each to five laboratories for testing according to the IEC 62804 (draft) system voltage durability qualification test for crystalline silicon modules. The stress tests were performed in environmental chambers at 60°C, 85% relative humidity, 96 h, and with module nameplate system voltage applied to the cells (two modules in each polarity and one control). Pass/fail results, means, and standard deviations of degradation of the modules tested as a function of module design and test laboratory are presented and discussed. Preliminary results from the module designs tested so far indicate the test protocol is able to discern susceptibility to potential-induced degradation with acceptable consistency from lab to lab. Influence of possible variations in the severity of the test between labs has so far not been distinguishable.

Introduction

- **Testing was performed according to IEC 62804 draft "SYSTEM VOLTAGE DURABILITY QUALIFICATION TEST FOR CRYSTALLINE SILICON MODULES." The motivation was to:**
  - **See if the specified sample size (2 modules per polarity) is adequate considering variations that might exist in shipping modules**
  - **See if possible lab to lab variation in stress levels overly influences results**

- **Modules were chosen to be near the pass/fail limit vis-à-vis the 60°C/85%RH/-1000 V 96h stress condition to attempt to get useful statistics (without 'censoring'). Said another way, we *could* have chosen modules that do not degrade at all, and modules that degrade an extreme amount, and shown how well the test differentiates the two, but such results would be less useful.**

Experiment

- **Highlights of round-robin test procedure based on IEC 62804 *draft*:**
  - Modules leads shorted and connected to high voltage, module frames grounded
  - Neither *in-situ* nor *ex-situ* I-V measurements are performed on the module over the course of the 96 h test
  - Leakage current from the active layer/cells to ground may optionally be measured during the testing (most labs did not report)
  - Open market modules chosen (but not necessarily currently shipping), not specially designed modules
  - Electroluminescence measurements are carried out before and after the test
  - Modules are tested in both polarities (2 each), although testing labs may instead choose to use the modules destined for the known stable polarity for outdoor tests
- **Stress conditions**
  - Chamber air temperature 60 °C ± 2°C
  - Chamber relative humidity 85 % ± 5 % RH
  - Test duration 96 h
  - Voltage: module nameplate rated system voltage (1000 V), 2 for each polarity, 1 module supplied for control, voltage applied during ramps
  - Pass criterion: both modules of a tested polarity must show < 5% power degradation and pass IEC 61215 ed. 2 visual inspection criteria

