NATIONAL LABORATORY OF THE ROCKIES

Testing of Prototype PV Modules

Cooperative Research and Development Final Report

CRADA Number: CRD-20-16876

NLR Technical Contact: Peter Hacke

The National Laboratory of the Rockies is a national laboratory of the U.S. Department of Energy, Office of Critical Minerals and Energy Innovation, operated under Contract No. DE-AC36-08GO28308.

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Technical Report
NLR/TP-5K00-99002
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NOTICE

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Cooperative Research and Development Final Report

Report Date: December 23, 2025

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Sunflex Solar

CRADA Number: CRD-20-16876

CRADA Title: Testing of Prototype PV Modules

Period of Performance: 6/23/2020 – 6/30/2024

Responsible Technical Contact at NLR:

Peter Hacke | peter.hacke@nlr.gov

Name and Email Address of POC at Company:

Zachary Holman | zachary.holman@asu.edu

Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NLR Shared Resources a/k/a Government In-Kind
Year 1	$84,495.36
Year 2, Modification #1	$.00
Year 3, Modification #2	$.00
Year 4, Modification #3	$50,000.00
TOTALS	$134,495.36

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Executive Summary of CRADA Work:

The American-Made Solar Prize is a prize competition from the U.S. Department of Energy (DOE) that is designed to revitalize U.S. solar manufacturing. The competition aims to support the growth of U.S. solar manufacturing and reenergize American energy innovation by tapping into Americans' competitive spirit and the nation's unparalleled innovation ecosystem, leveraging national labs, incubators, facilities, and more. Finalists have been chosen based on the work they intend to do with a manufacturing partner to advance their innovation to market. NLR will provide technical advisement to assist participants in demonstrating the full potential of their product.

CRADA benefit to DOE, Participant, and U.S. Taxpayer:

- Enhances U.S. competitiveness by utilizing DOE developed intellectual property and/or capabilities.
- Assists laboratory in achieving programmatic scope.
- Uses the laboratory's core competencies.

Summary of Research Results:

Task 1. NLR will perform the thermocycling and damp heat test sequences outlined in IEC61215 and the PID test sequence outlined in IEC62804-1 on six, 4-cell modules supplied by the Participant.

Set 2 modules provided by SunFlex for temperature cycling yielded standard test condition (STC) results shown in Fig. 1. Fill factor loss of about 2% relative is seen associated with series resistance.

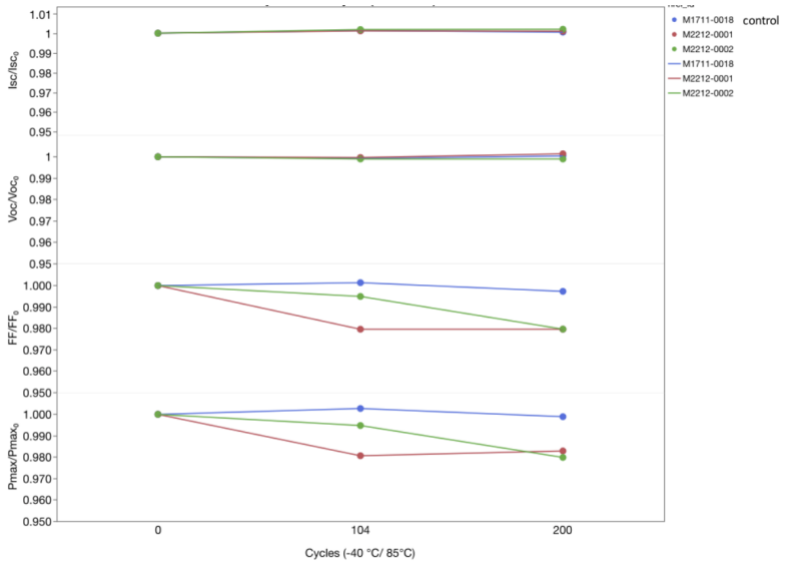

Fig. 1. Set 2 module results through temperature cycling

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STC results of Set 3 modules provided by SunFlex for temperature cycling are shown in Fig. 2. There was negligible degradation seen.

