



# BACKSHEET STRESS TESTING ENGINEERING REPORT

PET-, PVDF- and Tedlar®-based Backsheets

**DNV GL**

Report No.: CSTR-005B-4

August 3, 2018



## Executive Summary

Global advisory and certification services provider DNV GL recently conducted an independent test examining the reliability of commercial PV modules made with polyvinylidene fluoride (PVDF), polyethylene terephthalate (PET) and Tedlar® polyvinyl fluoride (PVF)-based backsheets.

For its study, DNV GL employed the Module Accelerated Sequential Testing (MAST) method, developed by DuPont. MAST uses a sequence of damp heat, followed by repeated UV temperature cycling steps, to replicate conditions experienced in the field. During and after the test, DNV GL researchers visually assessed the PV modules and measured their performance.

The testing revealed that in modules made with PVDF backsheets, cracking occurred in air-side layers over busbars. Visible cracks appeared on the backsheet over all busbar ribbons in the long machine direction of the module, indicating mechanical weakness along the transverse direction.

Test findings for PET-based backsheets showed significant yellowing, a sign of polymer degradation and mechanical weakening. The PVDF and PET backsheet failures noted in the test were also observed in the field.

The Tedlar® PVF-based backsheets showed no changes. In fact, Tedlar® backsheets have served in the field for more than 30 years with no observable change.

BACKSHEET STRESS TESTING

# Engineering Report

PET-, PVDF-, and Tedlar-based Backsheets

**Report No.:** CSTR-005B-4

**Date:** 14 September 2018



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Project name: Backsheet Stress Testing  
Report title: Engineering Report  
Customer: CONFIDENTIAL  
Contact person: CONFIDENTIAL  
Date of issue: 14 September 2018  
Project No.: CSTR-005  
Report No.: CSTR-005B-4

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Task and objective:  
Stress testing of PET, PVDF, and Tedlar-based backsheets for CONFIDENTIAL.

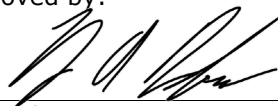
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Revision	Date	Reason for Issue	Prepared by	Verified by	Approved by
1	1/16/2018	Final	Jack O'Shaughnessy	Lee Malmgren	Ryan Desharnais
2	6/12/2018	Addition of Data	Jack O'Shaughnessy	Lee Malmgren	Ryan Desharnais
3	8/3/2018	Revision	Jack O'Shaughnessy	Lee Malmgren	Ryan Desharnais
4	9/6/2018	Revision	Lee Malmgren	Lee Malmgren	Ryan Desharnais

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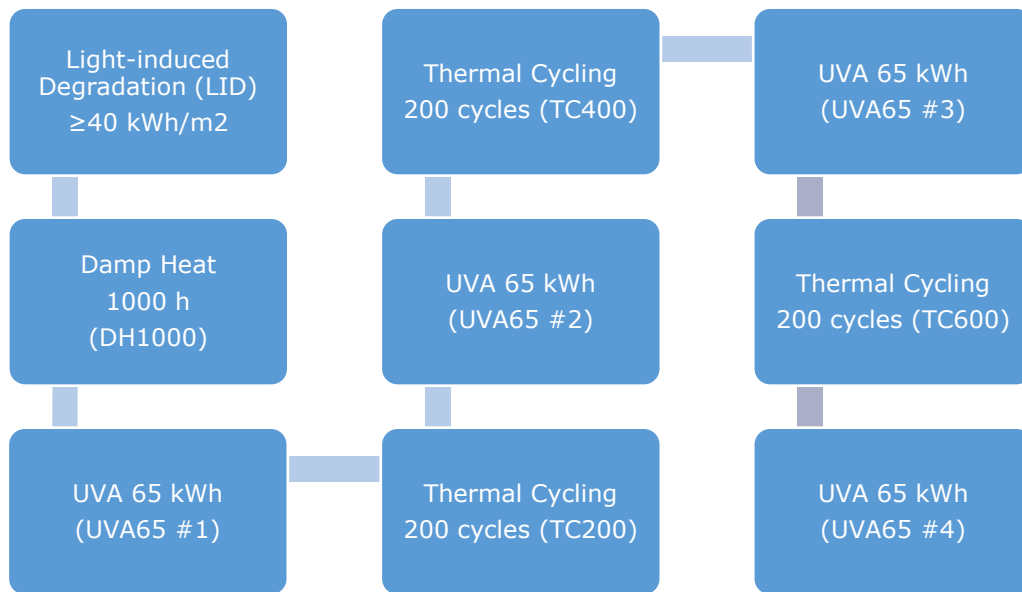
## List of abbreviations

<b>Abbreviation</b>	<b>Meaning</b>
DML	Dynamic mechanical load
DNV GL	DNV GL PVEL, LLC
EL	Electroluminescence
G/G	Glass/glass
G/P	Glass/polymer
IEC	International Electrotechnical Commission
$I_{MP}$	Current at maximum power
$I_{SC}$	Short-circuit current
$P_{MAX}$	Maximum power
PQP	Product Qualification Program
PV	Photovoltaic
STC	Standard test conditions
$V_{MP}$	Voltage at maximum power
$V_{OC}$	Open-circuit voltage

## 1 SUMMARY

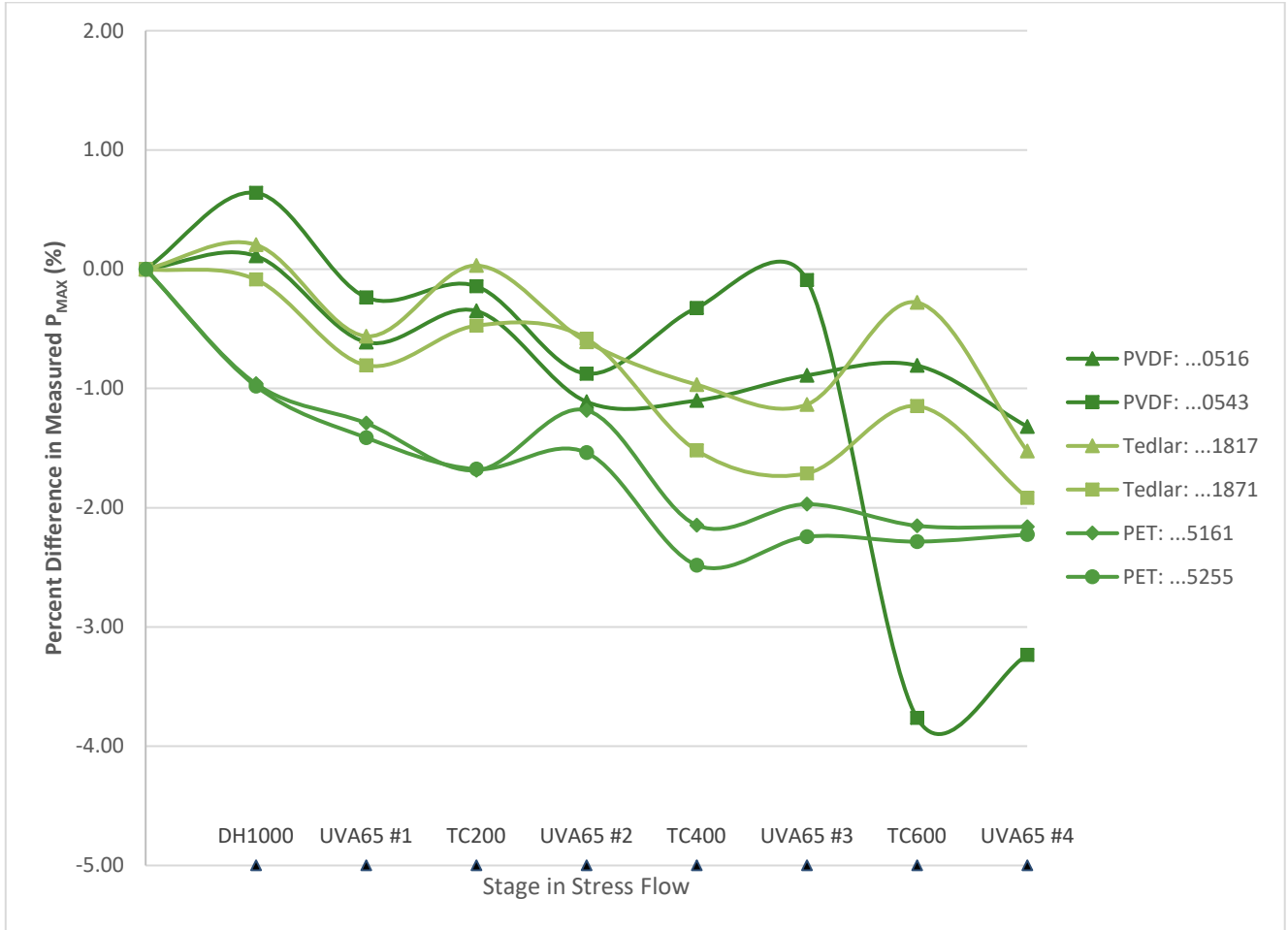
Twelve (12) photovoltaic (PV) modules from three (3) different manufacturers were submitted for backsheet testing by DNV GL PVEL, LLC ("DNV GL"). Each PV model consists of a different class of backsheet: PET-, PVDF-, and Tedlar-based backsheets. DNV GL selected two (2) modules per manufacturer to undergo stress testing and characterizations. The test stream can be found in Figure 1-1. Characterizations include color measurements, electroluminescence imaging (EL), flash-testing, visual inspection, and wet leakage-current testing.

This report includes additional testing data for TC600 and UV65 #4. The initial testing data can also be found in report CSTR-005A-1. Following the TC600 stress, the EL image for module ...0543 displayed significant damage to the cells; this is being investigated by DNV GL.



**Figure 1-1 Test stream for backsheet testing**

## 2 BACKSHEET STRESS TESTING



**Figure 2-1 Percent difference in measured  $P_{MAX}$  due to stress**



## 2.1 Color Measurements

Color measurements were done per ASTM E308 specifications.

### 2.1.1 Unstressed Measurements

Unstressed Measurements							
...4302 PET backsheet	L*	a*	b*	...1844 Tedlar backsheet	L*	a*	b*
1	93.24	-0.71	1.64	1	88.99	-0.03	0.31
2	93.21	-0.67	1.79	2	88.89	-0.06	0.33
3	93.34	-0.65	1.85	3	88.90	-0.02	0.31
4	93.26	-0.64	1.83	4	88.95	-0.02	0.30
5	93.35	-0.64	1.85	5	88.95	-0.09	0.25
6	93.34	-0.65	1.86	6	89.01	-0.07	0.28
7	93.24	-0.71	1.50	7	88.66	-0.23	0.14
8	93.41	-0.67	1.87	8	88.62	-0.28	0.06
9	93.29	-0.67	1.63	9	88.86	-0.04	0.26
10	93.40	-0.65	1.84	10	88.90	-0.07	0.26
<b>AVG</b>	93.31	-0.67	1.77	<b>AVG</b>	88.87	-0.09	0.25
<b>STD</b>	0.07	0.03	0.129	<b>STD</b>	0.13	0.09	0.09
...0184 PVDF backsheet	L*	a*	b*	...0501 PVDF backsheet	L*	a*	b*
1	93.06	-1.20	-0.63	1	92.78	-1.24	-0.71
2	93.16	-1.11	-0.44	2	93.14	-1.19	-0.64
3	93.47	-1.04	-0.23	3	93.02	-1.21	-0.61
4	93.28	-1.09	-0.35	4	93.02	-1.19	-0.54
5	93.21	-1.11	-0.45	5	92.89	-1.21	-0.61
6	93.27	-1.10	-0.39	6	92.99	-1.19	-0.56
7	93.22	-1.11	-0.47	7	93.12	-1.15	-0.52
8	93.26	-1.11	-0.46	8	92.85	-1.18	-0.55
9	93.49	-1.40	-0.29	9	93.31	-1.14	-0.42
10	93.13	-1.14	-0.53	10	93.10	-1.15	-0.49
<b>AVG</b>	93.26	-1.14	-0.42	<b>AVG</b>	93.02	-1.19	-0.57
<b>STD</b>	0.14	0.10	0.12	<b>STD</b>	0.16	0.03	0.08

## 2.1.2 Post-UVA65 #1 Measurements

Post UVA65 #1							
...5161 PET backsheet	L*	a*	b*	...5255 PET backsheet	L*	a*	b*
1	93.60	-0.73	1.53	1	93.63	-0.75	1.50
2	93.56	-0.77	1.48	2	93.61	-0.75	1.55
3	93.42	-0.78	1.47	3	93.43	-0.78	1.48
4	93.45	-0.78	1.53	4	93.50	-0.78	1.47
5	93.35	-0.82	1.50	5	93.55	-0.75	1.55
6	93.43	-0.78	1.52	6	93.54	-0.77	1.49
7	93.42	-0.78	1.58	7	93.55	-0.75	1.59
8	93.53	-0.78	1.49	8	93.55	-0.76	1.58
9	93.42	-0.78	1.52	9	93.54	-0.78	1.57
10	93.51	-0.78	1.68	10	93.54	-0.77	1.57
<b>AVG</b>	93.47	-0.78	1.53	<b>AVG</b>	93.54	-0.76	1.54
<b>STD</b>	0.08	0.02	0.06	<b>STD</b>	0.05	0.01	0.05
...0543 PVDF backsheet	L*	a*	b*	...0516 PVDF backsheet	L*	a*	b*
1	93.19	-1.15	-0.14	1	93.03	-1.23	-0.19
2	93.13	-1.21	-0.18	2	93.23	-1.18	-0.09
3	93.20	-1.13	-0.01	3	93.57	-1.11	0.08
4	93.37	-1.14	-0.06	4	93.66	-1.10	0.04
5	92.83	-1.25	-0.26	5	93.13	-1.18	-0.16
6	93.23	-1.19	-0.17	6	92.90	-1.29	-0.33
7	93.25	-1.17	-0.12	7	92.82	-1.25	-0.20
8	92.48	-1.35	-0.42	8	92.86	-1.28	-0.39
9	92.97	-1.08	0.19	9	93.13	-1.15	-0.08
10	92.96	-1.23	-0.21	10	93.08	-1.18	-0.05
<b>AVG</b>	93.06	-1.19	-0.14	<b>AVG</b>	93.14	-1.20	-0.14
<b>STD</b>	0.26	0.08	0.16	<b>STD</b>	0.28	0.07	0.15

Post UVA65 #1							
...1817 Tedlar backsheet	L*	a*	b*	...1871 Tedlar backsheet	L*	a*	b*
1	88.73	0.07	1.08	1	88.90	0.11	1.14
2	88.50	0.15	1.20	2	88.76	0.10	1.12
3	88.56	0.09	1.13	3	88.77	0.07	1.02
4	88.31	0.17	1.23	4	88.73	0.08	1.12
5	88.57	0.13	1.22	5	88.75	0.11	1.27
6	88.69	0.10	1.19	6	88.87	0.09	1.17
7	88.68	0.10	1.11	7	88.79	0.12	1.24
8	88.69	0.12	1.14	8	88.76	0.11	1.30
9	88.63	0.09	1.07	9	88.72	0.08	1.08
10	88.46	0.15	1.23	10	88.77	0.14	1.21
<b>AVG</b>	88.58	0.12	1.16	<b>AVG</b>	88.78	0.10	1.17
<b>STD</b>	0.13	0.03	0.06	<b>STD</b>	0.06	0.02	0.09

### 2.1.3 Post-UVA65 #2 Measurements

Post UVA65 #2							
...5161 PET backsheet	L*	a*	b*	...5255 PET backsheet	L*	a*	b*
1	93.51	-0.79	2.19	1	93.64	-0.77	2.23
2	93.51	-0.80	2.24	2	93.39	-0.82	2.19
3	93.37	-0.86	2.15	3	93.46	-0.81	2.16
4	93.51	-0.80	2.46	4	93.51	-0.78	2.46
5	93.45	-0.83	2.34	5	93.51	-0.80	2.42
6	93.53	-0.80	2.52	6	93.55	-0.78	2.45
7	93.44	-0.80	2.18	7	93.56	-0.79	2.42
8	93.38	-0.81	2.23	8	94.08	-0.26	4.49
9	93.55	-0.76	2.35	9	93.52	-0.77	2.24
10	93.45	-0.80	2.36	10	93.45	-0.80	2.35
<b>AVG</b>	93.47	-0.81	2.30	<b>AVG</b>	93.57	-0.74	2.54
<b>STD</b>	0.06	0.03	0.12	<b>STD</b>	0.19	0.17	0.69



Post UVA65 #2							
...0543 PVDF backsheet	L*	a*	b*	...0516 PVDF backsheet	L*	a*	b*
1	92.82	-1.24	-0.31	1	92.82	-1.22	-0.10
2	92.98	-1.20	-0.03	2	93.14	-1.17	0.13
3	93.29	-1.17	-0.11	3	93.57	-1.08	0.36
4	93.51	-1.14	0.07	4	93.39	-1.11	0.28
5	92.54	-1.34	-0.37	5	93.02	-1.21	0.01
6	93.04	-1.20	-0.07	6	93.01	-1.21	-0.01
7	93.07	-1.19	-0.04	7	92.95	-1.22	-0.03
8	92.99	-1.18	0.04	8	92.76	-1.24	-0.02
9	93.18	-1.16	0.06	9	93.17	-1.13	0.05
10	93.29	-1.14	0.14	10	93.03	-1.20	-0.01
<b>AVG</b>	93.07	-1.20	-0.06	<b>AVG</b>	93.09	-1.18	0.07
<b>STD</b>	0.27	0.06	0.16	<b>STD</b>	0.25	0.05	0.15
...1817 Tedlar backsheet	L*	a*	b*	...1871 Tedlar backsheet	L*	a*	b*
1	88.78	0.08	1.03	1	88.73	0.08	1.27
2	88.73	0.09	1.14	2	88.81	0.13	1.28
3	88.50	0.11	1.20	3	88.75	0.11	1.11
4	88.64	0.14	1.25	4	88.68	0.12	1.21
5	88.57	0.10	1.22	5	88.73	0.09	1.25
6	88.67	0.00	1.14	6	88.84	0.10	1.26
7	88.65	0.06	1.09	7	88.81	0.08	1.17
8	88.60	0.03	1.11	8	88.69	0.11	1.32
9	88.63	0.10	1.13	9	88.74	0.09	1.11
10	88.58	0.08	1.21	10	88.71	0.09	1.22
<b>AVG</b>	88.64	0.08	1.15	<b>AVG</b>	88.75	0.10	1.22
<b>STD</b>	0.08	0.04	0.07	<b>STD</b>	0.05	0.02	0.07

## 2.1.4 Post-UVA65 #3 Measurements

Post UVA65 #3							
...5161: PET backsheet	L*	a*	b*	...5255: PET backsheet	L*	a*	b*
1	93.58	-0.76	2.88	1	93.47	-0.79	2.89
2	93.48	-0.79	3.02	2	93.51	-0.79	3.01
3	93.32	-0.82	2.80	3	93.44	-0.81	2.88
4	93.24	-0.83	2.94	4	93.39	-0.76	3.17
5	93.22	-0.82	2.99	5	93.45	-0.76	3.34
6	93.50	-0.77	3.07	6	93.36	-0.78	3.16
7	93.28	-0.82	2.81	7	93.28	-0.71	3.27
8	93.28	-0.74	2.94	8	93.44	-0.76	2.91
9	93.34	-0.76	2.83	9	93.36	-0.77	2.96
10	93.46	-0.79	2.85	10	93.46	-0.71	3.13
<b>AVG</b>	93.37	-0.79	2.91	<b>AVG</b>	93.42	-0.76	3.07
<b>STD</b>	0.12	0.03	0.09	<b>STD</b>	0.07	0.03	0.16
...0543: PVDF backsheet	L*	a*	b*	...0516: PVDF backsheet	L*	a*	b*
1	93.18	-1.12	0.41	1	93.03	-1.16	0.36
2	92.75	-1.22	0.18	2	92.91	-1.14	0.40
3	93.13	-1.11	0.38	3	93.00	-1.16	0.48
4	93.31	-1.11	0.29	4	93.27	-1.10	0.55
5	92.77	-1.11	0.46	5	92.75	-1.14	0.44
6	93.20	-1.12	0.27	6	92.68	-1.20	0.23
7	93.07	-1.15	0.24	7	92.75	-1.21	0.21
8	93.40	-1.16	0.23	8	92.89	-1.12	0.51
9	93.49	-1.07	0.27	9	92.94	-1.13	0.35
10	93.13	-1.13	0.38	10	92.95	-1.16	0.36
<b>AVG</b>	93.14	-1.13	0.31	<b>AVG</b>	92.92	-1.15	0.39
<b>STD</b>	0.24	0.04	0.09	<b>STD</b>	0.17	0.03	0.11