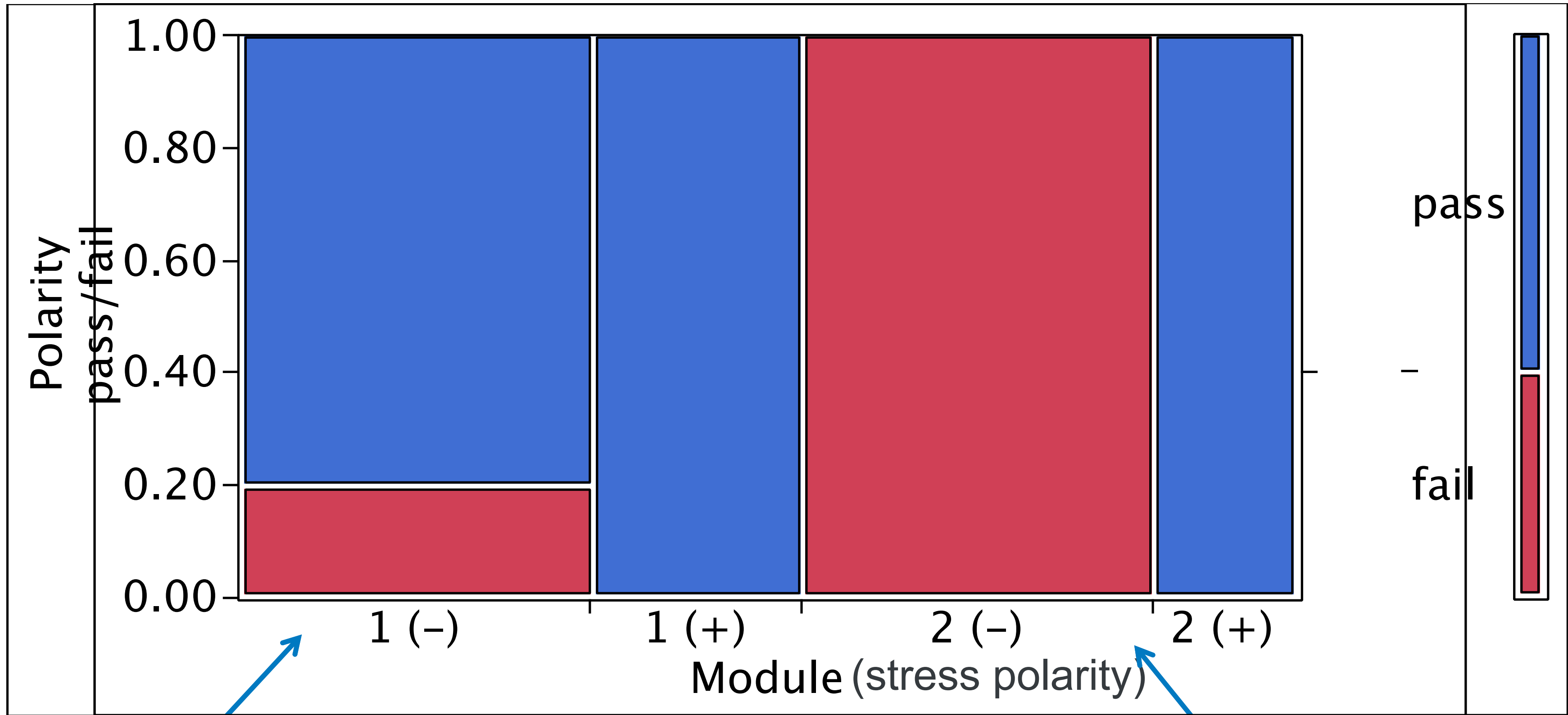
Experiment

- **Module designs 1 and 2 made with conventional front junction $n^+/p/p^+$ cells, Al frames, and polymeric backsheets were selected:**
- **Module 1**
  - 230 W class mc-Si module design (60 15.6 cm x 15.6 cm cell)
  - Manufactured from 2011 onward
  - Based on previously published reports of PID tests under different conditions, the module was expected to show a small PID signal with some scatter in results, but generally less that 5% degradation
- **Module 2**
  - a 170 W class mc-Si module design (72 12.5 cm x 12.5 cm cells)
  - Manufactured in 2008 or 2009
  - Expected to show PID based on data obtained at NREL under different conditions, but significant scatter in the data was expected due to poorer process control and increased variability in the cells made during this period and as evidenced in prior EL imaging.
- **Module 3, in test**

Participants	
Lab #	**Lab name**
1	NREL
2	Fraunhofer ISE
3	TÜV Rheinland
4	Fraunhofer CSP
5	PI Berlin

Overview of pass/fail results of two different module designs tested at 5 labs

Pass/fail condition: If 1 or 2 modules tested in a polarity fail (Pmax drop > 5%), that design is considered failed in that polarity at the given test lab