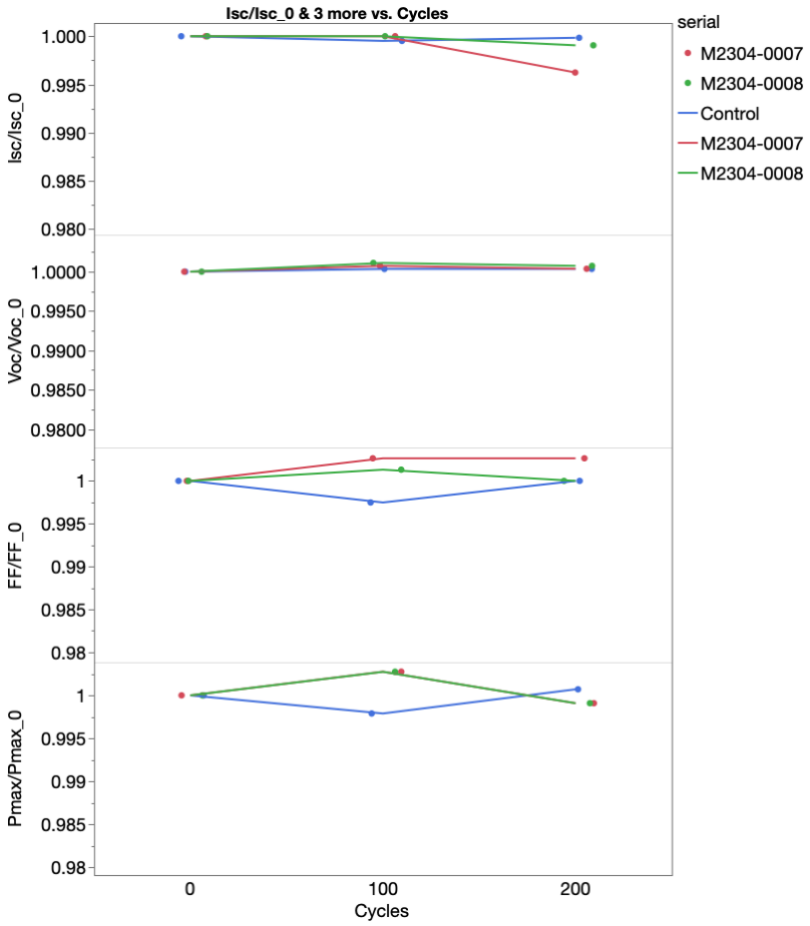

Fig. 2. Set 3 module results through temperature cycling

Damp heat and potential-induced degradation testing was not performed in favor of additional combined accelerated stress testing, covered below.

Task 2. NLR will perform the thermocycling and damp heat/mechanical load test sequences outlined in IEC 61215 and the pelvic inflammation disease (PID) test sequence outlined in IEC 62804-1 on six 60-cell modules supplied by the participant. Each of these accelerated environmental test sequences will be performed for twice the number of cycles stipulated in the IEC standards for photovoltaic (PV) module testing.

Testing of 60 cell modules was not performed in favor of additional combined accelerated stress testing, covered below.

Task 3: NLR will perform C-AST on two 4-cell modules.

A total of four sets of two mini modules per set were run through two cycles of the combined-accelerated stress testing (CAST) cycle shown in Fig. 3.

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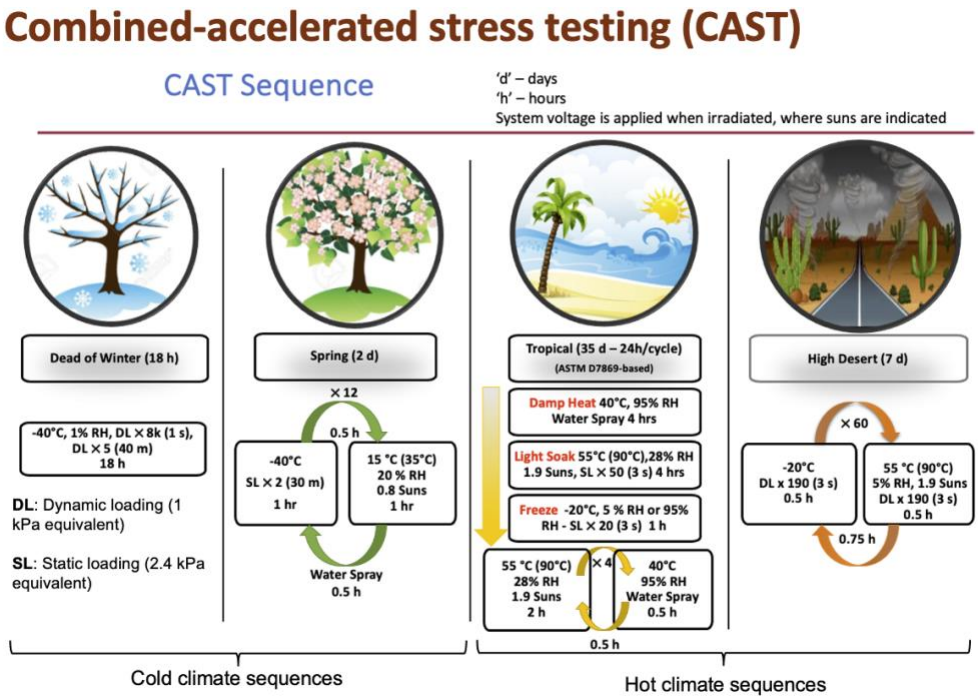