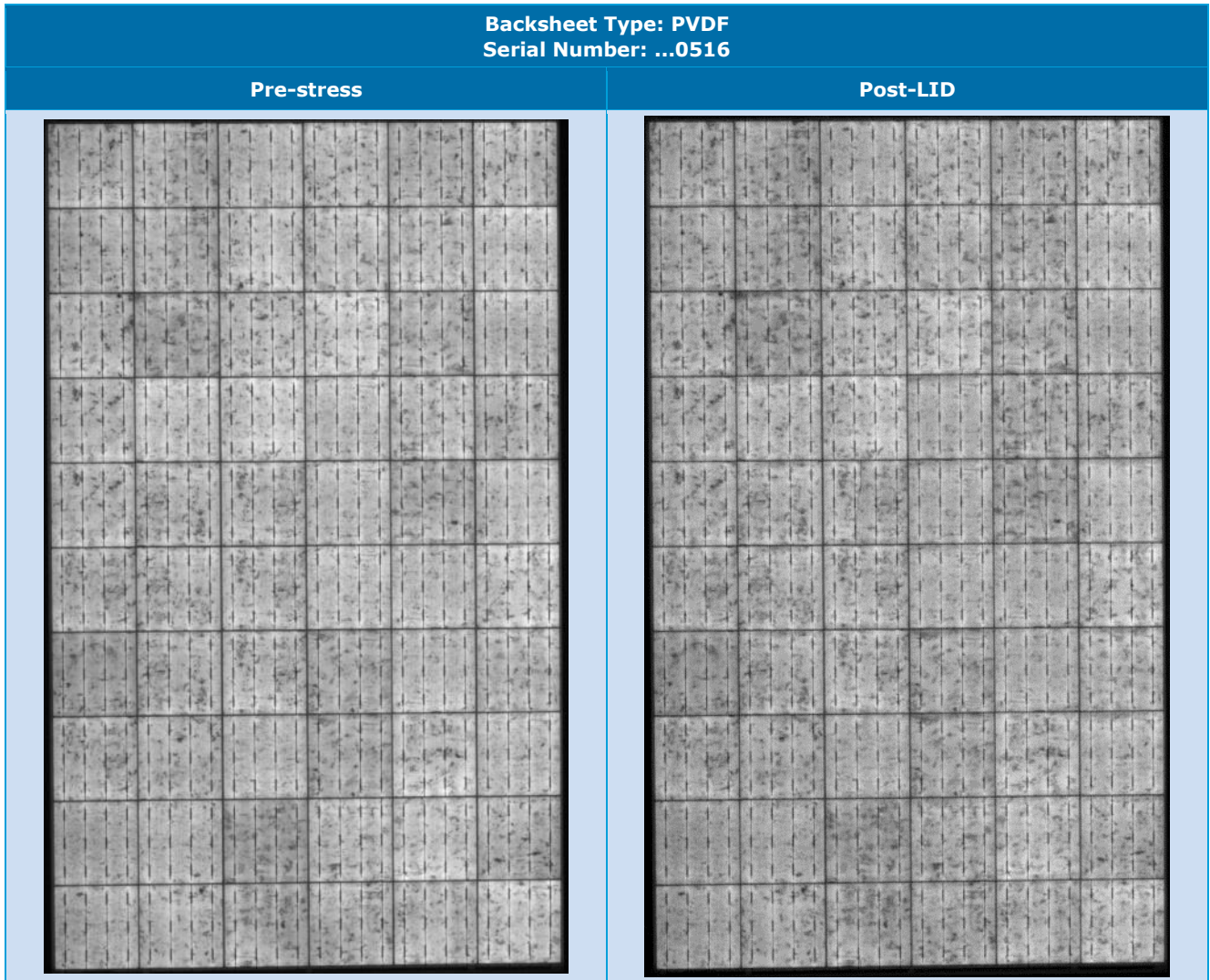
Post UVA65 #3							
...1817: Tedlar backsheet	L*	a*	b*	...1871: Tedlar backsheet	L*	a*	b*
1	88.72	0.05	1.05	1	88.80	0.07	1.28
2	88.68	0.07	1.13	2	88.76	0.07	1.22
3	88.40	0.10	1.20	3	88.83	0.06	1.16
4	88.44	0.08	1.22	4	88.72	0.07	1.25
5	88.79	0.07	1.17	5	88.75	0.10	1.35
6	88.76	0.06	1.17	6	88.85	0.07	1.26
7	88.62	0.05	1.12	7	88.77	0.06	1.21
8	88.63	0.09	1.16	8	88.68	0.05	1.27
9	88.69	0.07	1.09	9	88.60	0.01	1.16
10	88.44	0.11	1.19	10	88.59	0.09	1.33
<b>AVG</b>	88.62	0.08	1.15	<b>AVG</b>	88.74	0.07	1.25
<b>STD</b>	0.14	0.02	0.05	<b>STD</b>	0.09	0.02	0.06

### 2.1.5 Post-UVA65 #4 Measurements

Post UVA65 #4							
...5161: PET backsheet	L*	a*	b*	...5255: PET backsheet	L*	a*	b*
1	93.37	-0.72	3.220	1	93.42	-0.71	3.47
2	93.38	-0.75	3.210	2	93.43	-0.72	3.38
3	93.27	-0.78	3.080	3	93.28	-0.73	3.31
4	93.44	-0.74	3.180	4	93.25	-0.70	3.64
5	93.35	-0.76	3.140	5	93.43	-0.71	3.55
6	93.29	-0.72	3.210	6	93.37	-0.71	3.58
7	93.37	-0.71	3.180	7	93.19	-0.69	3.51
8	93.28	-0.64	3.650	8	93.38	-0.76	3.42
9	93.47	-0.69	3.220	9	93.45	-0.75	3.13
10	93.40	-0.71	3.230	10	93.27	-0.70	3.63
<b>AVG</b>	93.36	-0.72	3.23	<b>AVG</b>	93.35	-0.72	3.46
<b>STD</b>	0.07	0.04	0.15	<b>STD</b>	0.09	0.02	0.16

Post UVA65 #4							
...0543: PVDF backsheet	L*	a*	b*	...0516: PVDF backsheet	L*	a*	b*
1	92.57	-1.32	-0.180	1	92.62	-1.19	0.23
2	92.47	-1.33	0.020	2	92.97	-1.12	0.42
3	93.27	-1.16	0.300	3	93.28	-1.03	0.71
4	93.12	-1.21	0.280	4	93.03	-1.13	0.41
5	92.57	-1.29	0.120	5	92.72	-1.08	0.46
6	92.96	-1.18	0.300	6	92.84	-1.16	0.38
7	93.02	-1.20	0.220	7	92.99	-1.16	0.42
8	92.89	-1.20	0.390	8	92.62	-1.29	0.18
9	87.11	-0.34	6.430	9	92.92	-1.15	0.35
10	92.94	-1.17	0.440	10	92.89	-1.19	0.42
<b>AVG</b>	92.29	-1.14	0.83	<b>AVG</b>	92.89	-1.15	0.40
<b>STD</b>	1.84	0.29	1.98	<b>STD</b>	0.20	0.07	0.14
...1817: Tedlar backsheet	L*	a*	b*	...1871: Tedlar backsheet	L*	a*	b*
1	88.49	0.09	1.060	1	88.44	0.01	1.24
2	88.47	0.09	1.240	2	88.48	0.07	1.18
3	88.33	0.07	1.300	3	88.57	0.10	1.11
4	88.37	0.12	1.310	4	88.62	0.09	1.11
5	88.42	0.02	1.300	5	88.55	0.09	1.23
6	88.50	0.07	1.160	6	88.73	0.07	1.31
7	88.59	0.04	1.020	7	88.55	0.08	1.31
8	88.53	0.06	1.120	8	88.45	0.07	1.29
9	88.48	0.12	1.320	9	88.56	0.06	1.07
10	88.60	0.06	1.100	10	88.41	0.04	1.21
<b>AVG</b>	88.48	0.07	1.19	<b>AVG</b>	88.54	0.07	1.21
<b>STD</b>	0.09	0.03	0.11	<b>STD</b>	0.10	0.03	0.09