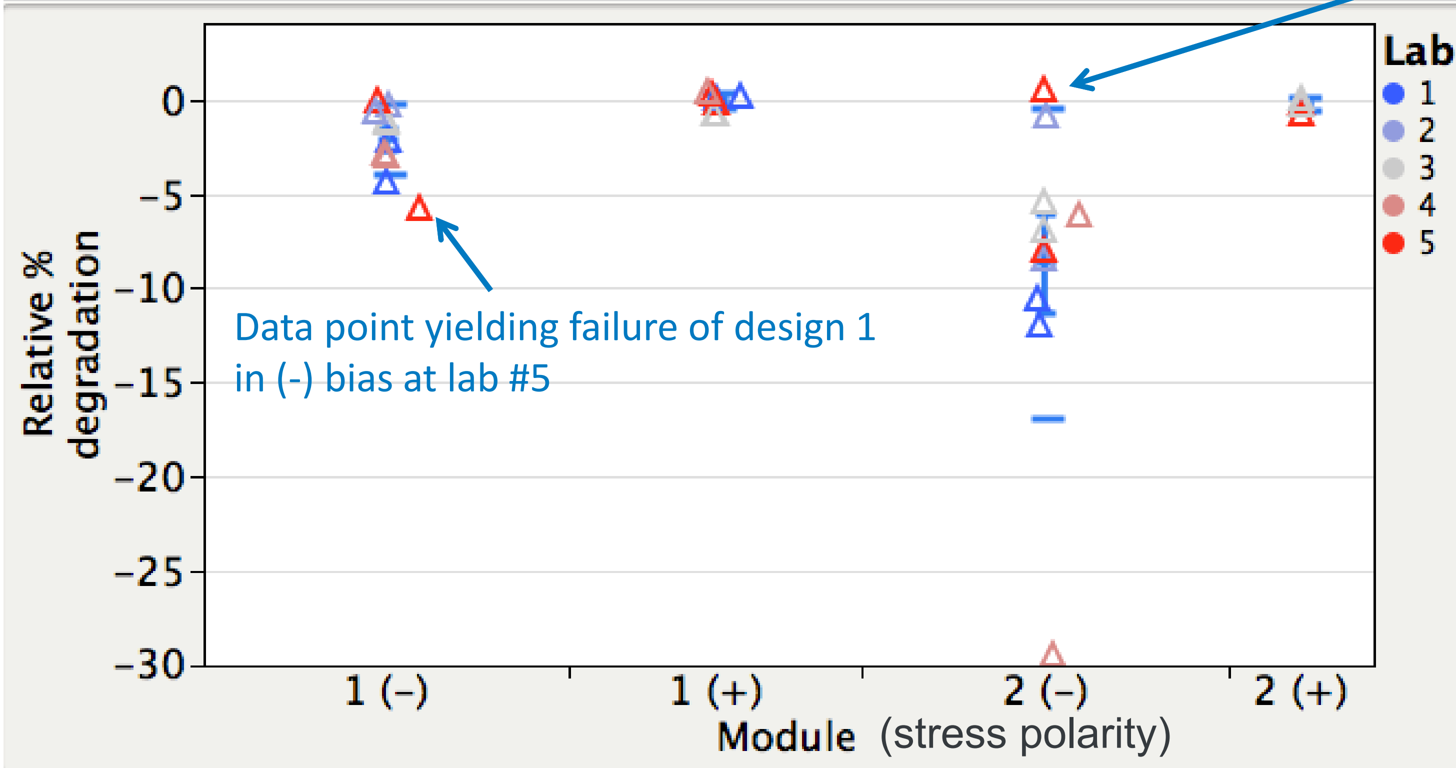


Module design 1 failed in the (-) polarity test at one of the five labs when one of the two replicas tested there failed.

Module design 2 failed in the (-) polarity test at all five labs when at least one of the two modules tested failed at each lab.

Considering stress in (-) bias, module design 1 shows both smaller mean degradation and standard deviation of degradation than design 2

Oneway Analysis of Relative % degradation By Module



What is the probability of both those 2 modules that degraded less than 5% arriving at one lab, and thus passing the stress test in the (-) polarity at that one lab?

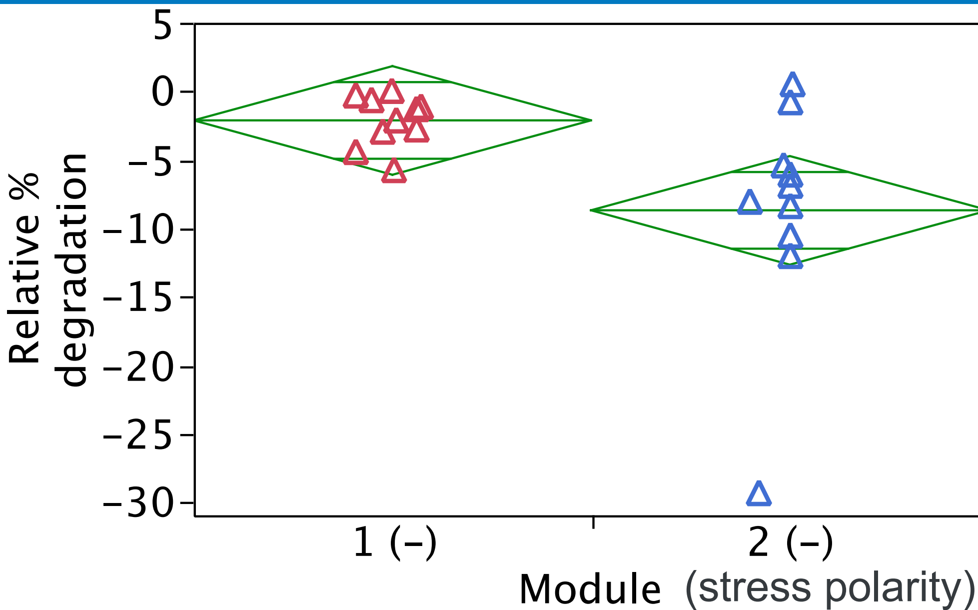
There are 45 different combinations when the number of samples is 10 with 2 samples in each combination. The probability of those two passing modules ending up at one lab is 1/45 (2.22%).