Fig. 3. Illustration of the combined-accelerated stress testing cycle, adapted from [1]

Set 1 Results

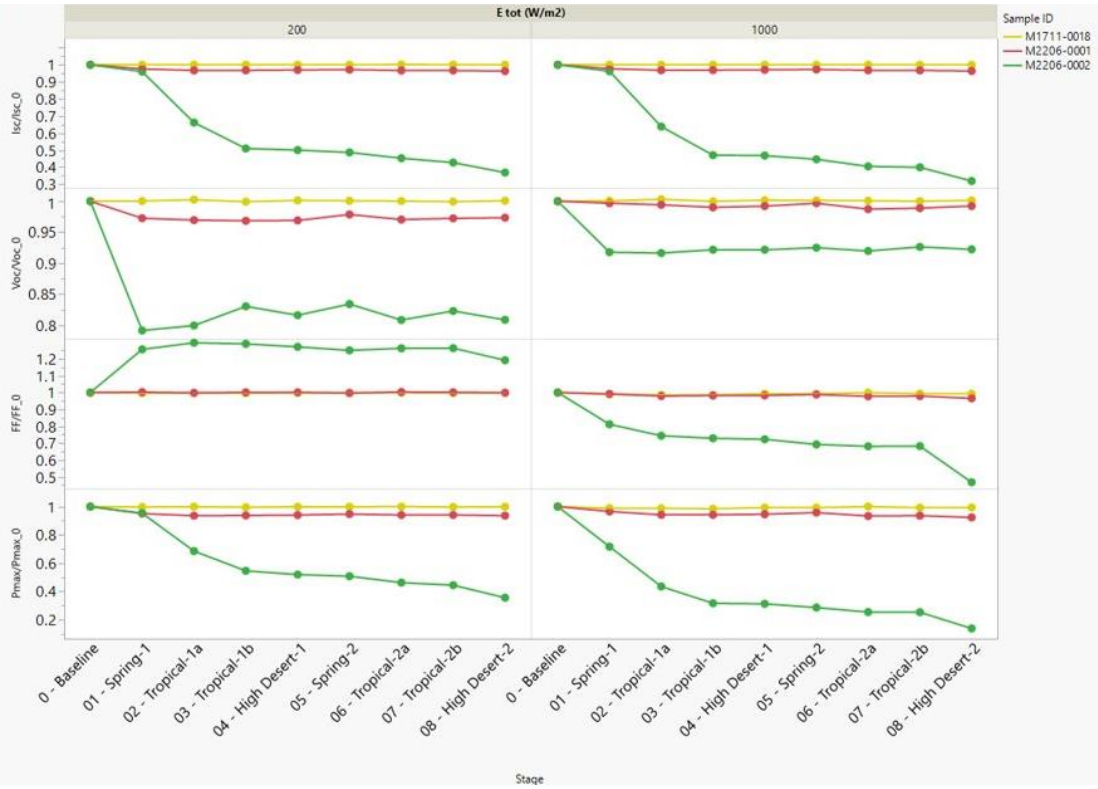

Fig 4. Results of set 1 sample through two cycles of CAST

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The results of set 1 sample through two cycles of CAST are shown in Fig. 4. Sample M2206-0002 had glass physically broken. The surviving sample, M2206-0001 had + 1000 V bias applied during CAST.