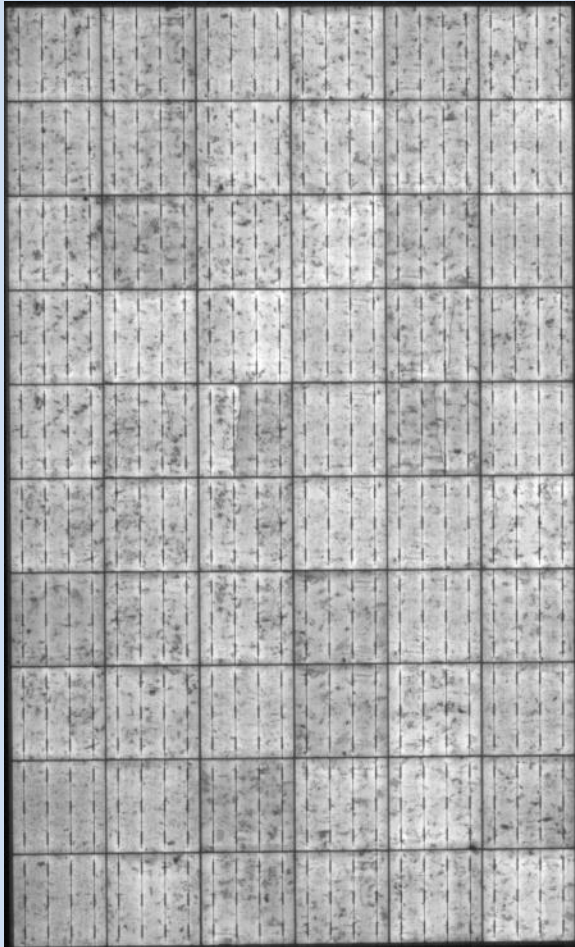
## 2.2 Electroluminescence images



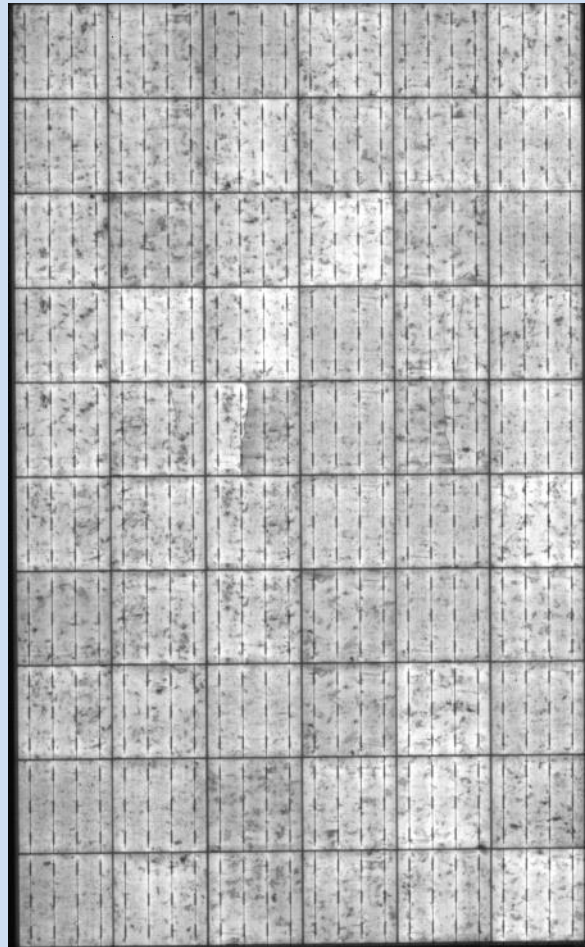


Backsheet Type: PVDF  
Serial Number: ...0516

Post-DH1000

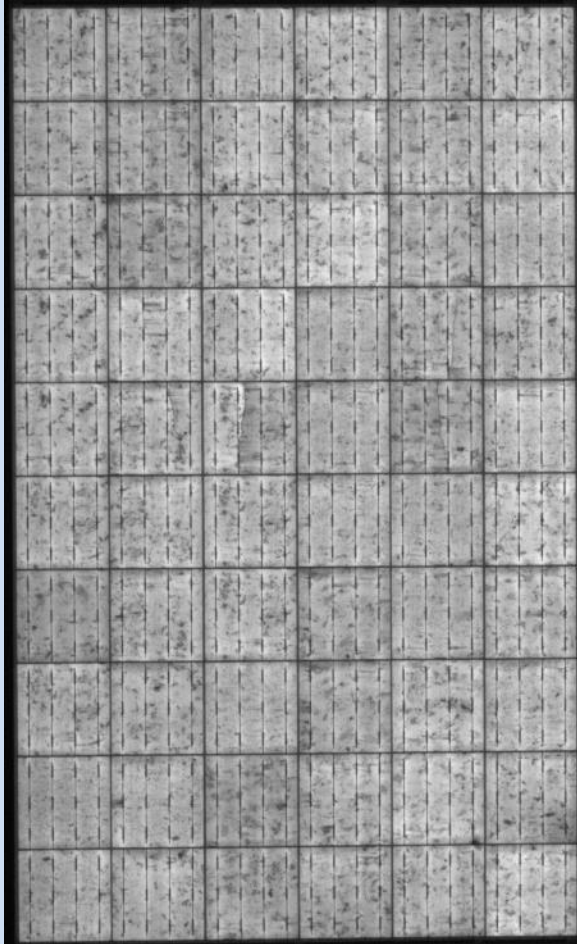


Post-UVA65 #1

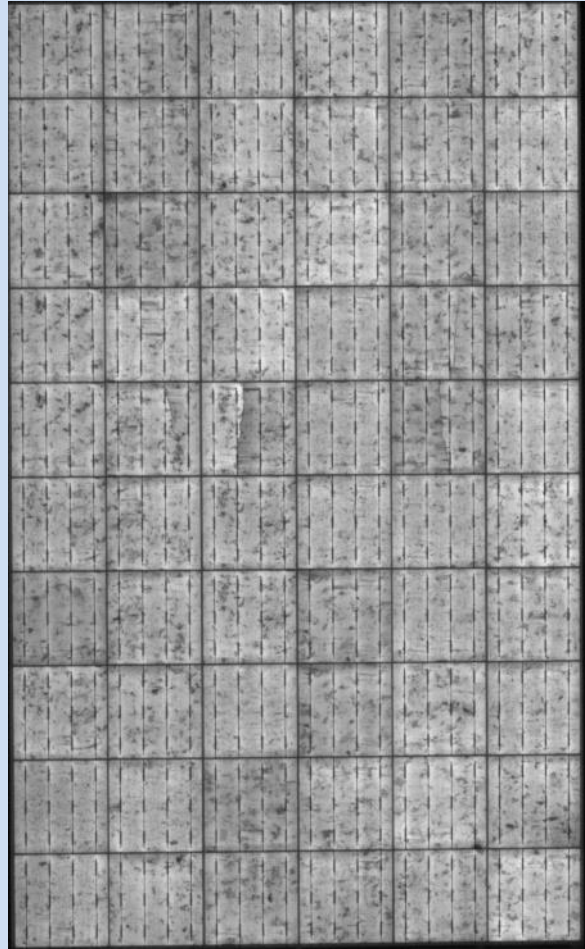


Backsheet Type: PVDF  
Serial Number: ...0516

Post-TC200

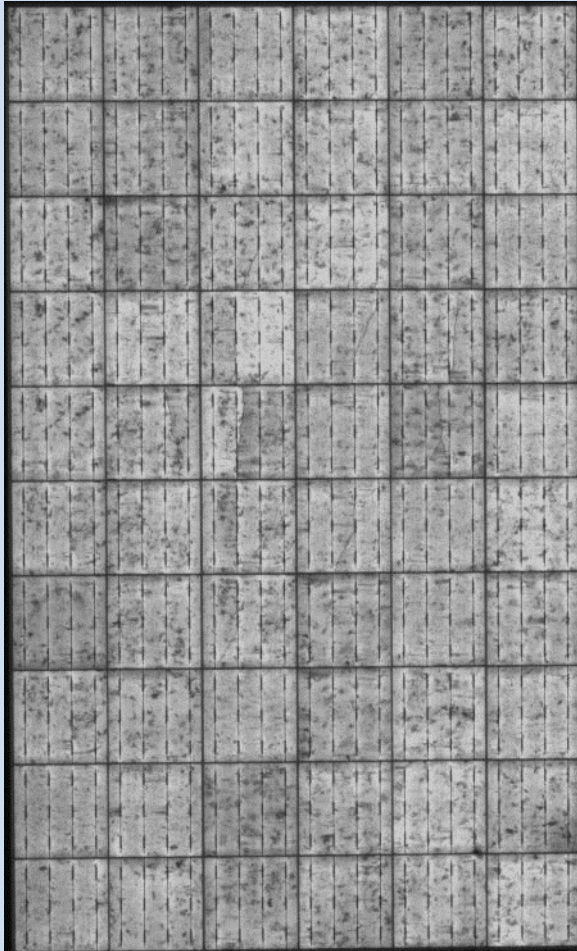


Post-UVA65 #2

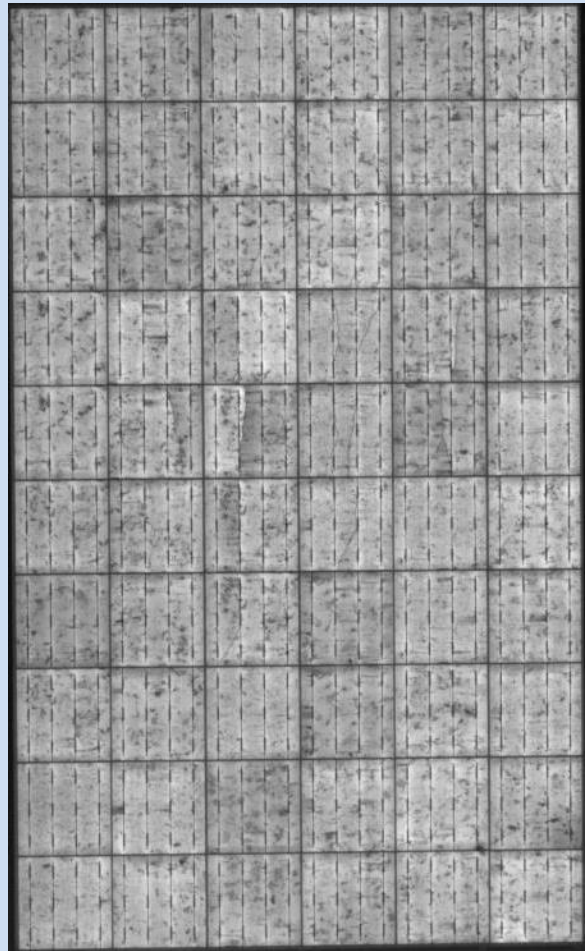


Backsheet Type: PVDF  
Serial Number: ...0516

Post-TC400

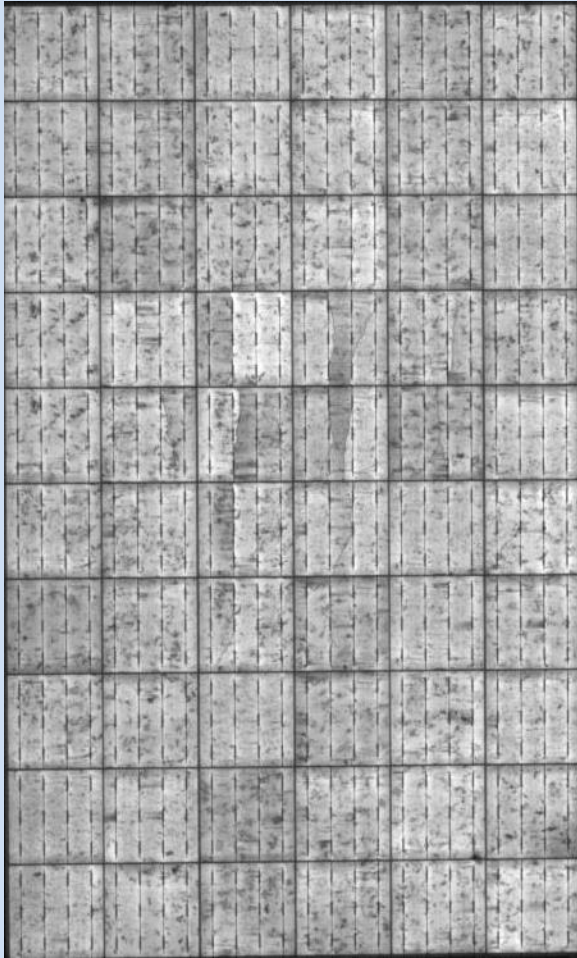


Post-UVA65 #3

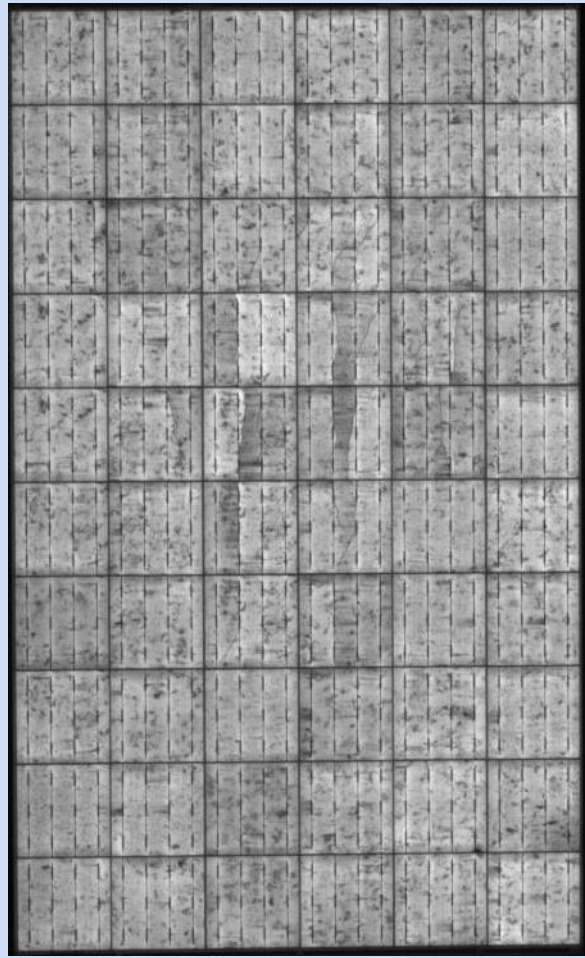


**Backsheet Type: PVDF**  
**Serial Number: ...0516**

**Post-TC600**

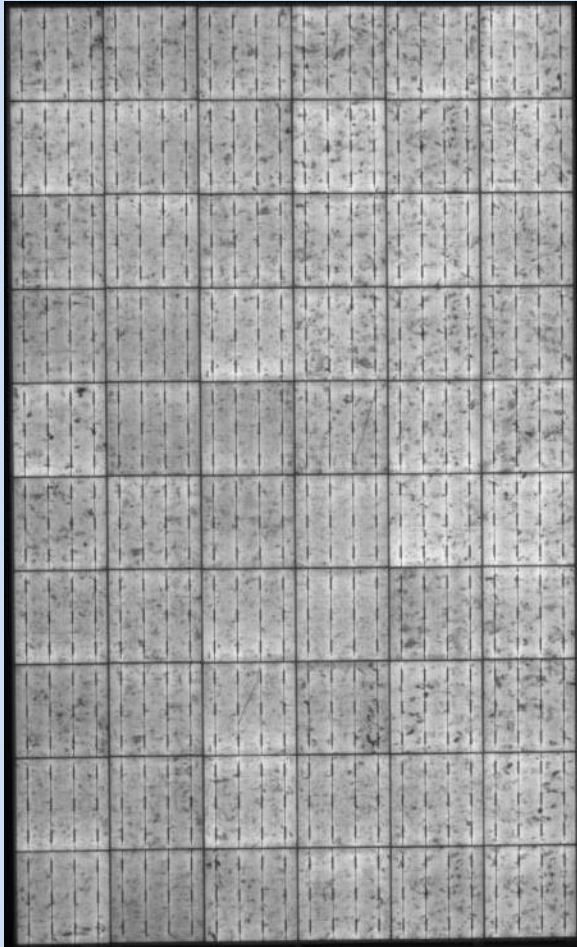


**Post-UVA65 #4**

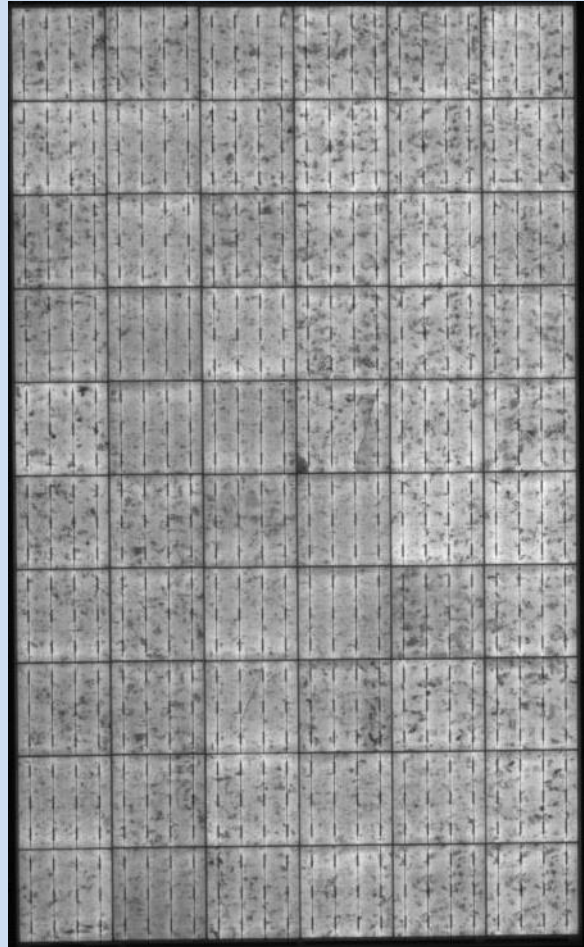


**Backsheet Type: PVDF**  
**Serial Number: ...0543**

**Pre-stress**

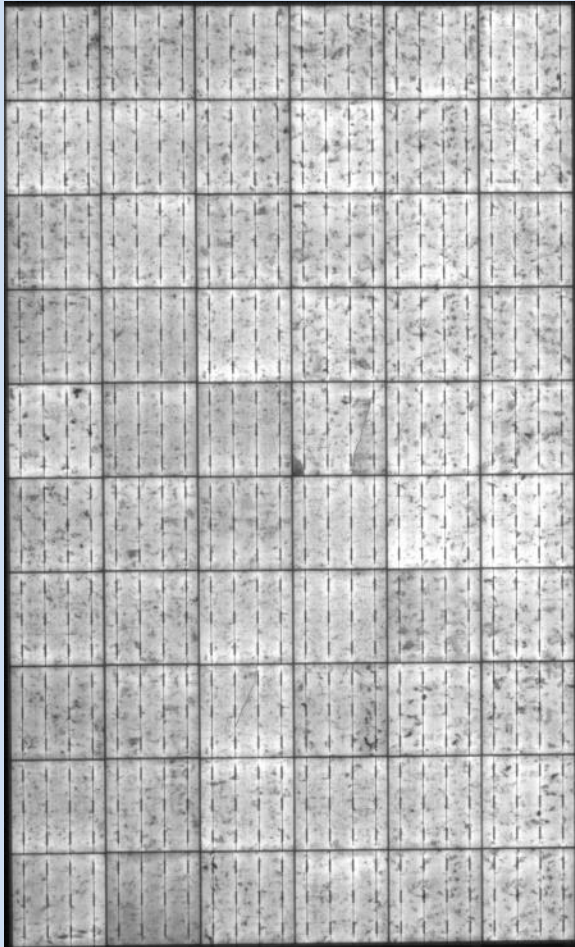


**Post-LID**

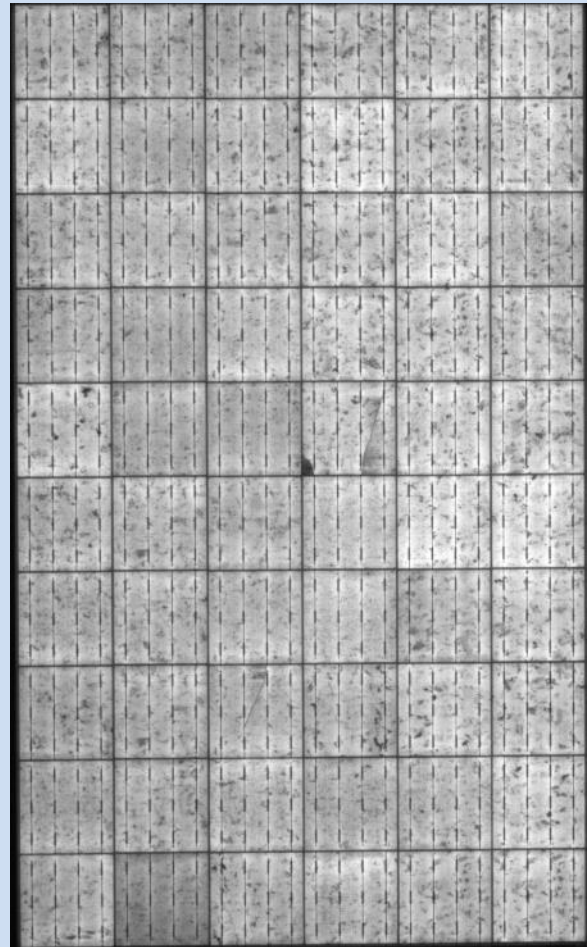


**Backsheet Type: PVDF**  
**Serial Number: ...0543**

**Post-DH1000**

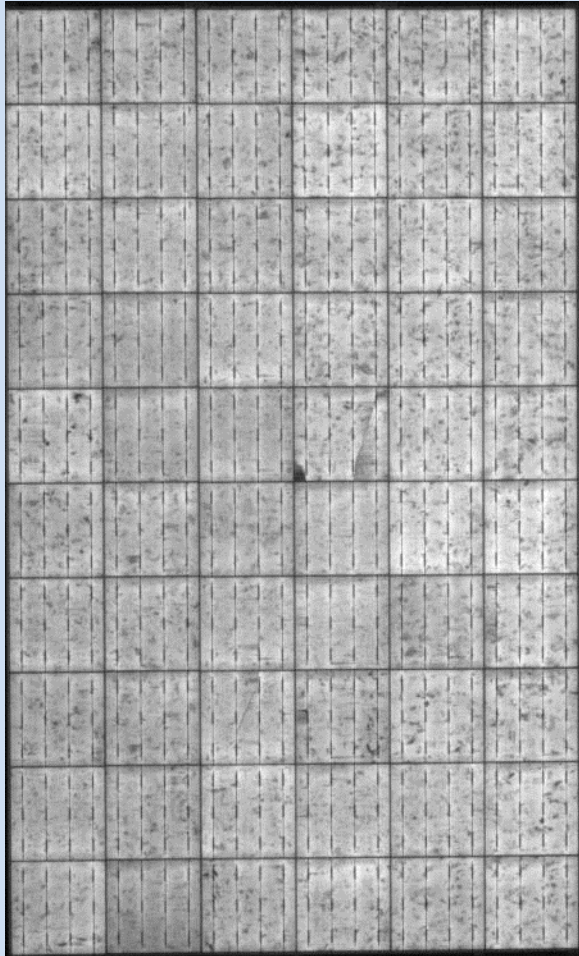


**Post-UVA65 #1**

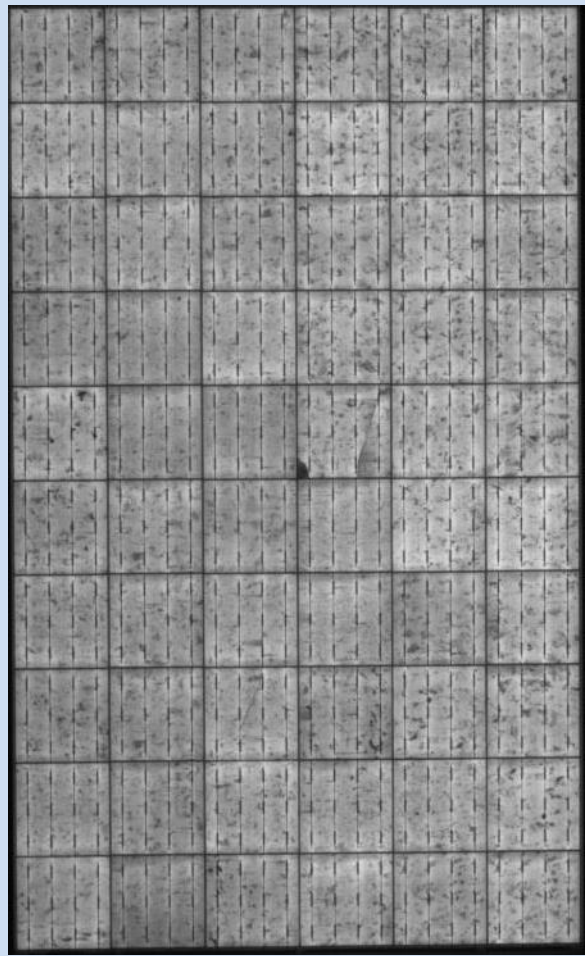


Backsheet Type: PVDF  
Serial Number: ...0543

Post-TC200

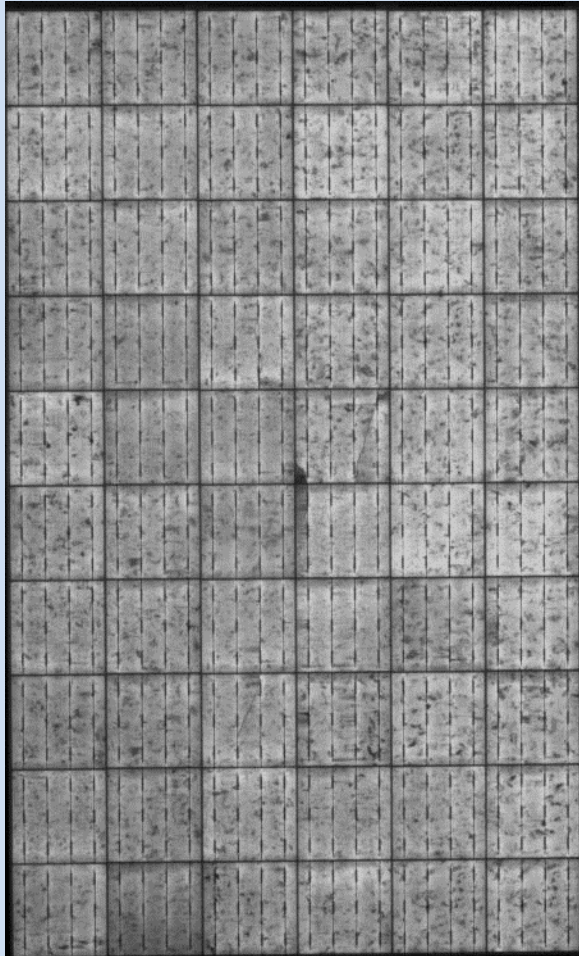


Post-UVA65 #2

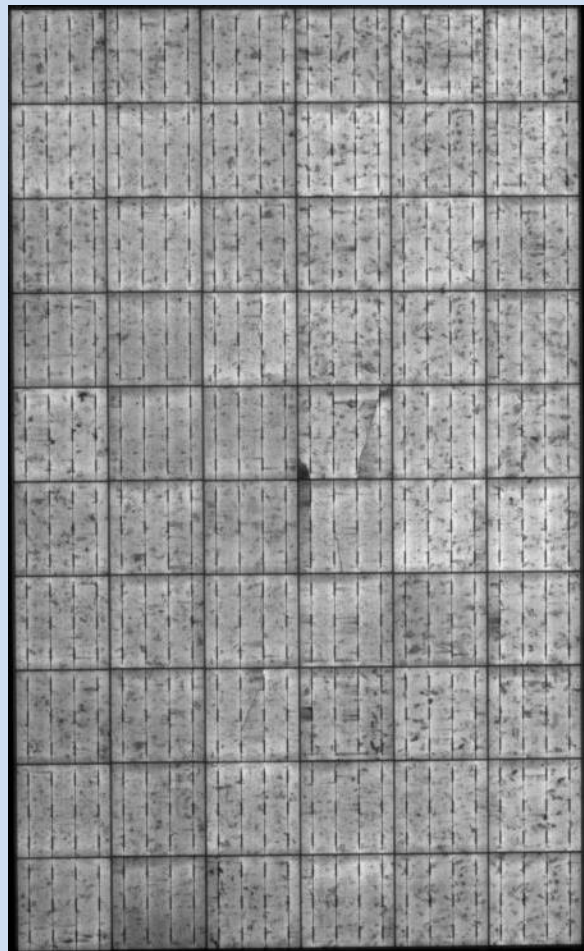


Backsheet Type: PVDF  
Serial Number: ...0543

Post-TC400



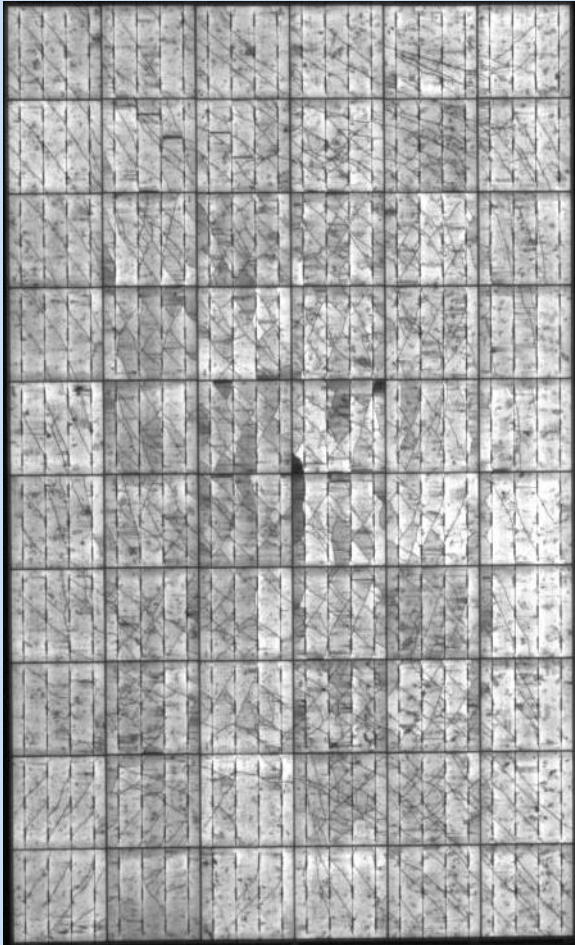
Post-UVA65 #3



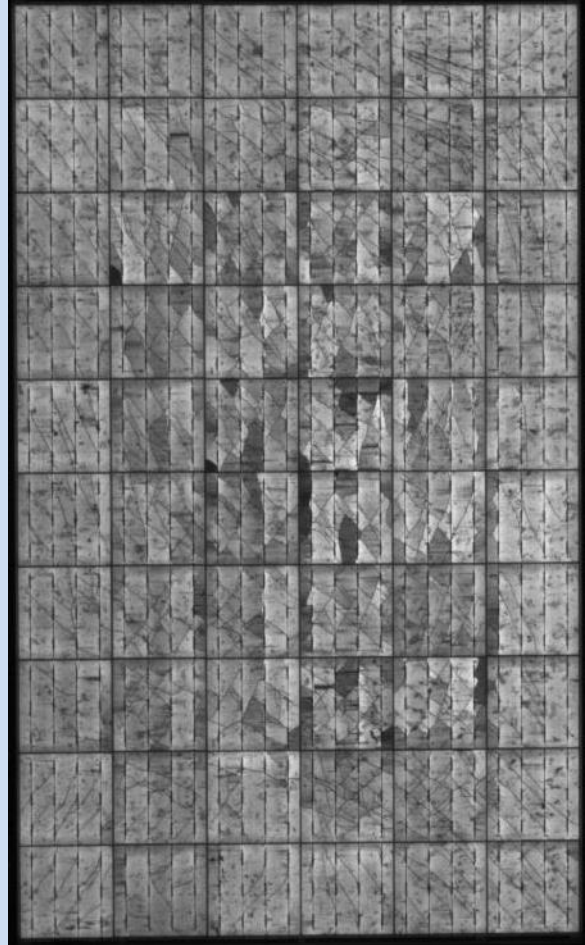


Backsheet Type: PVDF  
Serial Number: ...0543

Post-TC600

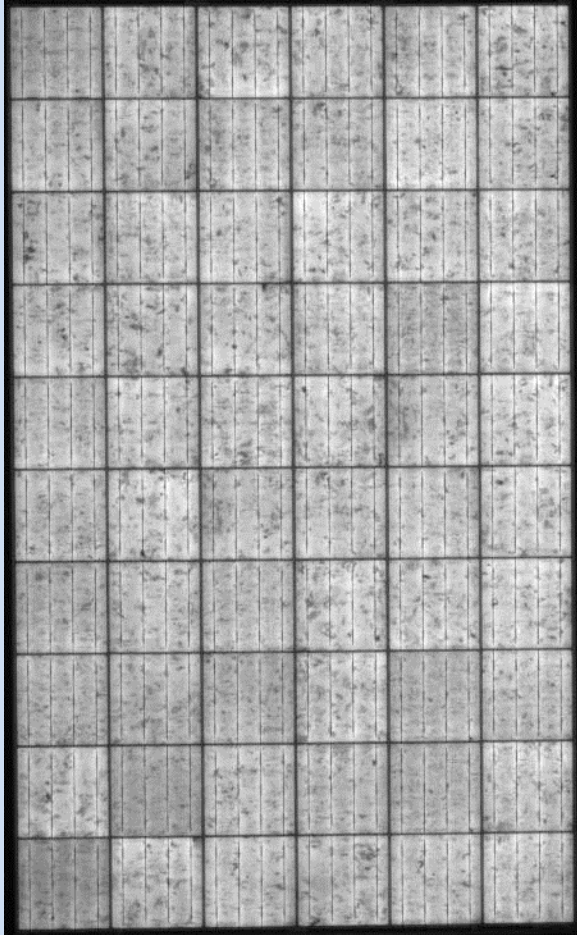


Post-UVA65 #4

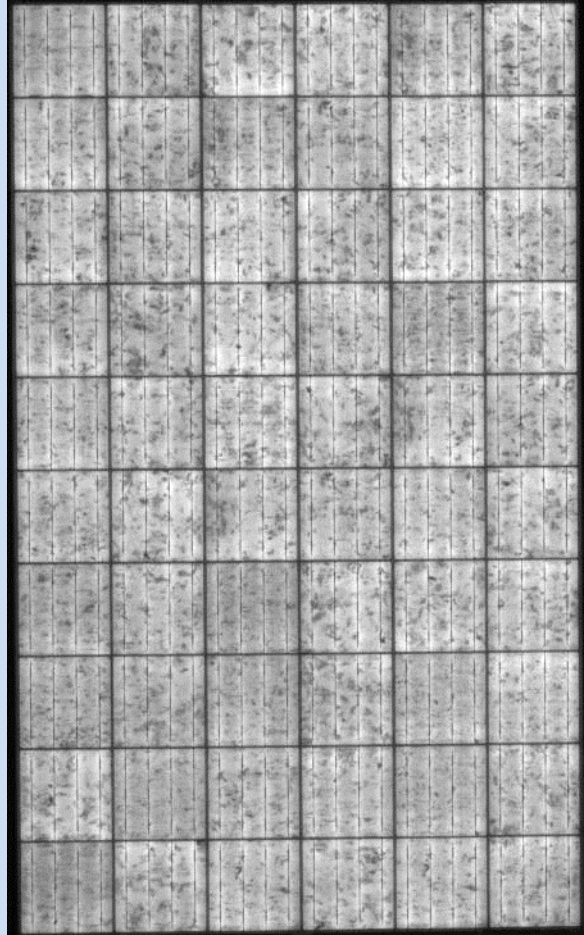


**Backsheet Type: Tedlar**  
**Serial Number: ...1817**

**Pre-stress**

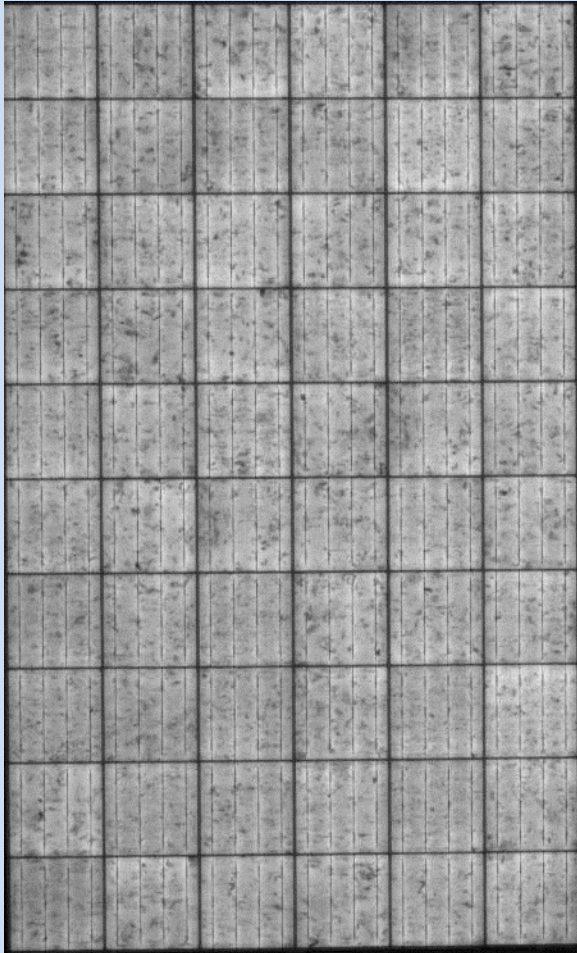


**Post-LID**

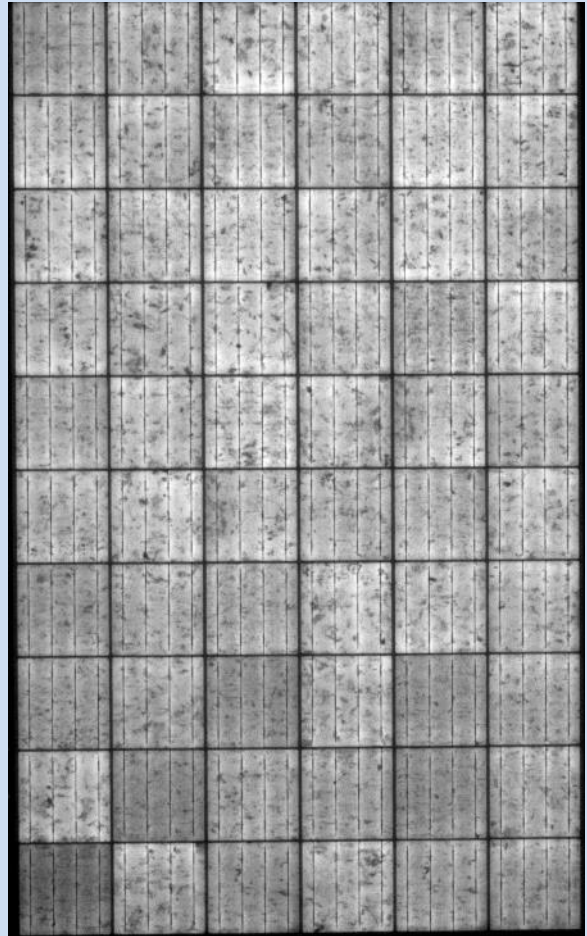