Missing Rows 10

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1 (-)	10	-2.1240	1.87072	0.5916	-3.46	-0.786
1 (+)	8	-0.1021	0.43217	0.1528	-0.46	0.259
2 (-)	10	-8.6960	8.22389	2.6006	-14.58	-2.813
2 (+)	4	-0.2900	0.31602	0.1580	-0.79	0.213

Results are controlled by module design, no conclusive proof that results are controlled by lab



Module

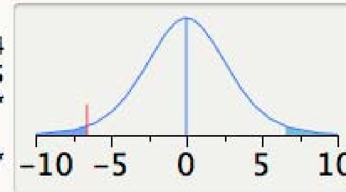
- 1 (–)
- 2 (–)

t Test

2 (–)-1 (–)

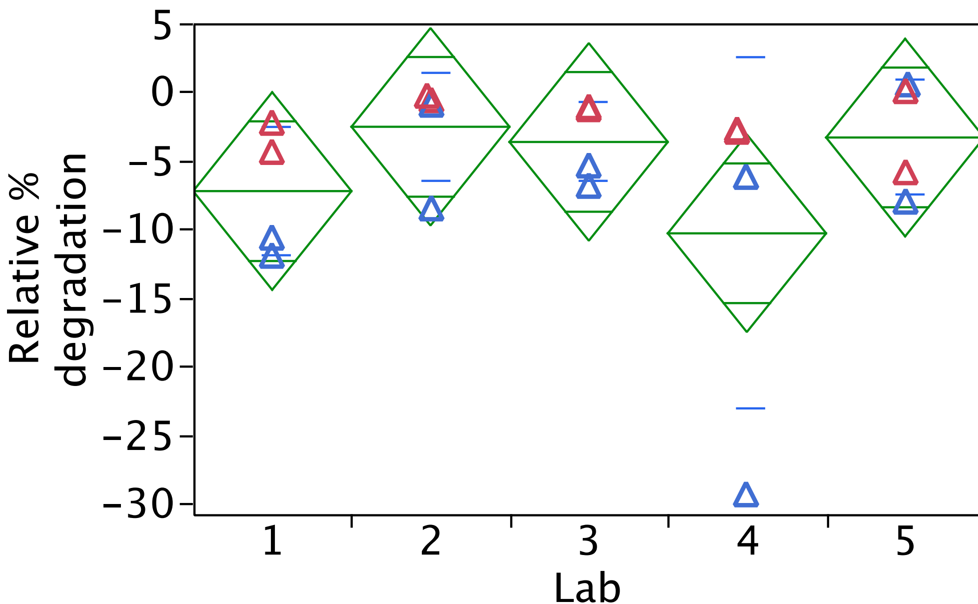
Assuming unequal variances

Difference	−6.572	t Ratio	−2.46414
Std Err Dif	2.667	DF	9.928915
Upper CL Dif	−0.624	Prob > |t|	0.0336*
Lower CL Dif	−12.520	Prob > t	0.9832
Confidence	0.95	Prob < t	0.0168*



Bayesian Variance Component Estimates

Random Effect	Var Component	Pct of Total
Lab	6.1232337	14.557
Module[Lab]	9.0064708	21.411
Residual	26.934157	64.032
Total	42.063861	100.000