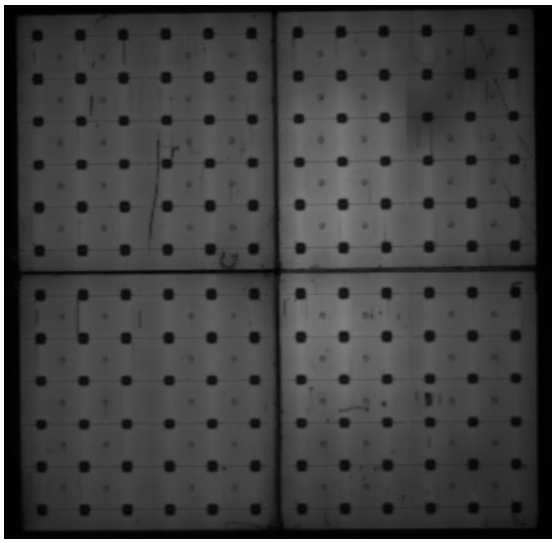

Fig. 5. Electroluminescence image M2206-0001-20230130154707-M2206-0001_3364mV_9234mA_1.6Sec.jpg

It appears there is more darkening at the cell edges of M2206-0001 (PERC type cell); see Fig 5. We can see one metallization wrap-through bond in the middle of the upper right cell having some series resistance issue. These factors contribute to the parameter losses seen in Fig. 4.

Set 2 results

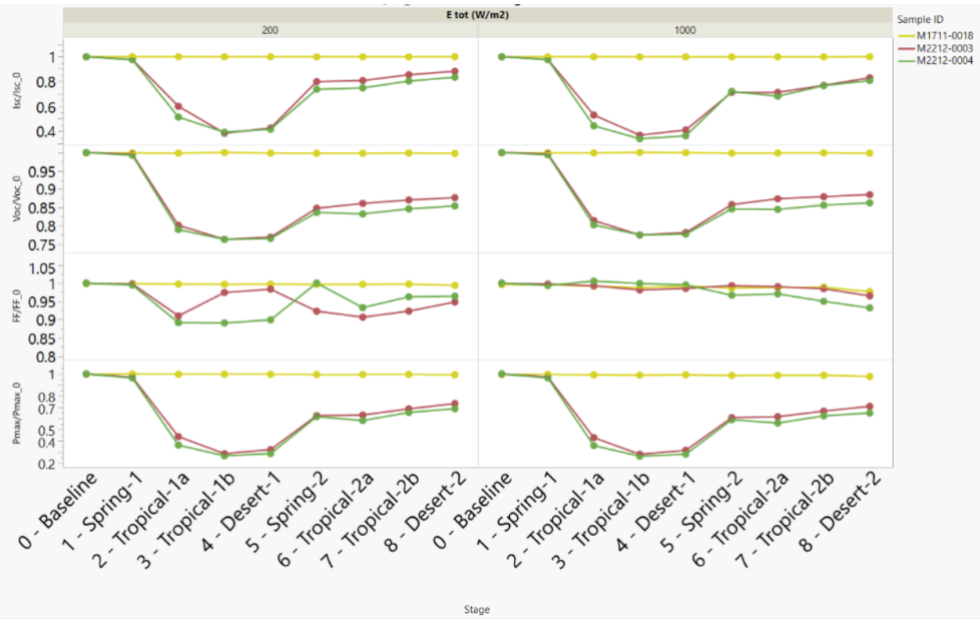

Fig. 6. Results of set 2 samples through two cycles of CAST

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Set two results using interdigitated back contact (IBC) cells were dominated by lifetime losses, leading to depressed Isc and Voc seen in Fig. 6. The transient nature and the +1000 V voltage bias point to PID-polarization being the root cause. Series resistance losses can be seen developing in the fill factor toward the end of testing based on the 1000 W/m^2 flash test measurements.