**Backsheet Type: Tedlar**  
**Serial Number: ...1817**

**Post-DH1000**

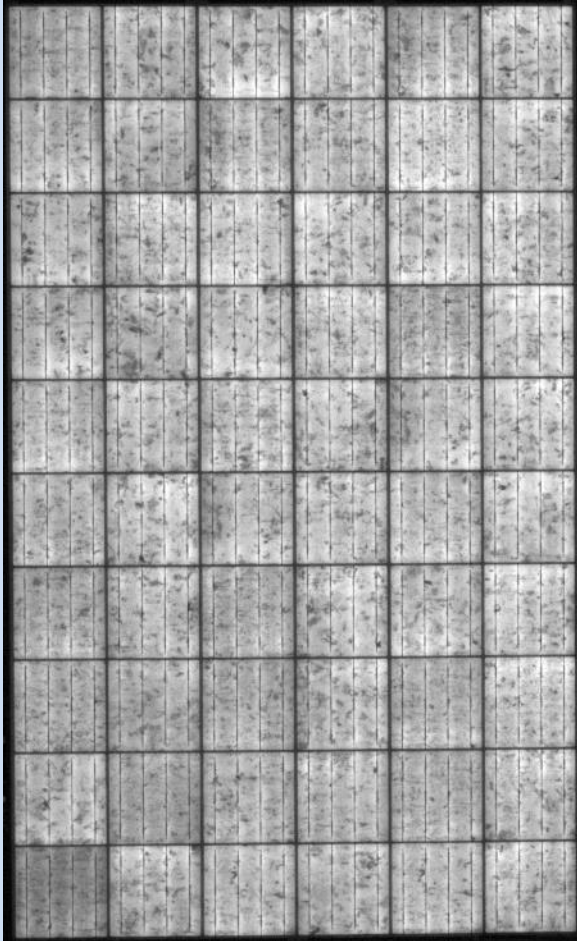


**Post-UVA65 #1**

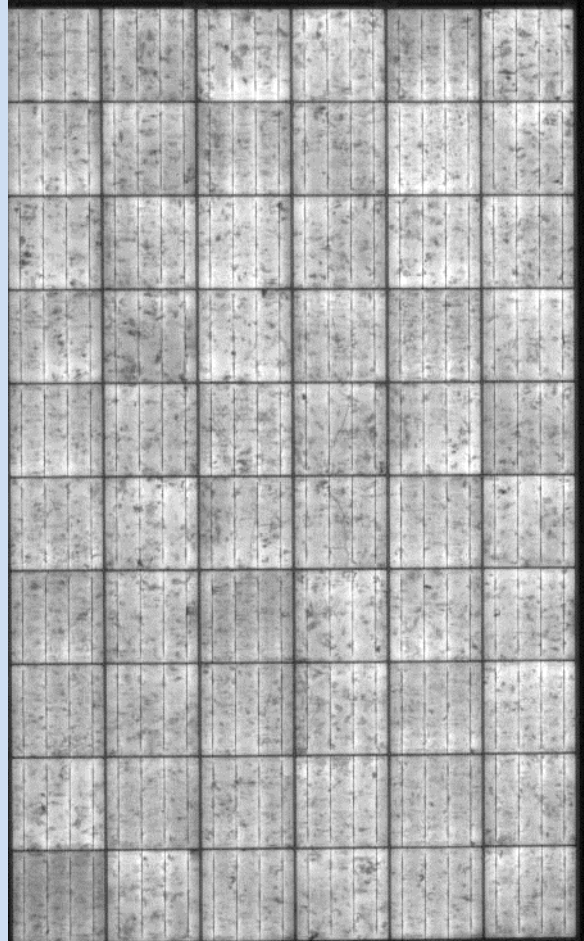


**Backsheet Type: Tedlar**  
**Serial Number: ...1817**

**Post-TC200**



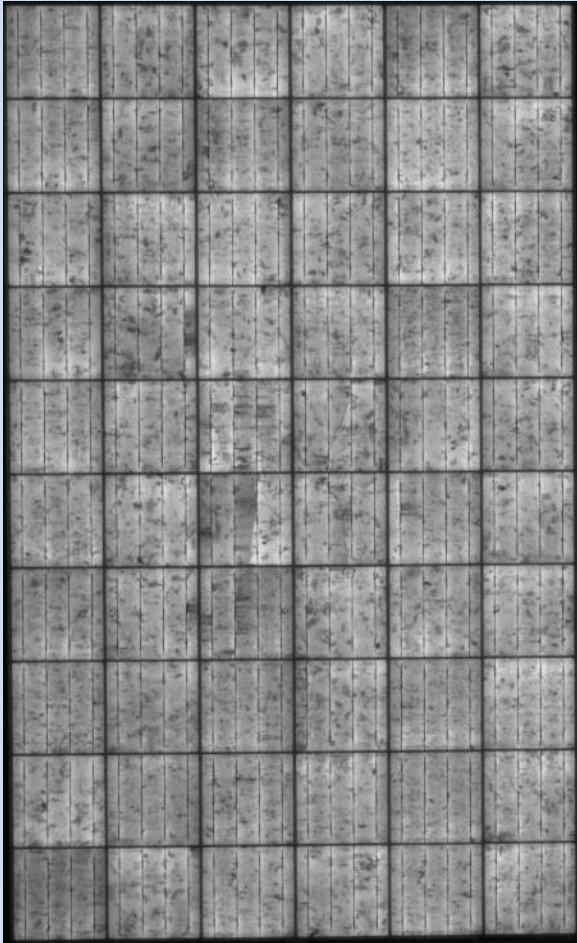
**Post-UVA65 #2**



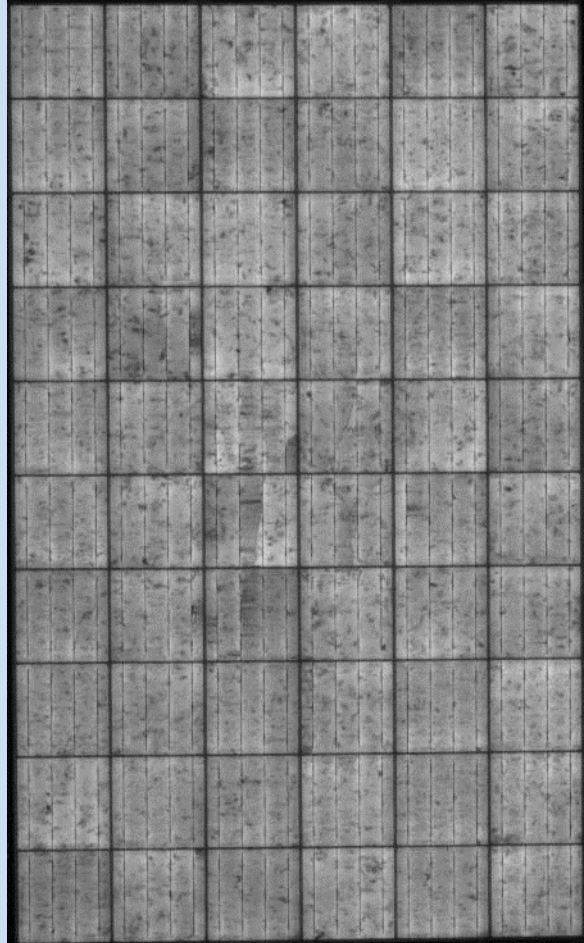


**Backsheet Type: Tedlar**  
**Serial Number: ...1817**

**Post-TC400**

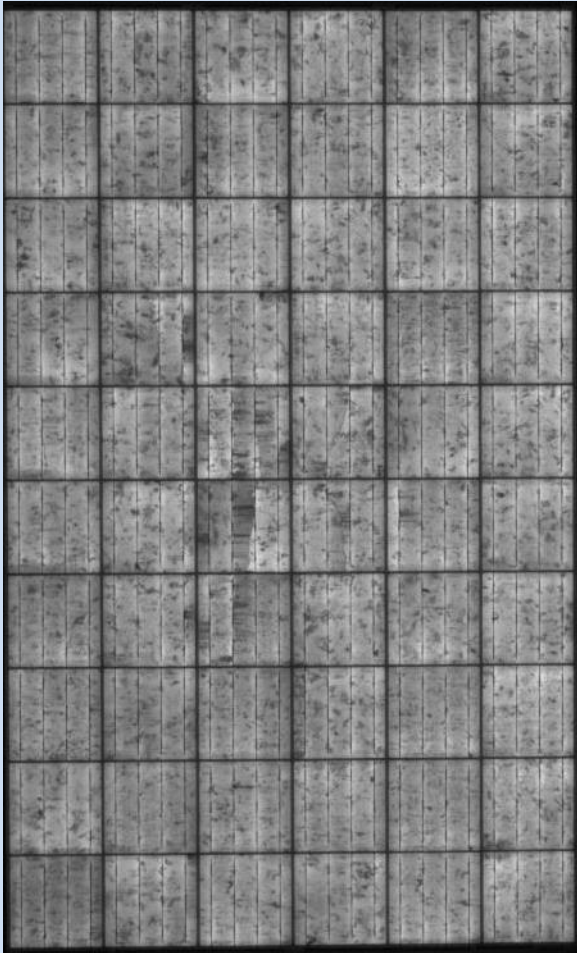


**Post-UVA65 #3**

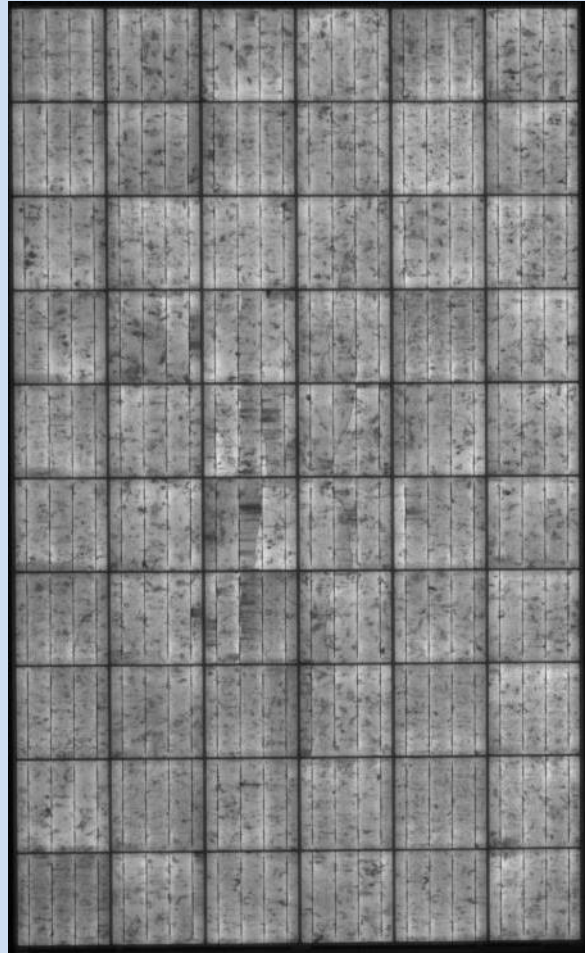


**Backsheet Type: Tedlar**  
**Serial Number: ...1817**

**Post-TC600**

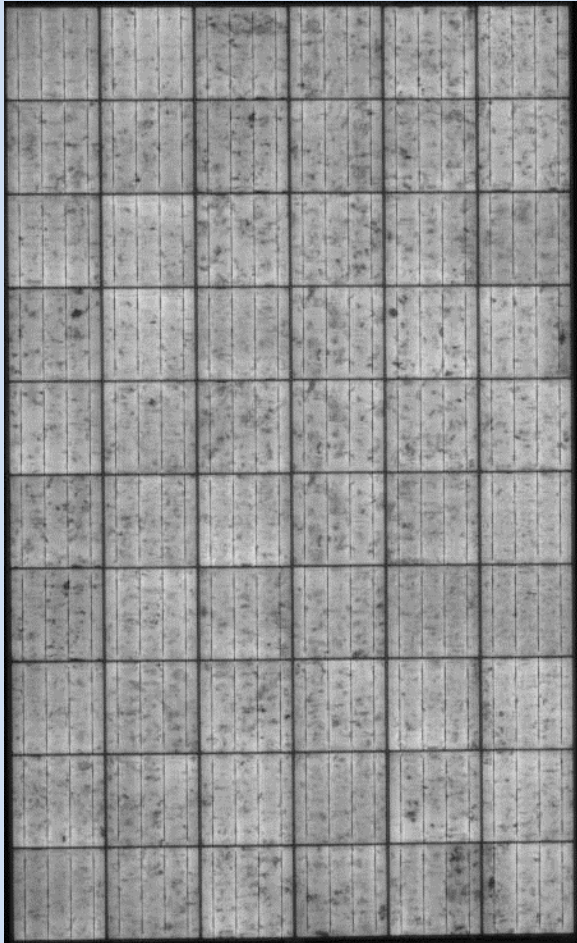


**Post-UVA65 #4**

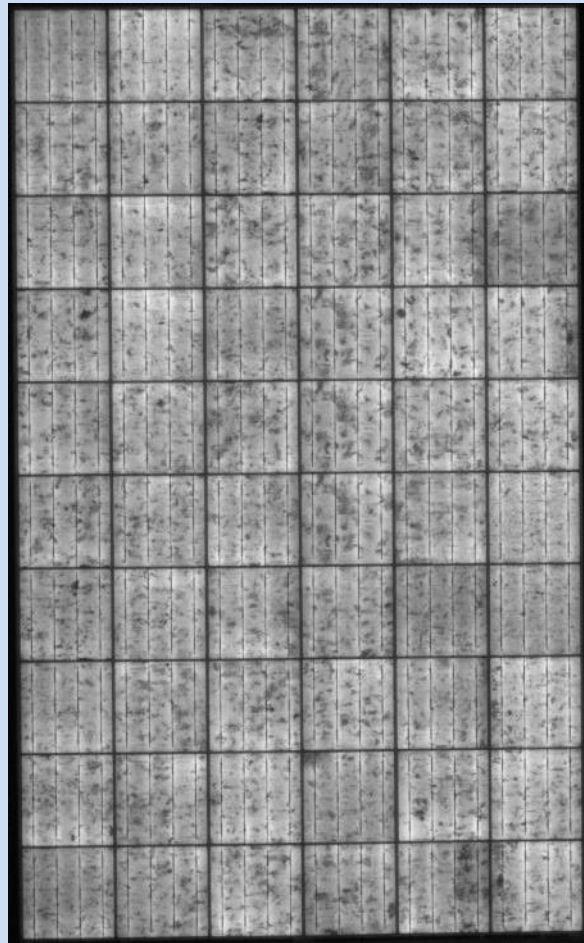


**Backsheet Type: Tedlar**  
**Serial Number: ...1871**

**Pre-stress**

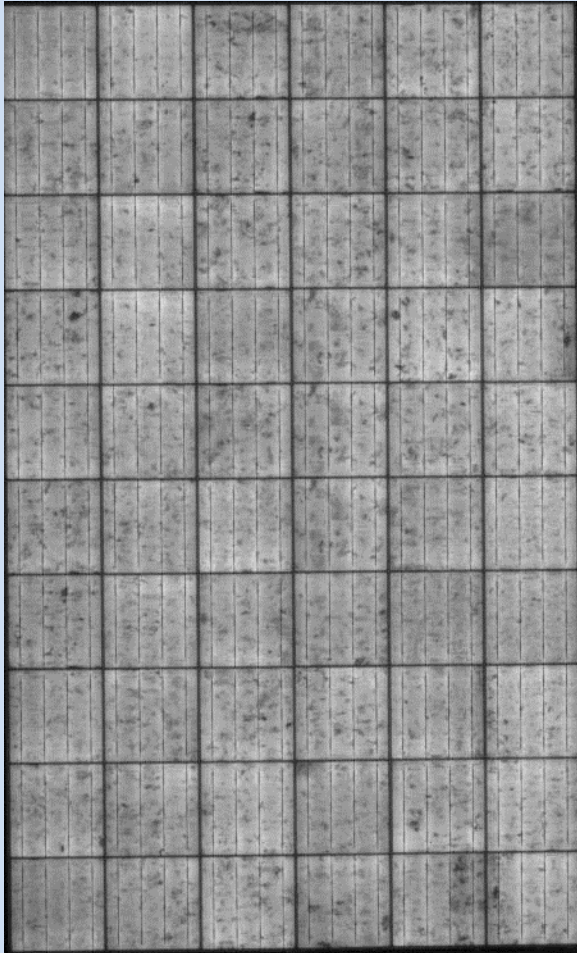


**Post-LID**

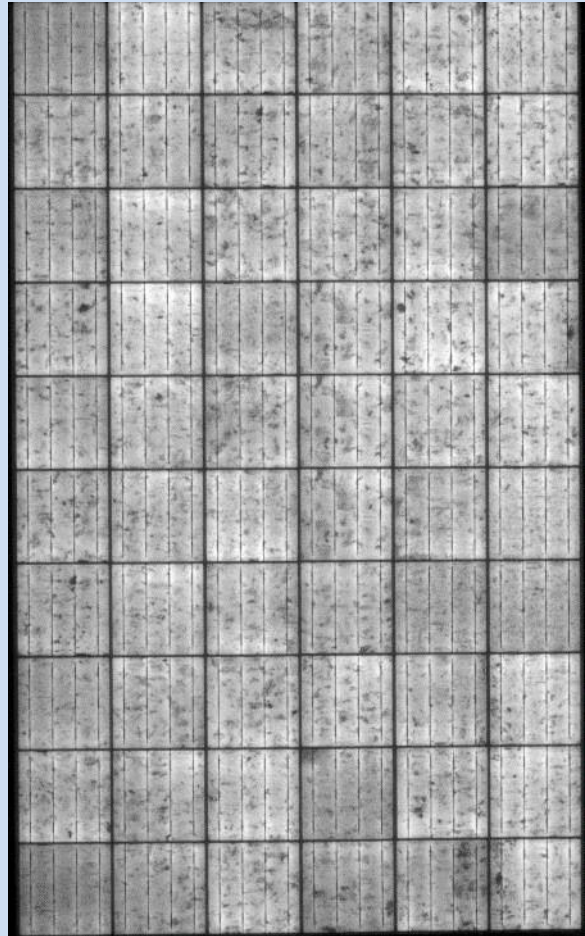


**Backsheet Type: Tedlar**  
**Serial Number: ...1871**

**Post-DH1000**



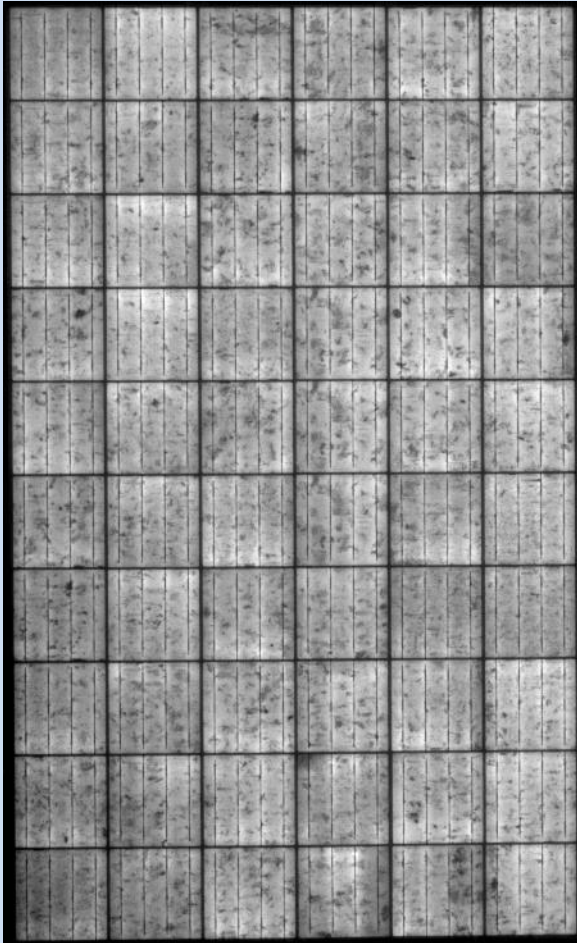
**Post-UVA65 #1**



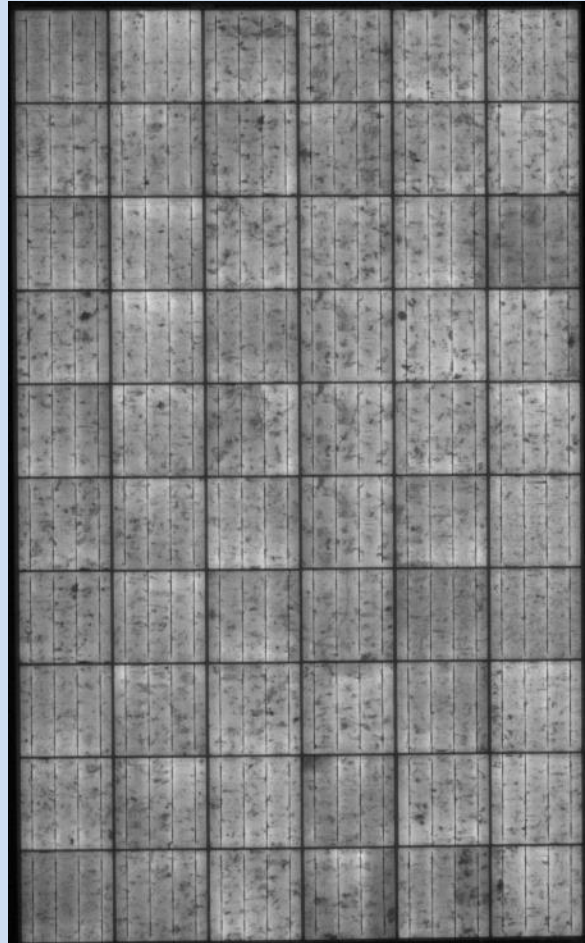


**Backsheet Type: Tedlar**  
**Serial Number: ...1871**

**Post-TC200**

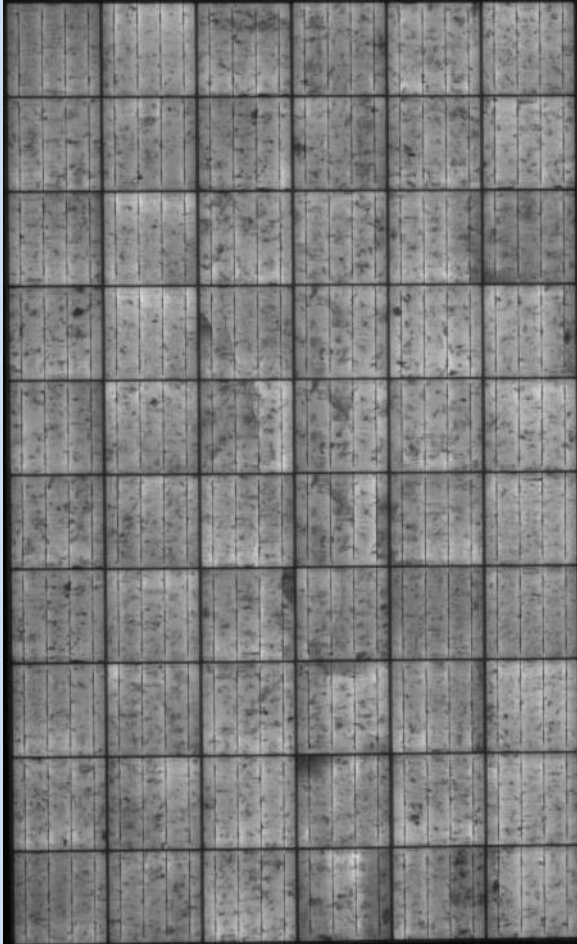


**Post-UVA65 #2**

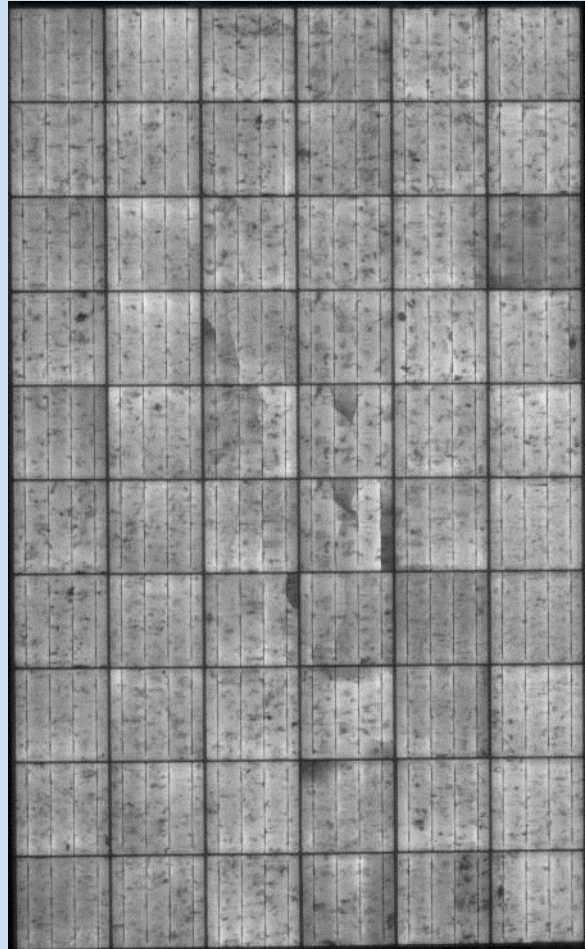


**Backsheet Type: Tedlar**  
**Serial Number: ...1871**

**Post-TC400**

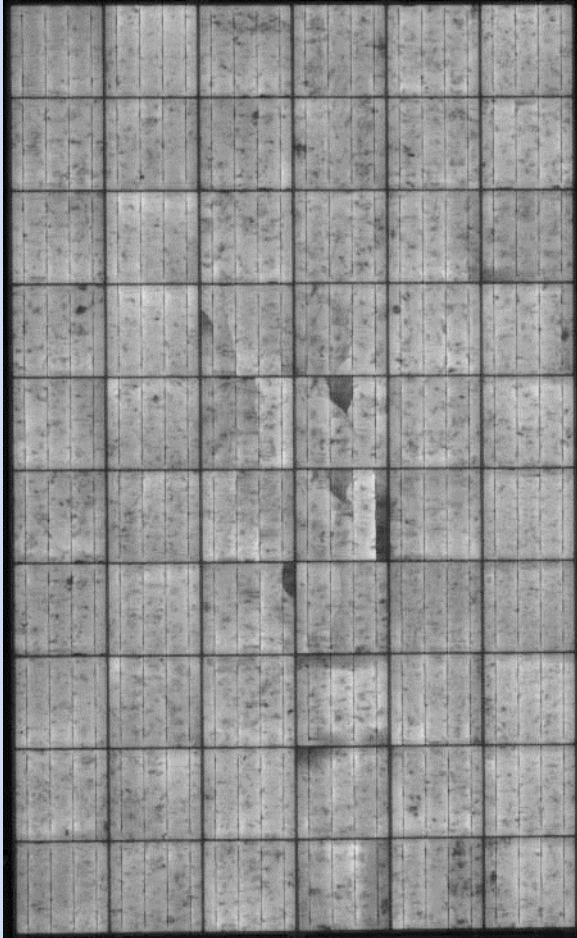


**Post-UVA65 #3**

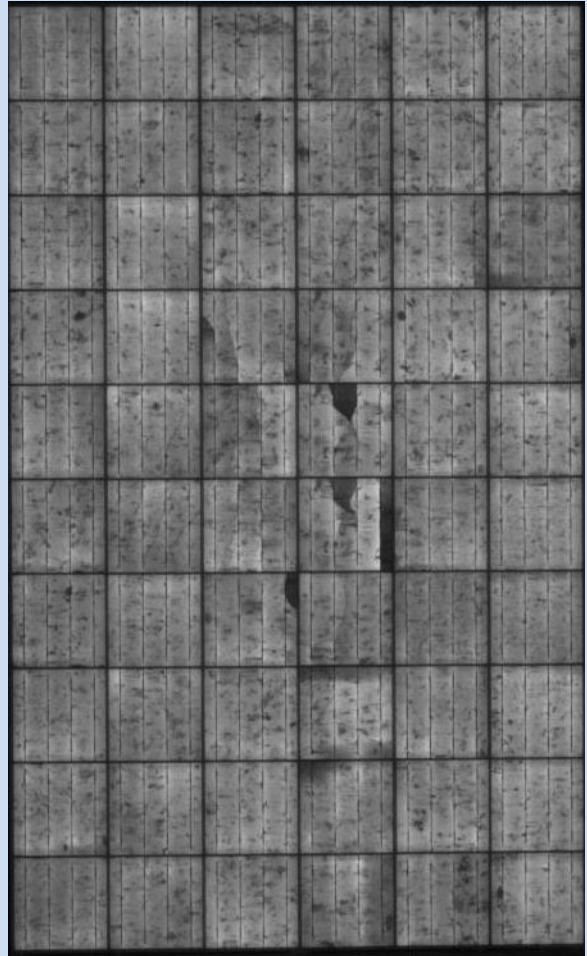


**Backsheet Type: Tedlar**  
**Serial Number: ...1871**

**Post-TC600**

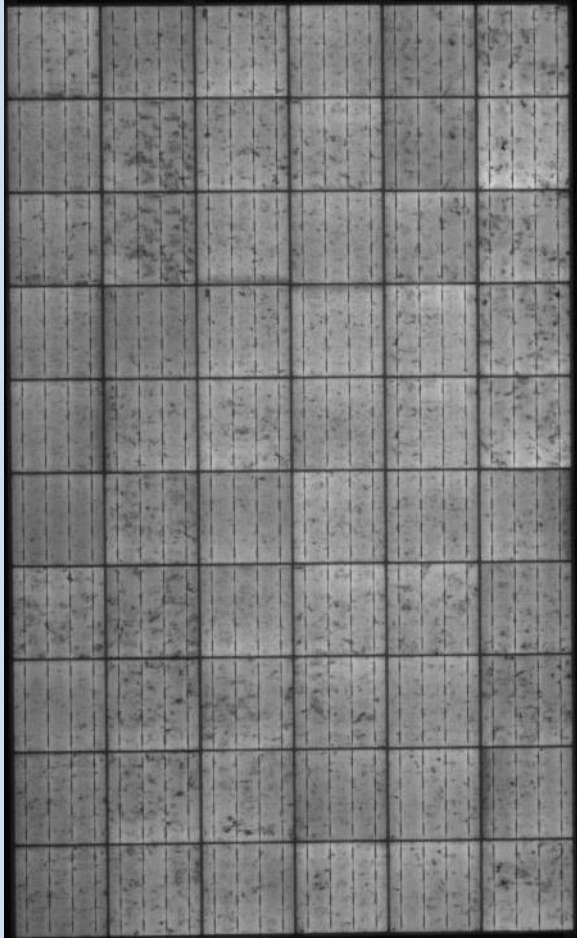


**Post-UVA65 #4**

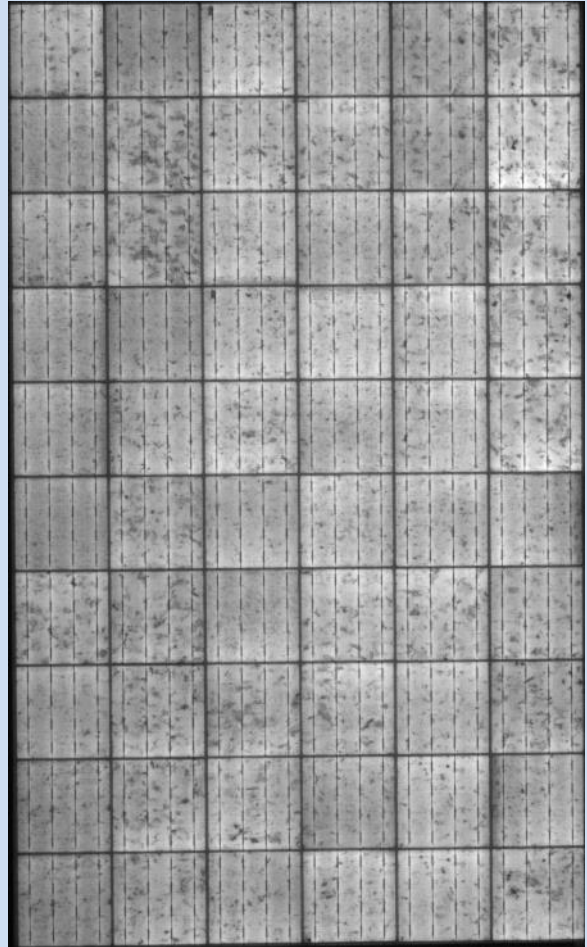


**Backsheet Type: PET**  
**Serial Number: ...5161**

**Pre-stress**

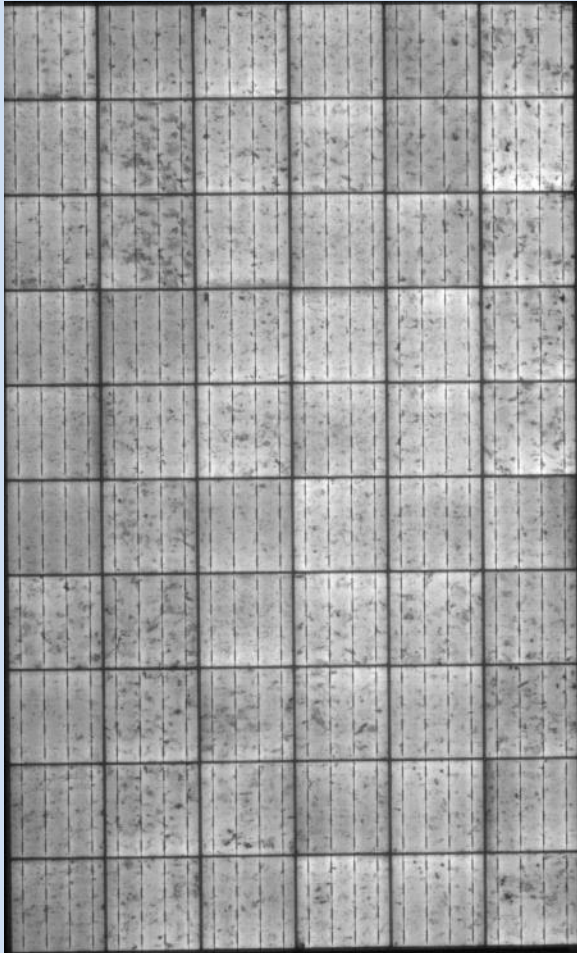


**Post-LID**

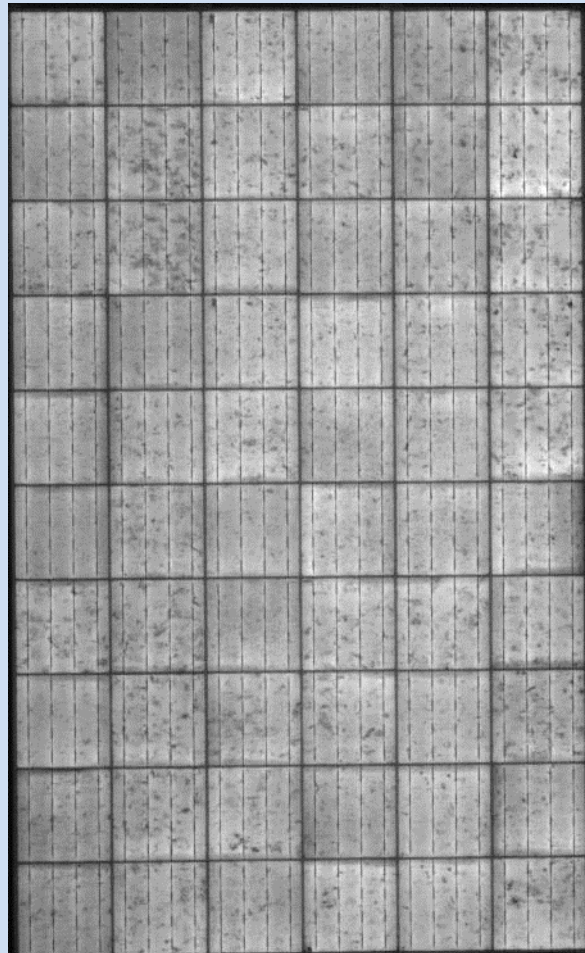