Module

- 1 (–)
- 2 (–)

Analysis of Variance

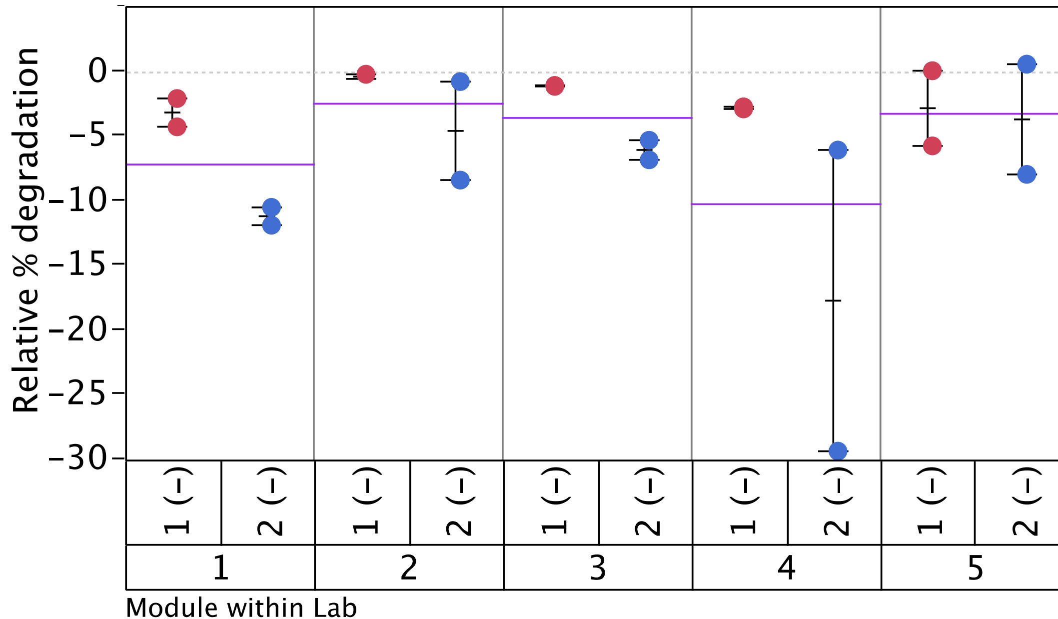
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Lab	4	171.71495	42.9287	0.9408	0.4672
Error	15	684.42845	45.6286		
C. Total	19	856.14340			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	4	−7.233	3.3774	−14.43	−0.034
2	4	−2.545	3.3774	−9.74	4.654
3	4	−3.645	3.3774	−10.84	3.554
4	4	−10.303	3.3774	−17.50	−3.104
5	4	−3.325	3.3774	−10.52	3.874

Std Error uses a pooled estimate of error variance

What extent did the possible varying severity of the test labs influence outcomes?



Module degradation [(-) bias only] viewed as a function of lab to determine if any labs are more severe than others.

The analysis shows that the choice of lab is the least influential component of the variation, the type of module is the next important factor, but variation of the modules within a given module type (residual) is the most influential.