Set 3 results

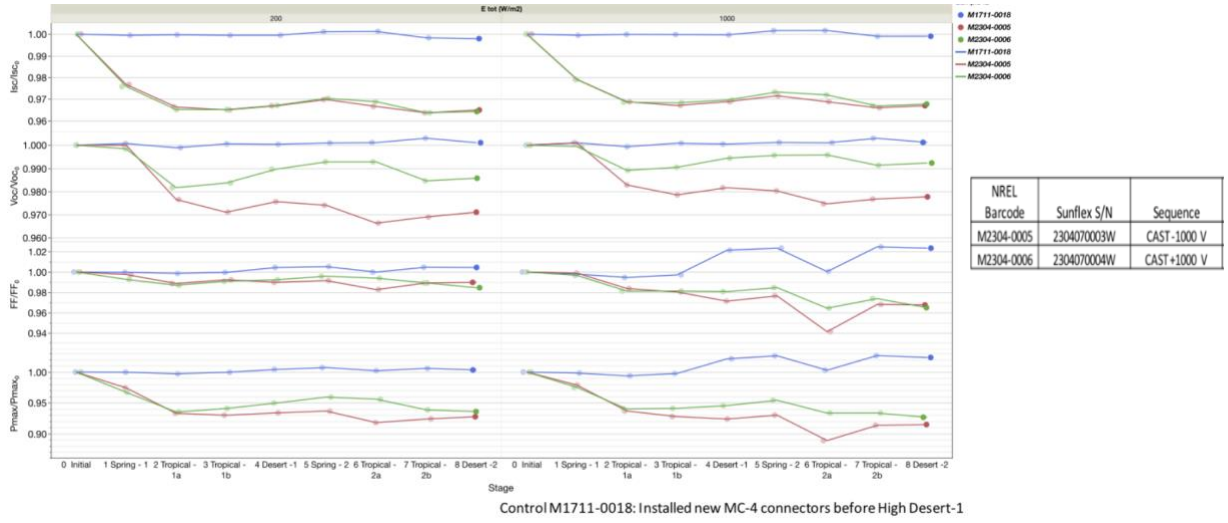

Fig. 7. Results of set 3 samples through two cycles of CAST

Results of set 3 samples through two cycles of CAST are shown in Fig. 7. Looking closely at the EL in M2304-0006 having +1000 V applied (Fig. 8), with darkening appearing in the middle and edges of the glass/backsheet-constructed module, it could be grid finger (usually contact) resistance developing, contributing to the 1-sun FF loss. We aren't seeing anywhere this level of contrast in the 0.1 Isc image on the right, so I would conclude series resistance as the source.

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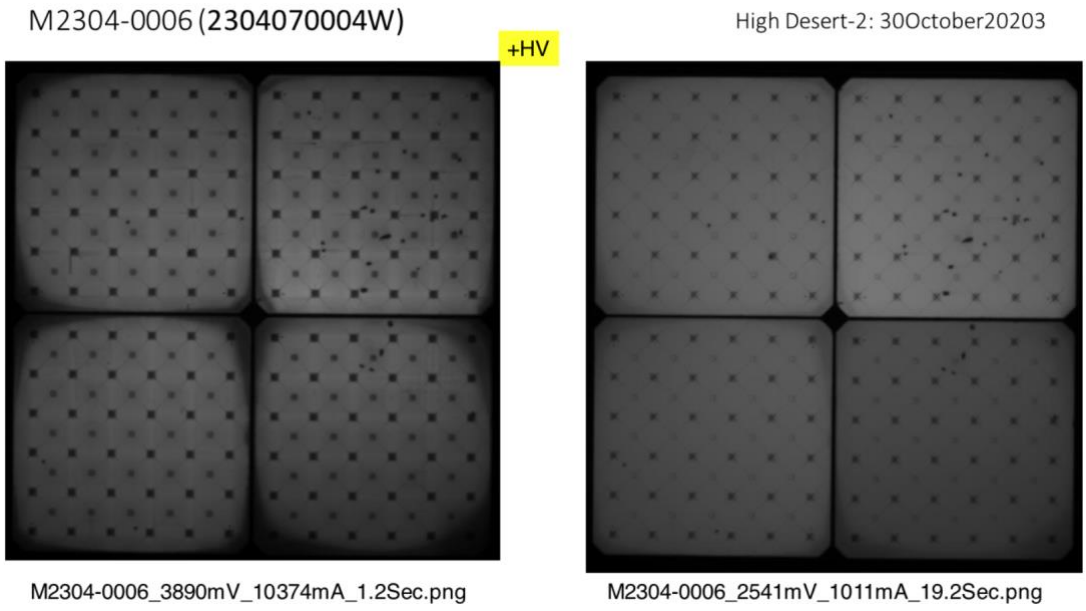

Fig. 8. Final electroluminescence images of sample M2304-0006 through two cycles of CAST; left image taken with Isc driving current; right, 0.1·Isc.