**Backsheet Type: PET**  
**Serial Number: ...5161**

**Post-DH1000**

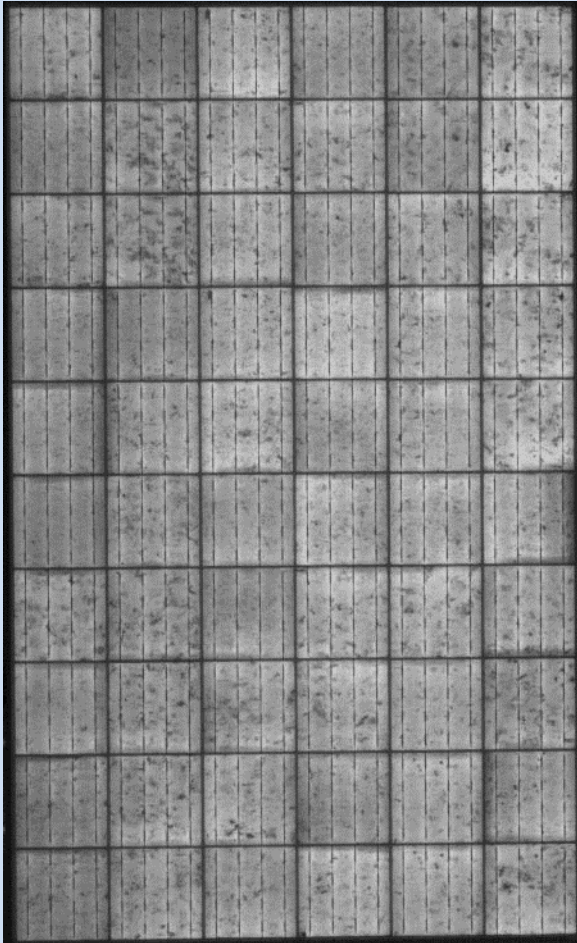


**Post-UVA65 #1**

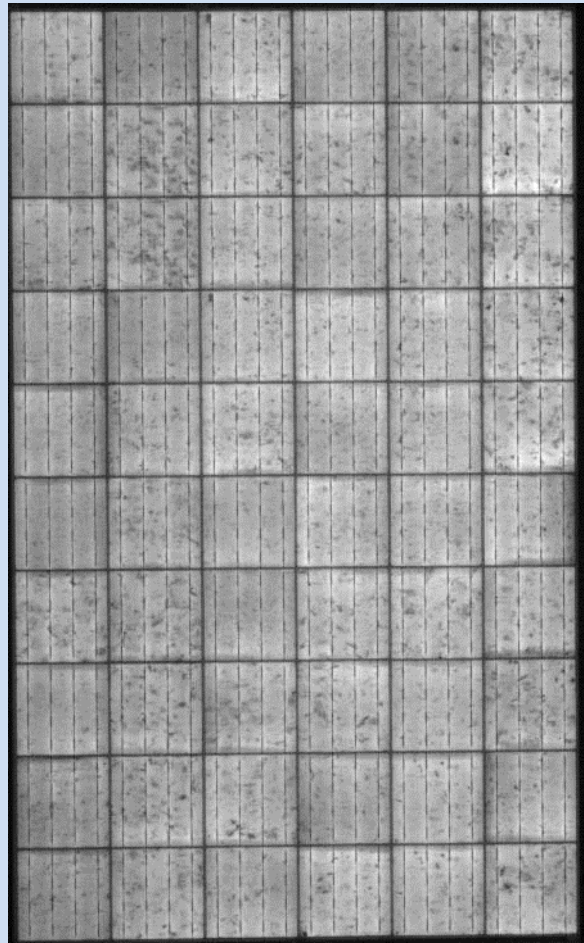


**Backsheet Type: PET**  
**Serial Number: ...5161**

**Post-TC200**

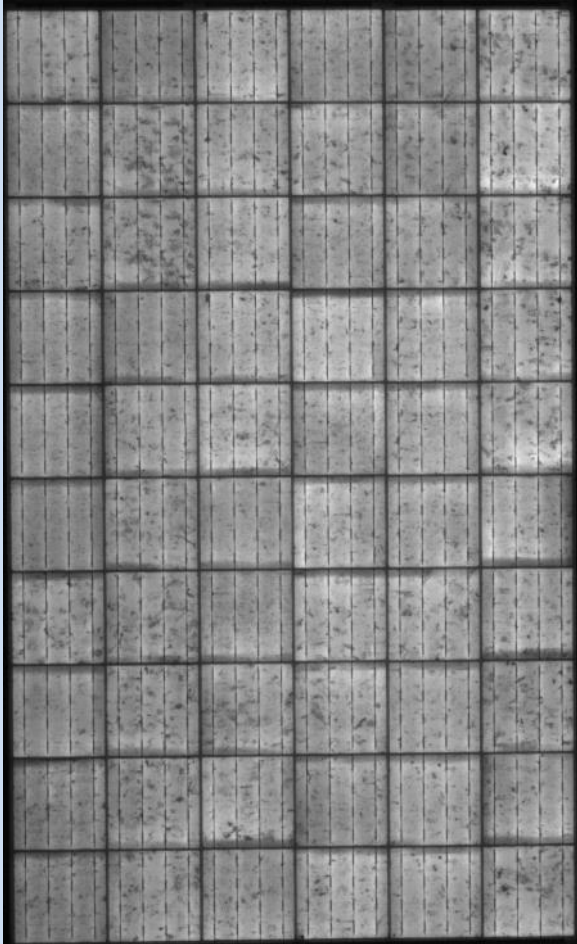


**Post-UVA65 #2**

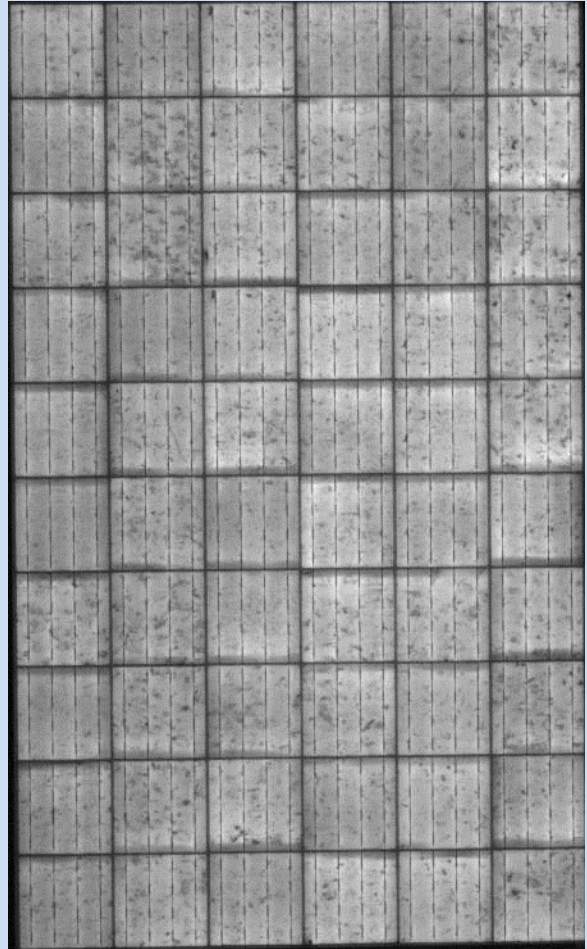


Backsheet Type: PET  
Serial Number: ...5161

Post-TC400

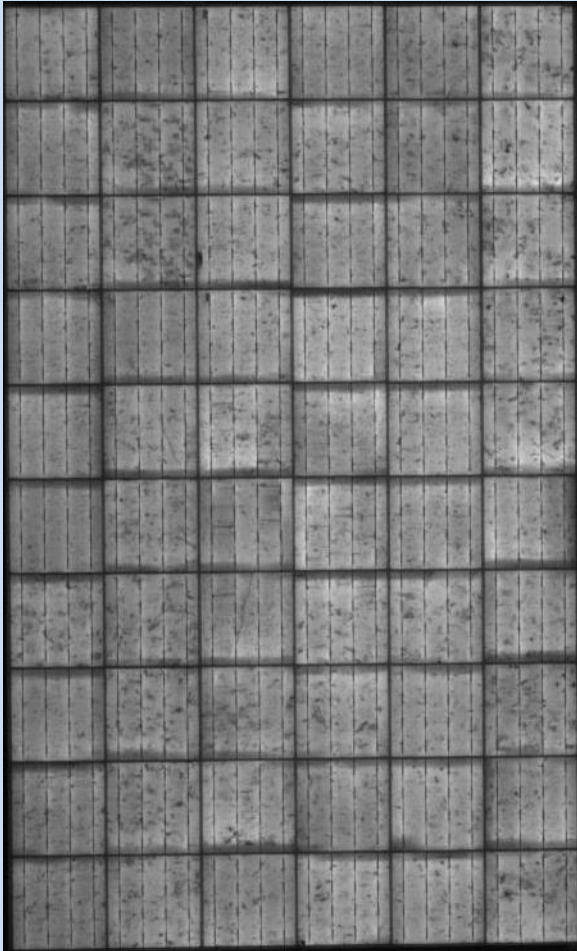


Post-UVA65 #3

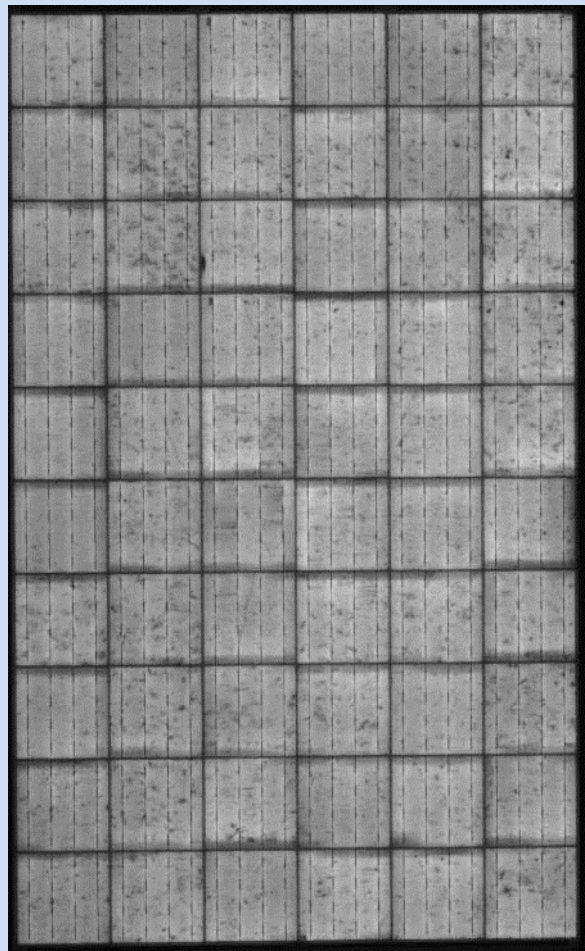


Backsheet Type: PET  
Serial Number: ...5161

Post-TC600



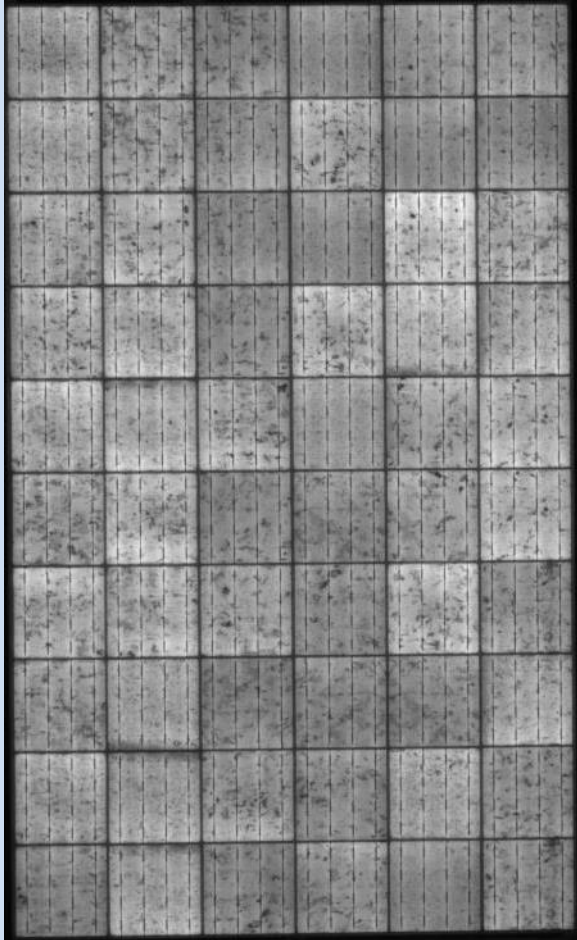
Post-UVA65 #4



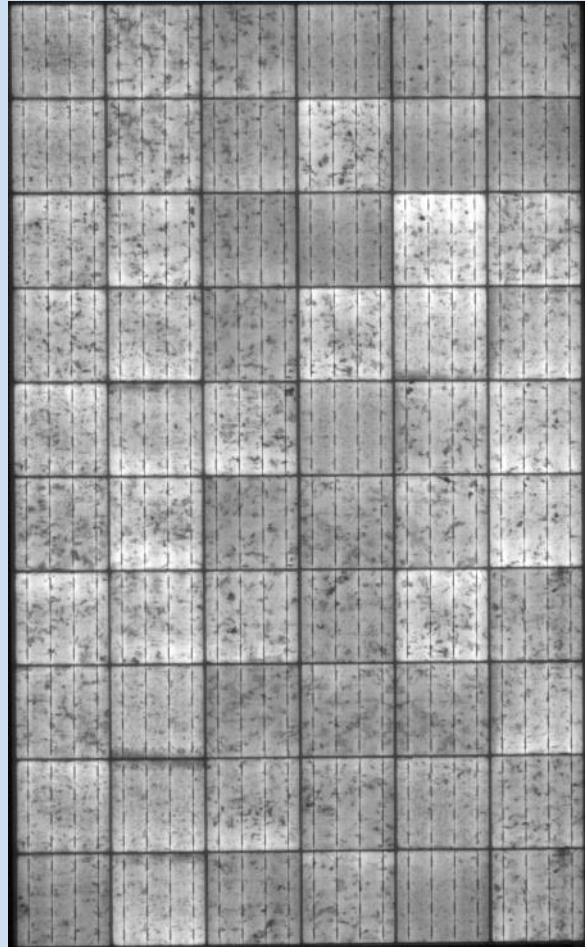


Backsheet Type: PET  
Serial Number: ...5255

Pre-stress

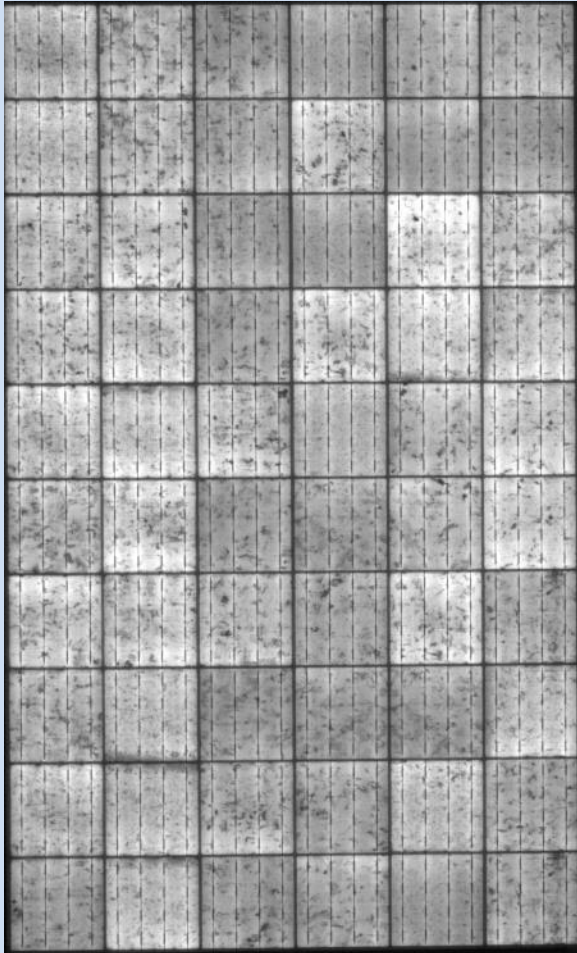


Post-LID

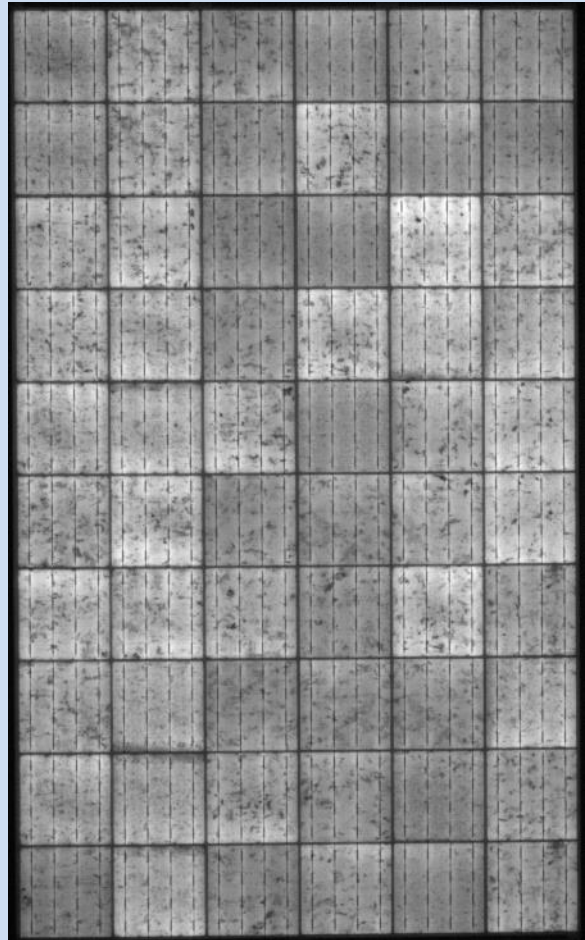


**Backsheet Type: PET**  
**Serial Number: ...5255**

**Post-DH1000**

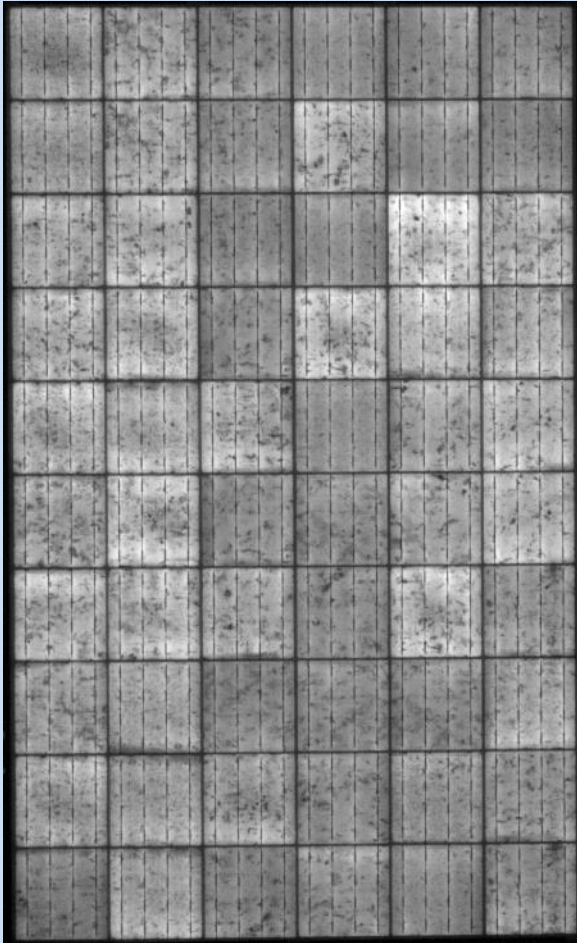


**Post-UVA65 #1**

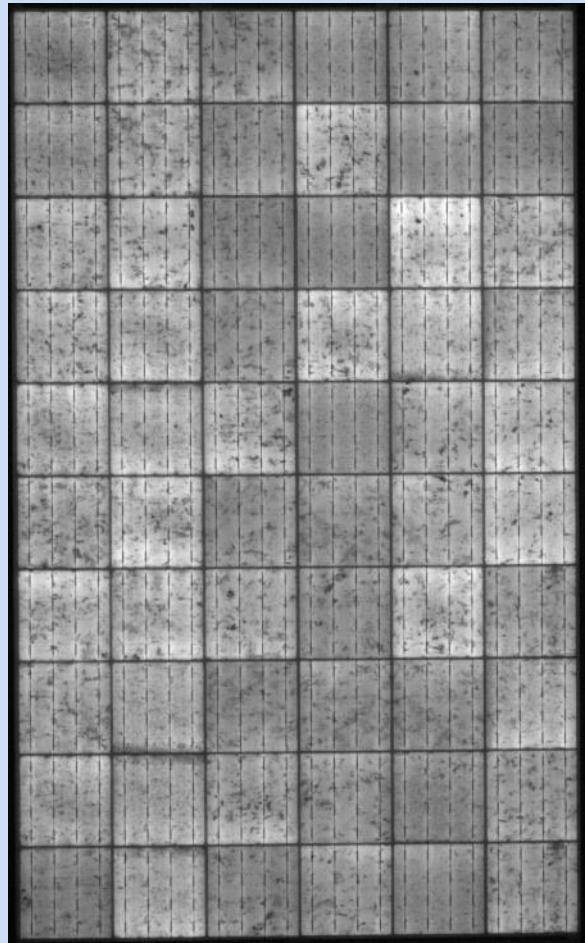


Backsheet Type: PET  
Serial Number: ...5255

Post-TC200

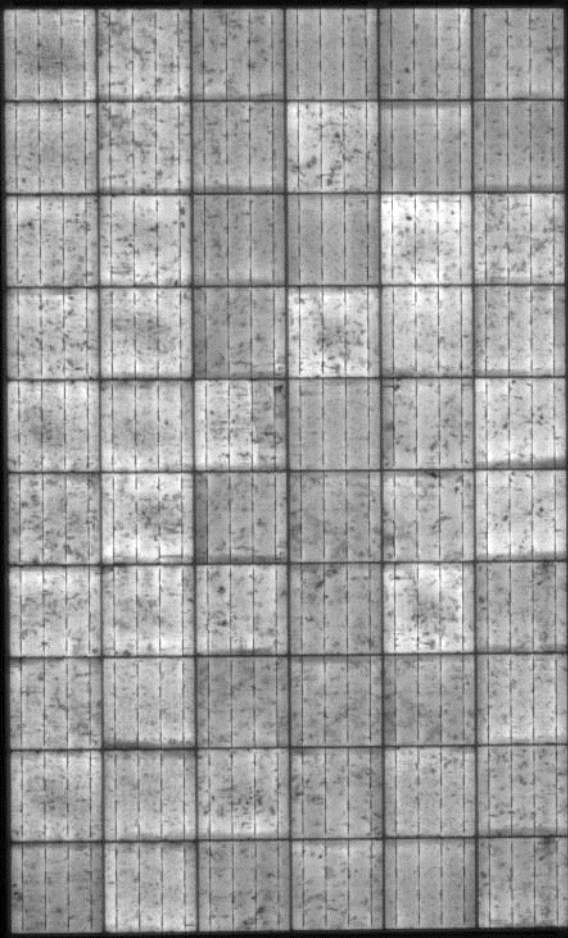


Post-UVA65 #2

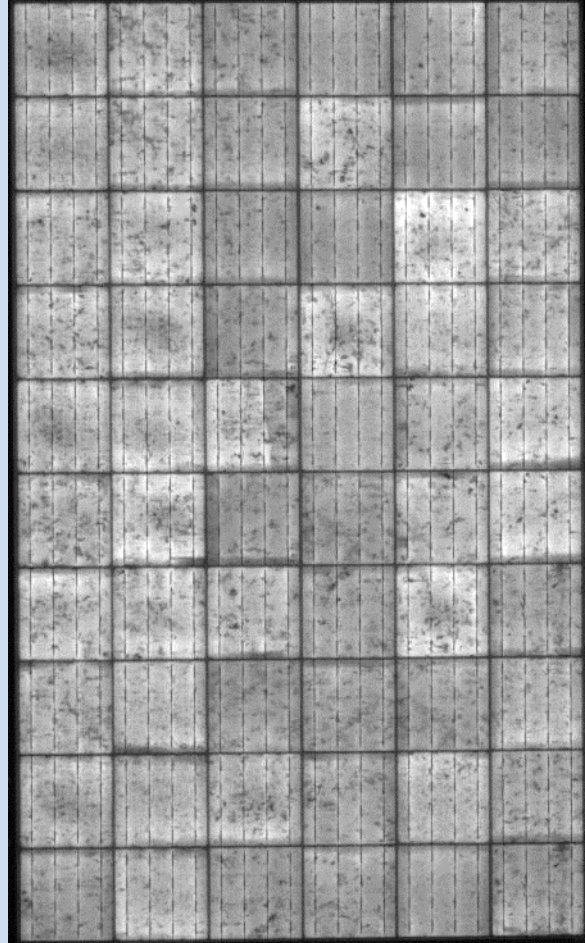


Backsheet Type: PET  
Serial Number: ...5255

Post-TC400

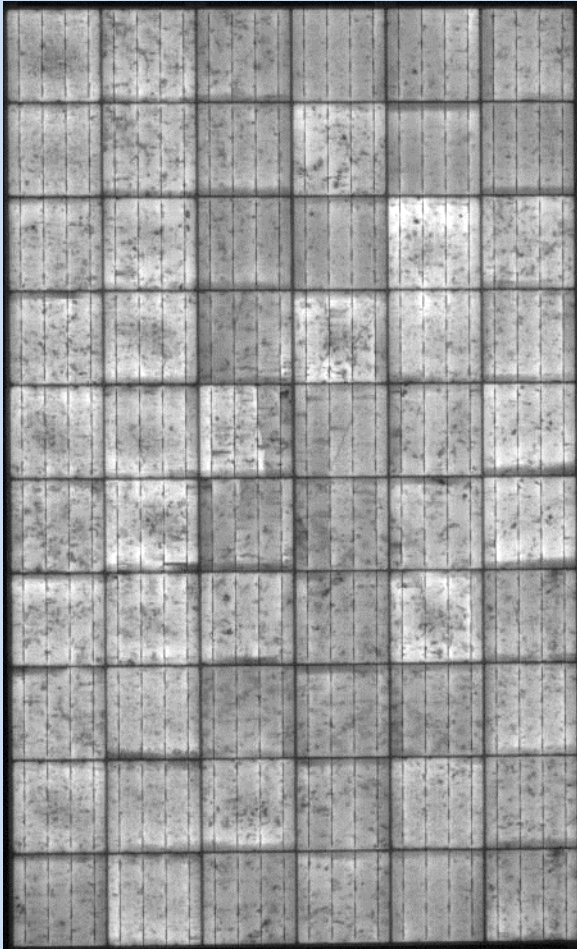


Post-UVA65 #3

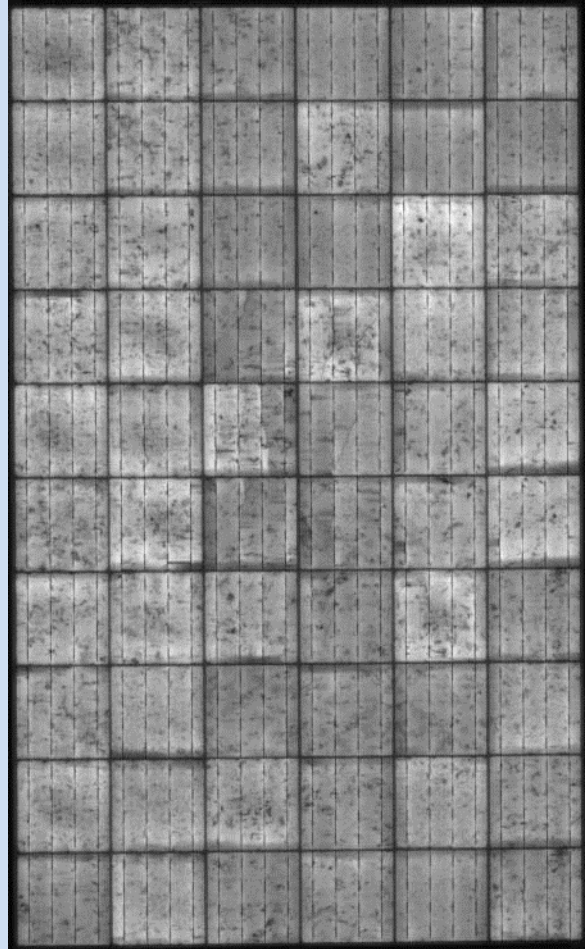


Backsheet Type: PET  
Serial Number: ...5255

Post-TC600



Post-UVA65 #4



## 2.3 STC performance testing data

Pre-stress Testing Data						
Backsheet Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	263.6	38.22	30.98	9.038	8.508
PVDF	...0543	262.3	38.11	30.84	9.025	8.504
Tedlar	...1817	262.8	37.91	30.66	9.137	8.571
Tedlar	...1871	263.9	37.92	30.78	9.154	8.575
PET	...5161	263.9	38.01	30.78	9.148	8.576
PET	...5255	263.7	38.05	30.78	9.114	8.567