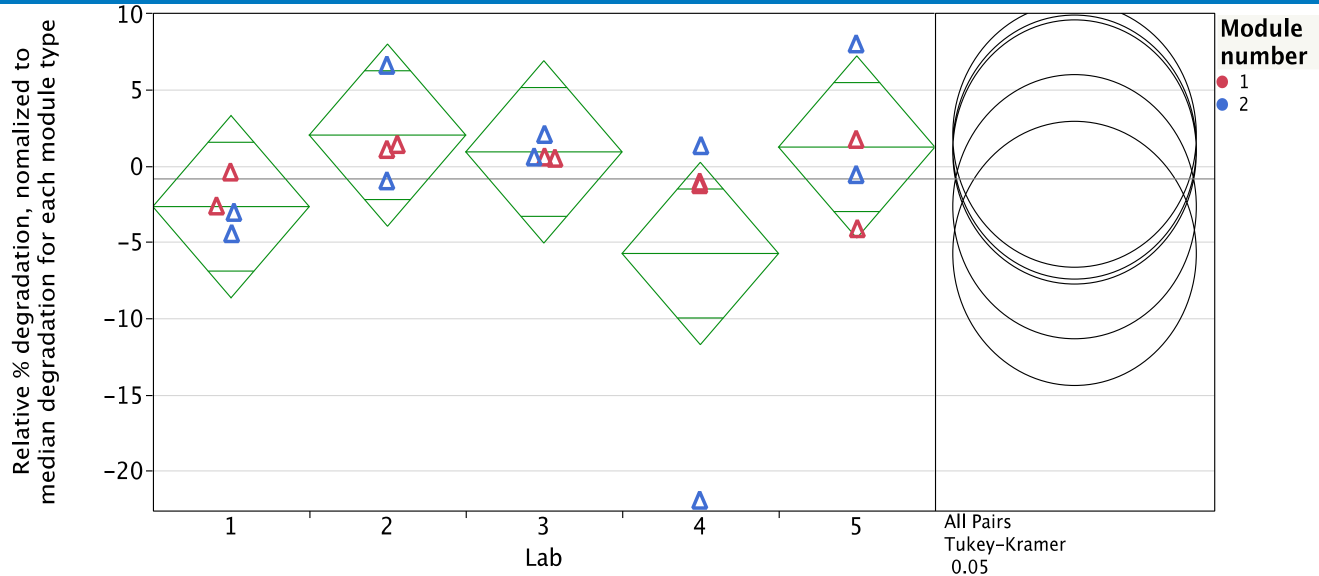
Bayesian Variance Component Estimates

Random Effect	Var Component	Pct of Total
Lab	6.1232337	14.557
Module[Lab]	9.0064708	21.411
Residual	26.934157	64.032
Total	42.063861	100.000

Variance Components

Component	Var Component	% of Total	20 40 60 80
Lab	6.123234	14.6	
Module[Lab]	9.006471	21.4	
Within	26.934157	64.0	
Total	42.063861	100.0	

Examination of lab to lab variability



Level		Mean
2	A	2.012500
5	A	1.232500
3	A	0.912500
1	A	−2.675000
4	A	−5.745000

Levels not connected by same letter are significantly different.

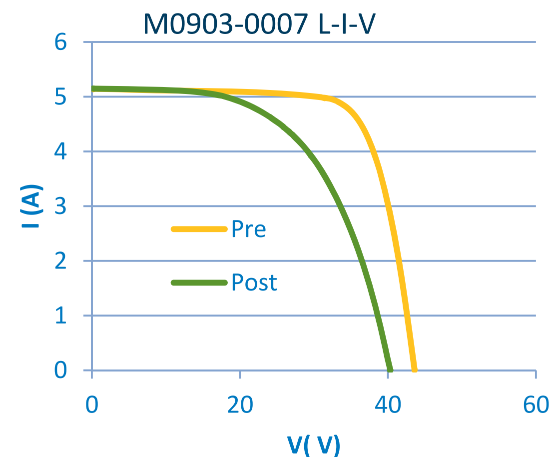
Ordered Differences Report

Level	− Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
2	4	7.757500	3.965387	−4.4873	20.00232	0.3319
5	4	6.977500	3.965387	−5.2673	19.22232	0.4303
3	4	6.657500	3.965387	−5.5873	18.90232	0.4745
2	1	4.687500	3.965387	−7.5573	16.93232	0.7611
5	1	3.907500	3.965387	−8.3373	16.15232	0.8577
3	1	3.587500	3.965387	−8.6573	15.83232	0.8907
1	4	3.070000	3.965387	−9.1748	15.31482	0.9342
2	3	1.100000	3.965387	−11.1448	13.34482	0.9985
2	5	0.780000	3.965387	−11.4648	13.02482	0.9996
5	3	0.320000	3.965387	−11.9248	12.56482	1.0000