The effect, like corrosion, seems accelerated by the +1000 V because the signature is different/missing with the sample M2304-0005 having -1000 V applied.

Other issues seen are glass solarization based on the Isc loss that is incongruent with the development of the Voc loss. Voc loss, especially in M2304-0005, which experienced HV -1000 V bias applied, has PID occurring, but there are additional Voc loss sources considering Voc losses in both -1000 V and +1000 V. Light and elevated temperature-induced degradation may be the cause because it happened at a higher temperature (Tropical 1a), but that is just speculation.

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Set 4 results

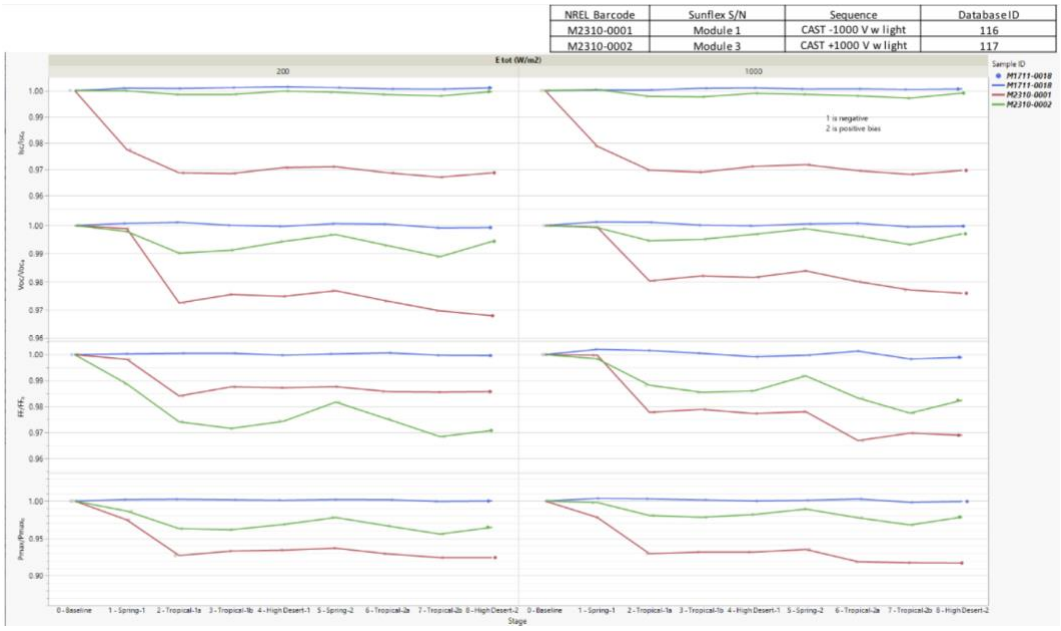

Fig. 9. Results of set 4 samples through two cycles of CAST

Set 4 as seen in the results in Fig. 9 did not fare as well as set 3. We saw evidence of PID-shunting for cells in -1000 V bias developing after the first Tropical stage as seen in Fig. 10.

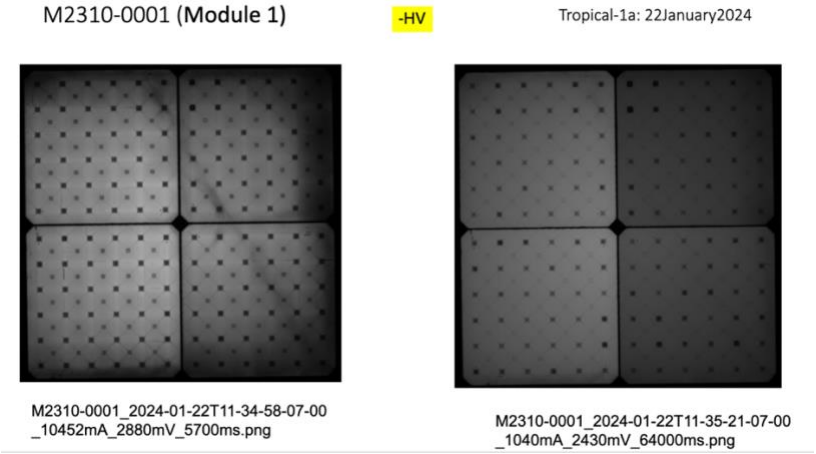

Fig. 10. Electroluminescence images of sample M2310-0001 through the Tropical 1a stage of CAST; left image taken with Isc driving current; right, 0.1·Isc.