Percent Difference from Nameplate Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-2.37	0.85	0.59	-3.03	-2.77
PVDF	...0543	-2.85	0.56	0.14	-3.16	-2.81
Tedlar	...1817	-0.82	-1.80	-2.34	1.19	1.55
Tedlar	...1871	-0.40	-1.76	-1.97	1.37	1.60
PET	...5161	-0.40	-0.75	-0.08	0.52	-0.39
PET	...5255	-0.48	-0.66	-0.05	0.16	-0.50

Post-LID Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	256.9	38.04	30.63	8.897	8.386
PVDF	...0543	256.0	38.03	30.54	8.908	8.382
Tedlar	...1817	255.7	37.66	30.25	9.006	8.455
Tedlar	...1871	257.7	37.68	30.39	9.044	8.481
PET	...5161	261.4	37.89	30.62	9.109	8.538
PET	...5255	261.3	37.96	30.63	9.077	8.531
Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-2.55	-0.49	-1.13	-1.56	-1.43
PVDF	...0543	-2.41	-0.23	-0.98	-1.30	-1.44
Tedlar	...1817	-2.70	-0.65	-1.37	-1.44	-1.35
Tedlar	...1871	-2.37	-0.64	-1.29	-1.20	-1.10

Post-LID Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PET	...5161	-0.95	-0.32	-0.51	-0.42	-0.44
PET	...5255	-0.91	-0.23	-0.49	-0.41	-0.42

Post-DH1000 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	257.2	38.19	31.00	8.796	8.294
PVDF	...0543	257.6	38.11	30.85	8.851	8.350
Tedlar	...1817	256.3	37.89	30.70	8.890	8.347
Tedlar	...1871	257.5	37.95	30.74	8.893	8.375
PET	...5161	258.9	38.00	30.75	8.993	8.420
PET	...5255	258.8	38.03	30.71	8.973	8.428

Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	0.11	0.41	1.22	-1.13	-1.09
PVDF	...0543	0.64	0.23	1.03	-0.65	-0.38
Tedlar	...1817	0.21	0.62	1.51	-1.29	-1.29
Tedlar	...1871	-0.09	0.73	1.17	-1.67	-1.24
PET	...5161	-0.96	0.28	0.43	-1.27	-1.39
PET	...5255	-0.98	0.19	0.23	-1.14	-1.21

Post-UVA65 #1 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	255.3	38.15	30.85	8.783	8.276
PVDF	...0543	255.4	38.07	30.72	8.823	8.313
Tedlar	...1817	254.3	37.80	30.58	8.840	8.317