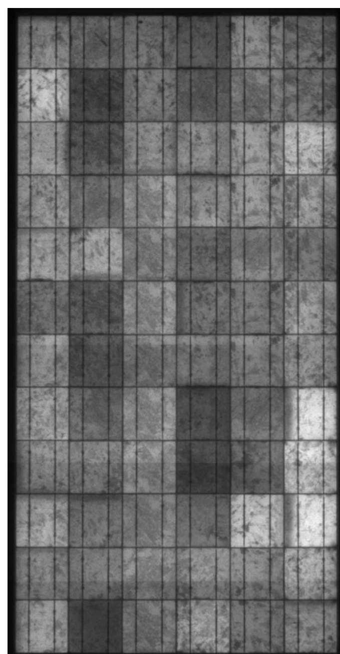
Subtracting median degradation for each module type also failed to show a statistically significant difference between labs

Results of a module design 2 from lab 4

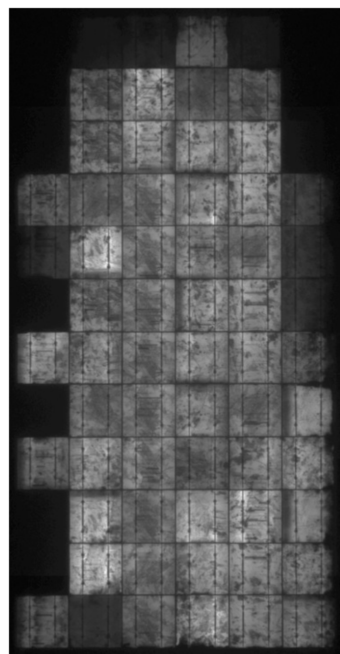
NREL ID	Round	Sequence	Voc (V)	Isc (A)	FF (%)	Vmax (V)	Imax (A)	Pmax (W)	Pmax change (%)
M0903-0007	0	-1000V	43.59	5.14	74.03	34.97	4.74	165.80	
M0903-0007	96hr	-1000V	40.32	5.15	56.41	28.2	4.15	117.13	-29.36
M0903-0014	0	-1000V	43.57	5.17	73.14	34.64	4.76	164.92	
M0903-0014	96hr	-1000V	43.43	5.19	68.71	34.42	4.5	154.82	-6.12



Potential-induced degradation in the most degraded module design



EL: M0903-0007, pre



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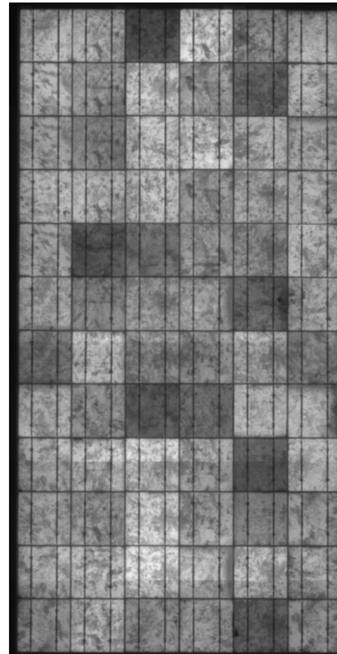
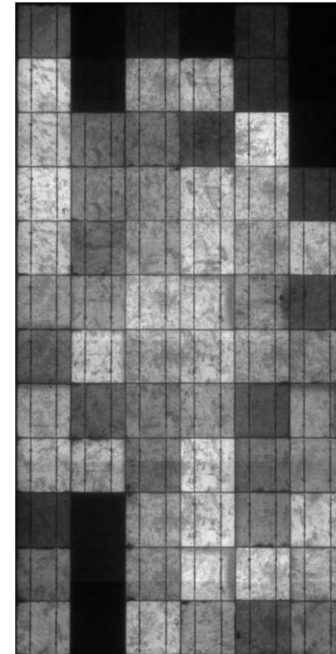


EL: M0903-0014, pre



EL: M0914-0014, post

Images/Data:
Sascha Dietrich
Fraunhofer CSP

Conclusions

- **2 module designs completed testing at 5 labs for system voltage durability**
- **The test was able to statistically significantly discern the two module designs for potential-induced degradation**
- **Extent of variability measured for each module design was in line with expectations based on previous experience**
- **Potential-induced degradation was observed in the modules by electroluminescence**
- **lab to lab variability was the least influential variable**
- **The test (per IEC 62804 draft) appears successful with respect to the scope of this round robin with results of two of the three modules analyzed**

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