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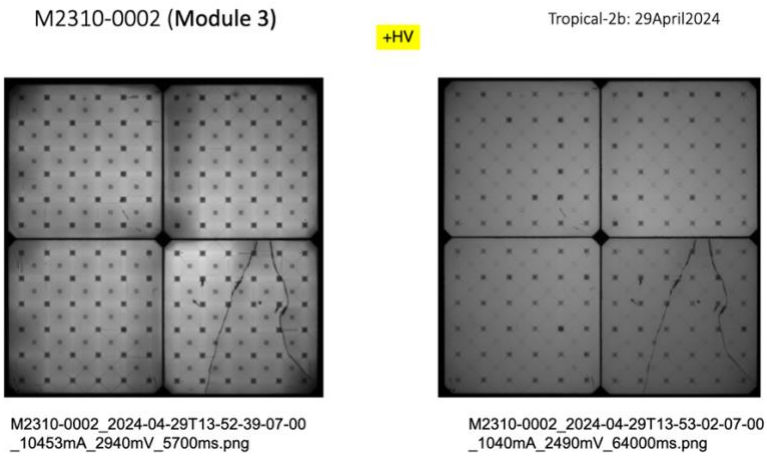

Fig. 11. Electroluminescence images of sample M2310-0002 through two cycles of CAST; left image taken with Isc driving current; right, 0.1·Isc.

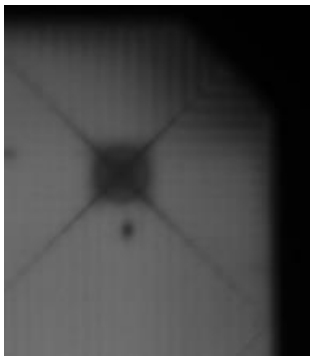

Fig 12. Electroluminescence image M2310-0002_2024-04-29T13-52-39-07-00_10453mA_2940mV_5700ms_cropped.jpg

In the +1000 V (+HV) voltage bias conditions of sample M2310-0002, at cell edges, there are some series resistance effects visible in the EL at Isc (Fig. 11); look at the left part of the upper right cell in Fig. 11 obtained with Isc driving current (left-side image) and magnified in Fig. 12. The area became brighter under further testing. It's a little hard to imagine the contacts of the laser welds improving when going from tropical to desert sequences of CAST, but it is a possibility. There is clearly some corrosion at the cell corners, maybe gridfingers. I have been thinking there are some PID-corrosion effects in +1000 V CAST.

Task 4: NLR will measure STC equivalent parameters and take EL images of each of the Participant's supplied modules undergoing environmental stress tests with an appropriate measurement schedule to determine the points in the test schedule where failure (if any) occurs.

This was performed for all modules tested, and the results were supplied to the customer; these STC results are all summarized graphically in the above sections. Key electroluminescence images are also given in the above sections. Hundreds of images were taken.

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Task 5: NLR will measure STC equivalent parameters and take EL images of each of the Participant's supplied modules undergoing environmental stress tests with an appropriate measurements schedule to determine the points in the test schedule where failure (if any) occurs.

Task 6: NLR agrees to provide the following to DOE Office of Scientific and Technical Information (OSTI): (1) an initial abstract suitable for public release at the time the CRADA is executed; (2) a final report, within thirty (30) days upon completion or termination of this CRADA, to include a list of Subject Inventions; and (3) other scientific and technical information in any format or medium that is produced as a result of this CRADA.

Task 7: CRADA Final Report: Preparation and submission in accordance with Article X.

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Article X.

References:

[1] Hacke P, Owen-Bellini M, Kempe MD, Sulas-Kern DB, Miller DC, Jankovec M, Mitterhofer S, Topič M, Spataru S, Gambogi W, Tanahashi T. Acceleration factors for combined-accelerated stress testing of photovoltaic modules. Solar RRL. 2023 Jun;7(12):2300068.

Subject Inventions Listing:

None

ROI #:

None

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