Tedlar	...1871	255.6	37.77	30.58	8.895	8.360
PET	...5161	258.1	37.93	30.68	8.988	8.412
PET	...5255	257.6	37.93	30.59	8.981	8.423

Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]

Post-UVA65 #1 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	-0.61	0.30	0.70	-1.27	-1.31
PVDF	...0543	-0.24	0.12	0.58	-0.96	-0.82
Tedlar	...1817	-0.56	0.36	1.09	-1.84	-1.64
Tedlar	...1871	-0.81	0.25	0.63	-1.65	-1.43
PET	...5161	-1.29	0.11	0.19	-1.34	-1.48
PET	...5255	-1.41	-0.06	-0.15	-1.06	-1.26

Post-TC200 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	256.0	38.19	30.81	8.820	8.308
PVDF	...0543	255.6	38.08	30.60	8.869	8.352
Tedlar	...1817	255.8	37.81	30.52	8.930	8.381
Tedlar	...1871	256.5	37.83	30.53	8.961	8.401
PET	...5161	257.0	37.88	30.50	9.014	8.428
PET	...5255	257.0	37.96	30.48	8.988	8.431

Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-0.35	0.40	0.59	-0.86	-0.93
PVDF	...0543	-0.14	0.15	0.21	-0.44	-0.35
Tedlar	...1817	0.03	0.41	0.92	-0.84	-0.89
Tedlar	...1871	-0.47	0.40	0.47	-0.92	-0.94
PET	...5161	-1.69	-0.04	-0.40	-1.05	-1.29
PET	...5255	-1.68	0.00	-0.52	-0.98	-1.17

Post-UVA65 #2 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	254.0	38.12	30.57	8.835	8.310
PVDF	...0543	253.7	38.12	30.42	8.865	8.341
Tedlar	...1817	254.2	37.75	30.41	8.923	8.359
Tedlar	...1871	256.2	37.92	30.54	8.945	8.387



Post-UVA65 #2 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PET	...5161	258.3	38.02	30.63	9.018	8.435
PET	...5255	257.3	37.96	30.48	9.019	8.442
Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-1.11	0.22	-0.21	-0.70	-0.90
PVDF	...0543	-0.88	0.26	-0.39	-0.49	-0.48
Tedlar	...1817	-0.61	0.23	0.54	-0.92	-1.14
Tedlar	...1871	-0.58	0.63	0.52	-1.10	-1.10
PET	...5161	-1.18	0.33	0.02	-1.00	-1.21
PET	...5255	-1.54	-0.01	-0.51	-0.63	-1.04

Post-TC400 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	254.0	38.13	30.60	8.835	8.302
PVDF	...0543	255.1	38.08	30.57	8.854	8.345
Tedlar	...1817	253.3	37.79	30.39	8.899	8.334
Tedlar	...1871	253.8	37.74	30.38	8.915	8.354
PET	...5161	255.8	37.93	30.40	9.013	8.414
PET	...5255	254.8	37.86	30.32	8.999	8.406
Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-1.10	0.25	-0.10	-0.70	-1.00
PVDF	...0543	-0.32	0.14	0.12	-0.61	-0.44
Tedlar	...1817	-0.97	0.35	0.48	-1.19	-1.44
Tedlar	...1871	-1.52	0.17	-0.02	-1.43	-1.50
PET	...5161	-2.15	0.11	-0.71	-1.06	-1.45
PET	...5255	-2.48	-0.26	-1.03	-0.86	-1.47

Post-UVA65 #3 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	254.6	38.08	30.54	8.867	8.336
PVDF	...0543	255.7	38.08	30.50	8.909	8.386
Tedlar	...1817	252.8	37.83	30.28	8.910	8.350
Tedlar	...1871	253.3	37.74	30.25	8.943	8.374
PET	...5161	256.3	37.80	30.30	9.052	8.459
PET	...5255	255.5	37.80	30.21	9.058	8.457
Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-0.89	0.13	-0.30	-0.34	-0.60
PVDF	...0543	-0.09	0.15	-0.14	0.01	0.05
Tedlar	...1817	-1.14	0.45	0.12	-1.06	-1.25
Tedlar	...1871	-1.71	0.17	-0.45	-1.11	-1.26
PET	...5161	-1.97	-0.25	-1.05	-0.63	-0.93
PET	...5255	-2.24	-0.43	-1.39	-0.21	-0.86

Post-TC600 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	254.8	38.20	30.60	8.854	8.326
PVDF	...0543	246.3	37.90	29.99	8.895	8.214
Tedlar	...1817	255.0	37.93	30.37	8.971	8.396
Tedlar	...1871	254.7	37.78	30.28	8.984	8.412
PET	...5161	255.8	37.82	30.24	9.085	8.460
PET	...5255	255.4	37.84	30.17	9.067	8.465
Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-0.81	0.43	-0.09	-0.48	-0.72
PVDF	...0543	-3.76	-0.33	-1.80	-0.15	-2.00
Tedlar	...1817	-0.28	0.71	0.43	-0.39	-0.70
Tedlar	...1871	-1.15	0.28	-0.34	-0.66	-0.81
PET	...5161	-2.15	-0.18	-1.24	-0.27	-0.92



Post-TC600 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PET	...5255	-2.28	-0.33	-1.53	-0.11	-0.77

Post-UVA65 #4 Testing Data						
Type	Serial Number	P <sub>MAX</sub> [W]	V <sub>OC</sub> [V]	V <sub>MP</sub> [V]	I <sub>SC</sub> [A]	I <sub>MP</sub> [A]
PVDF	...0516	253.5	38.12	30.38	8.898	8.344
PVDF	...0543	247.7	37.89	29.97	8.912	8.266
Tedlar	...1817	251.8	37.73	30.00	8.994	8.394
Tedlar	...1871	252.8	37.76	30.08	8.995	8.403
PET	...5161	255.8	37.84	30.19	9.095	8.472
PET	...5255	255.5	37.86	30.17	9.078	8.468

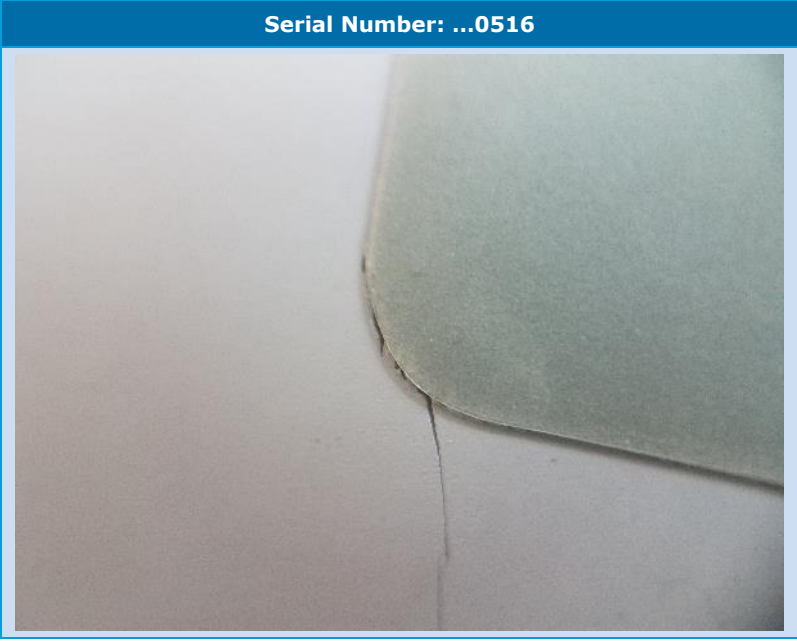
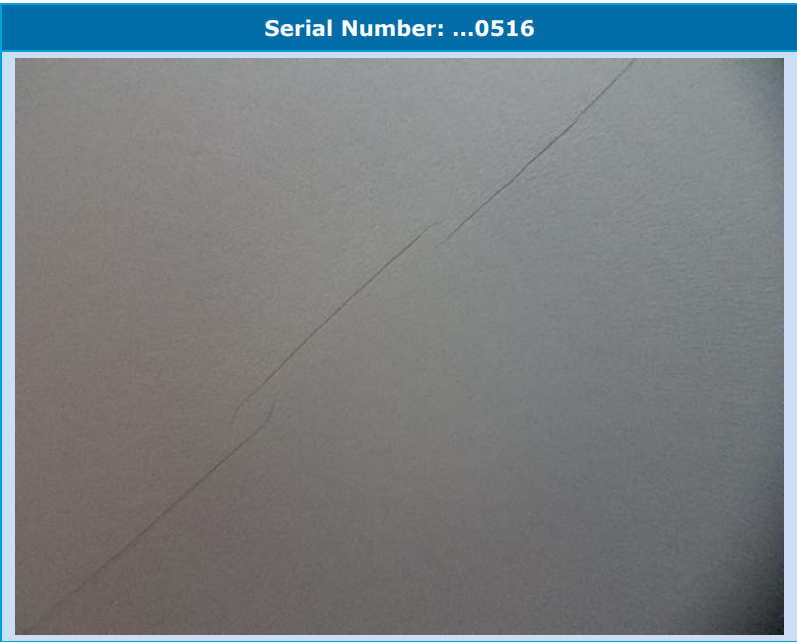
Percent Difference from Pre-stress Testing Data						
Type	Serial Number	P <sub>MAX</sub> [%]	V <sub>OC</sub> [%]	V <sub>MP</sub> [%]	I <sub>SC</sub> [%]	I <sub>MP</sub> [%]
PVDF	...0516	-1.32	0.21	-0.82	0.01	-0.50
PVDF	...0543	-3.24	-0.35	-1.88	0.04	-1.39
Tedlar	...1817	-1.52	0.19	-0.80	-0.13	-0.73
Tedlar	...1871	-1.92	0.23	-1.01	-0.54	-0.92
PET	...5161	-2.16	-0.13	-1.39	-0.16	-0.78
PET	...5255	-2.23	-0.25	-1.50	0.01	-0.73

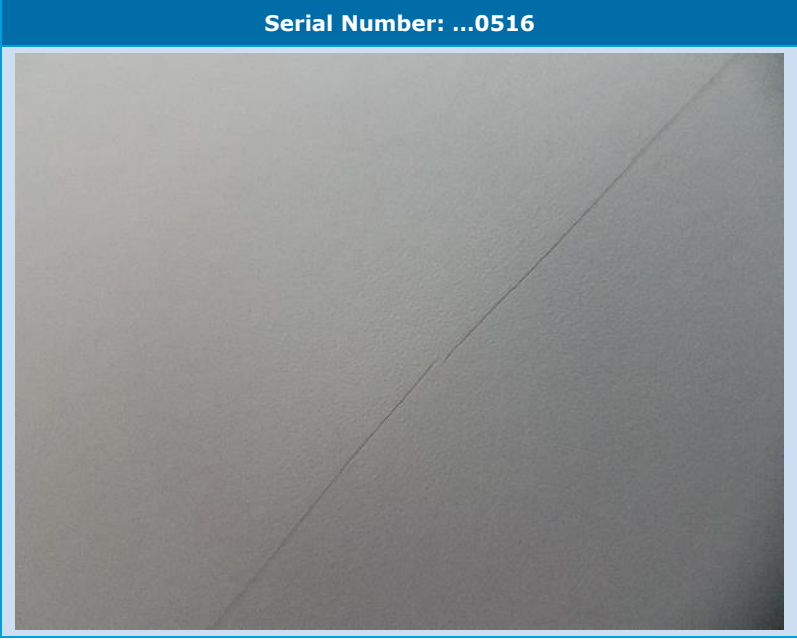
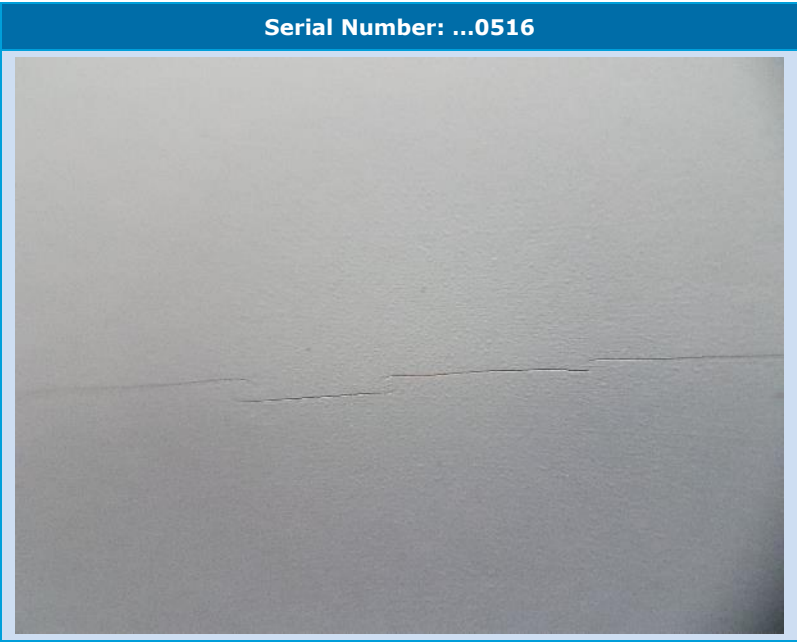
## 2.4 Visual inspection notes

Visual inspection was performed per ASTM D2244. Abnormalities found throughout testing are noted below.

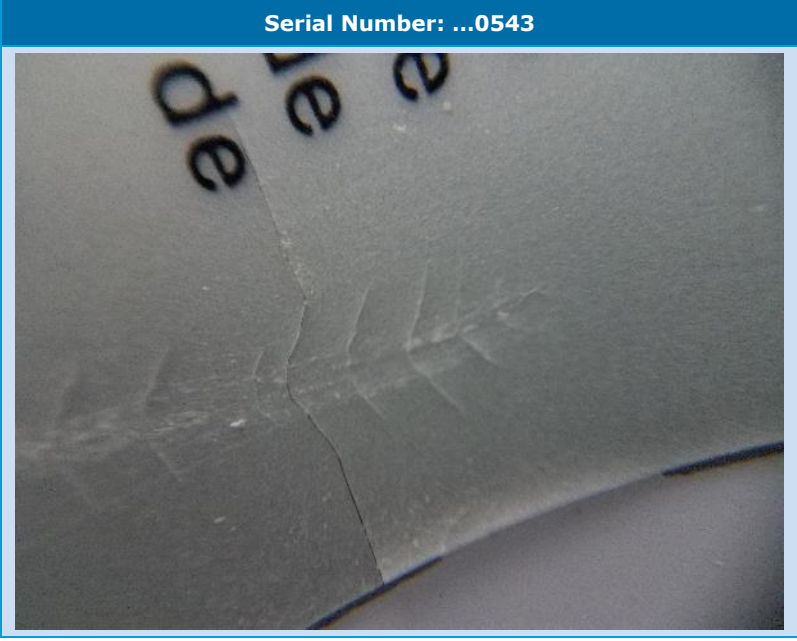
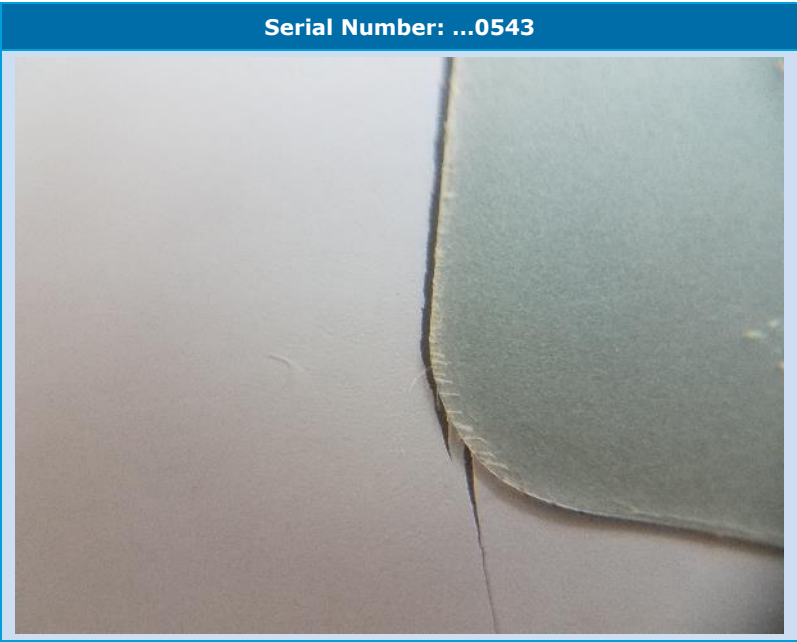
Post-UVA65 #3 Inspection Notes		
Type	Serial Number	Notes
PVDF	...0516	Backsheet cracks along ribbons
PVDF	...0543	Backsheet cracks along ribbons



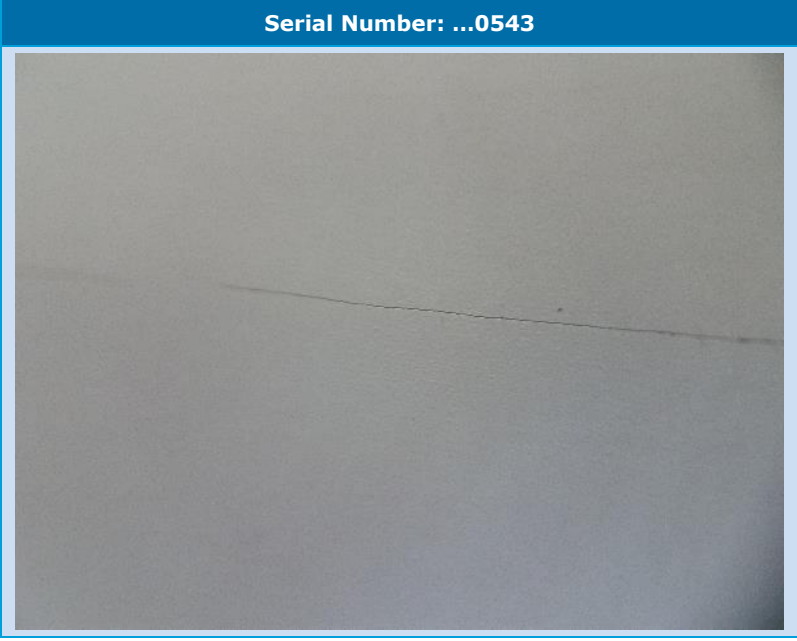
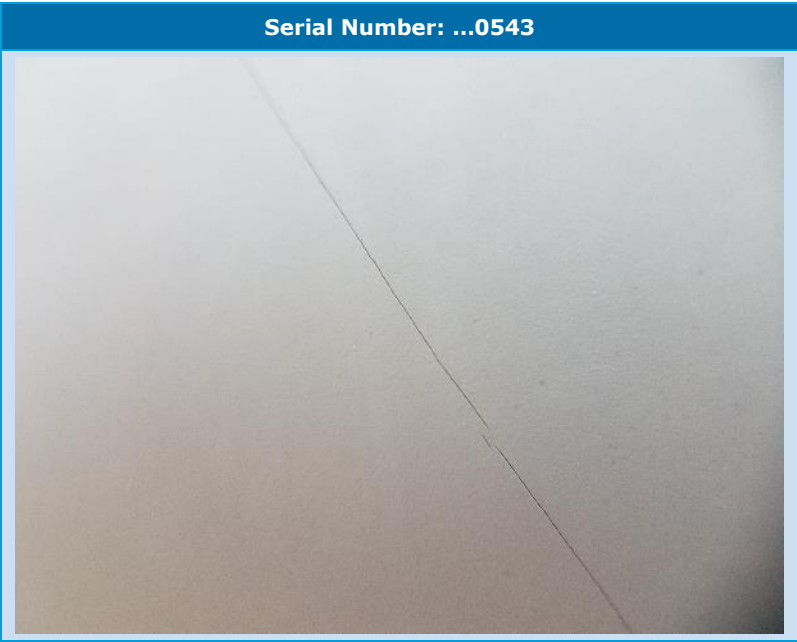












## 2.5 Wet leakage-current testing data

IEC 61215 Sec. 10.15 defines a passing insulation resistance for the type of module tested to be no less than 40 M $\Omega$ ·m<sup>2</sup>.

Post-LID Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [M $\Omega$ ·m <sup>2</sup> ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670

Post-DH1000 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [M $\Omega$ ·m <sup>2</sup> ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670



Post-UVA65 #1 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [ $M\Omega \cdot m^2$ ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670

Post-TC200 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [ $M\Omega \cdot m^2$ ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670

Post-UVA65 #2 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [ $M\Omega \cdot m^2$ ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670



Post-TC400 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [ $M\Omega \cdot m^2$ ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670

Post-UVA65 #3 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [ $M\Omega \cdot m^2$ ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670

Post-TC600 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [ $M\Omega \cdot m^2$ ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670



Post-UVA65 #4 Testing Data			
Type	Serial Number	Leakage-current [ $\mu$ A]	Insulation Resistance [ $M\Omega \cdot m^2$ ]
PVDF	...0516	1	1609
PVDF	...0543	1	1609
Tedlar	...1817	1	1637
Tedlar	...1871	1	1637
PET	...5161	1	1670
PET	...5255	1	1670

## APPENDIX A – FLASH-TEST MEASUREMENT SUMMARY

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Per IEC 60904-1 Second Edition 2006-9

Pasan SunSim 3b pulsed solar simulator (flash-tester)

- Class A+A+A+
  - Non-uniformity of irradiance  $\leq 1\%$
  - Long-term pulse instability  $\leq 1\%$
  - Spectral irradiance distribution  $\leq \pm 12.5\%$
- All performance values are extracted from the measured I-V data
- Expanded ( $k = 1.96$ ) uncertainty values at STC (assuming a spectral mismatch factor of 1 and not including module metastability behavior):
  - $V_{OC}$ :  $\pm 0.79\%$
  - $I_{SC}$ :  $\pm 1.64\%$
  - $P_{MAX}$ :  $\pm 2.00\%$
- Maximum difference of achieved temperature/irradiance from target temperature/irradiance:
  - Temperature:  $\pm 1^{\circ}\text{C}$
  - Irradiance:  $\pm 0.5\%$

DNV GL's Pasan SunSim 3b pulsed solar simulator was calibrated using a JA Solar polycrystalline reference module (Serial Number 147P607222930001) that was calibrated by Fraunhofer Institut für Solare Energiesysteme (ISE). The next calibration due date is October 27, 2018. After calibrating the flash-tester to the JA Solar reference module, the modules were flash-tested according to IEC 60904-1.



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