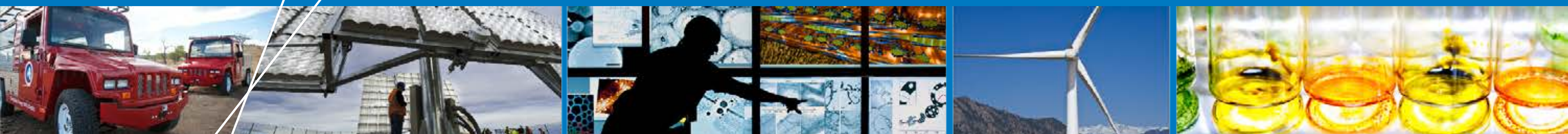
Testing Protocol for Module Encapsulant Creep



National Renewable Energy Laboratory – Photovoltaic Module Reliability Workshop

NREL-PVMRW

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Background, Concerns and Objectives

- **Background:**
  - Creep is the permanent deformation of a solid material under the influence of mechanical stresses.
  - PV manufacturers are using thermoplastic materials.
  - Qualification tests only test to 85^{o}C whereas modules can reach 105^{o}C outdoors, though only for a short time.
- **Concerns:**
  - Live components may be exposed.
  - Cells, tabbing, busbars, and etc. may be stressed and broken.
  - Internal short circuits may be created.
- **Objectives:**
  - Evaluate the potential for creep in outdoor exposure.
  - Provide guidance for the risks and for the design needs with thermoplastic materials.
  - Provide a basis for modifying standards to account for materials with the potential to creep

Outline

- Experimental Materials Used
- Outdoor Exposure Results
- Indoor Exposure
- Conclusions

Eight Representative Encapsulants Studied

Encapsulant Material Type		DSC Determined Transitions			DMA Determined Transitions at 0.1 rad/s	
		T_g (°C)	T_m (°C)	T_f (°C)	T_g (°C)	T_m (°C)
Commercial PV EVA resin	EVA	-31.4	55.1	45	-30	47
Commercial PV EVA Resin with all components but the peroxide	NC-EVA	-30.6	65.4	45.3	-28	69
Polyvinyl Butyral	PVB	14.8	NA	NA	17	NA
Aliphatic Thermalplastic Polyurethane	TPU	1.8	NA	NA	3	NA
Pt Catalyzed, Addition Cure Polydimethyl Silioxane Gel	PDMS	-158.6	-39.7	-80.3		
Thermoplastic Polyolefin #1	TPO-1	-43.1	92.9	80.6	-35	105
Thermoplastic Polyolefin #3	TPO-3	-44.2	61.0	55.3	-41	79
Thermoplastic Polyolefin #4	TPO-4	-33.5	105.5	99.2	-21	115

Thin Film Mock Modules

(1) 3.18 mm TCO glass with edge delete
(2) Encapsulant
(3) 3.18 mm back glass with through hole for electrical contact to TCO
(4) Black Paint, thermocouples and rails on back
(5) 2.5 cm fiberglass matte insulation, 46.5 m^2K/W^2 (R 6.7)
(6) 2.5 cm polyisocyanurate sheating foam insulation board, 45.1 m^2K/W^2 (R 6.6)
(7) 1.3 cm plywood back

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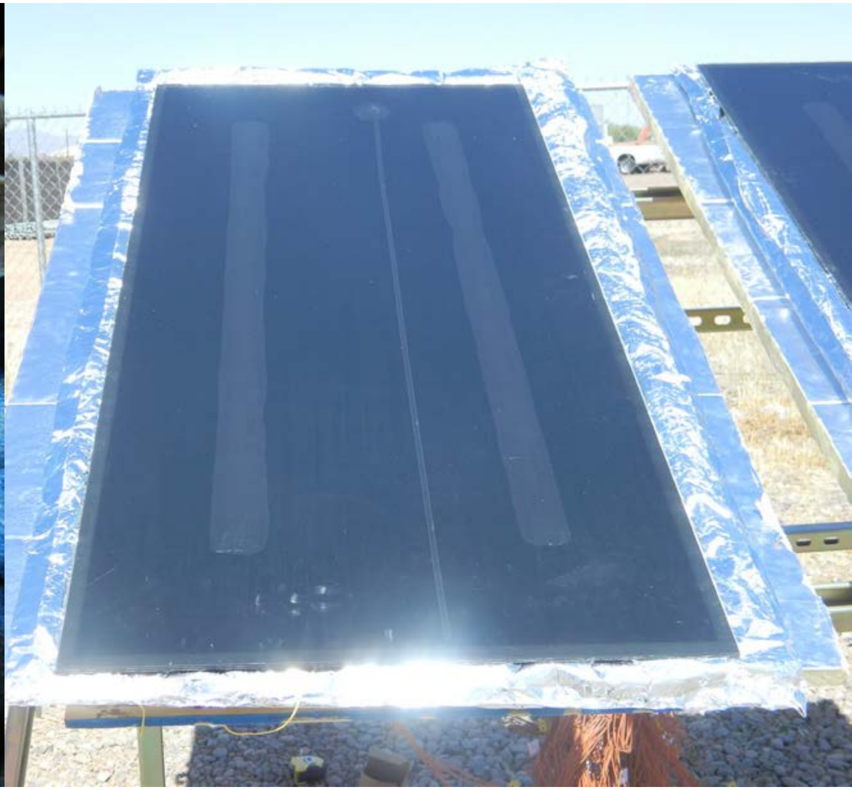

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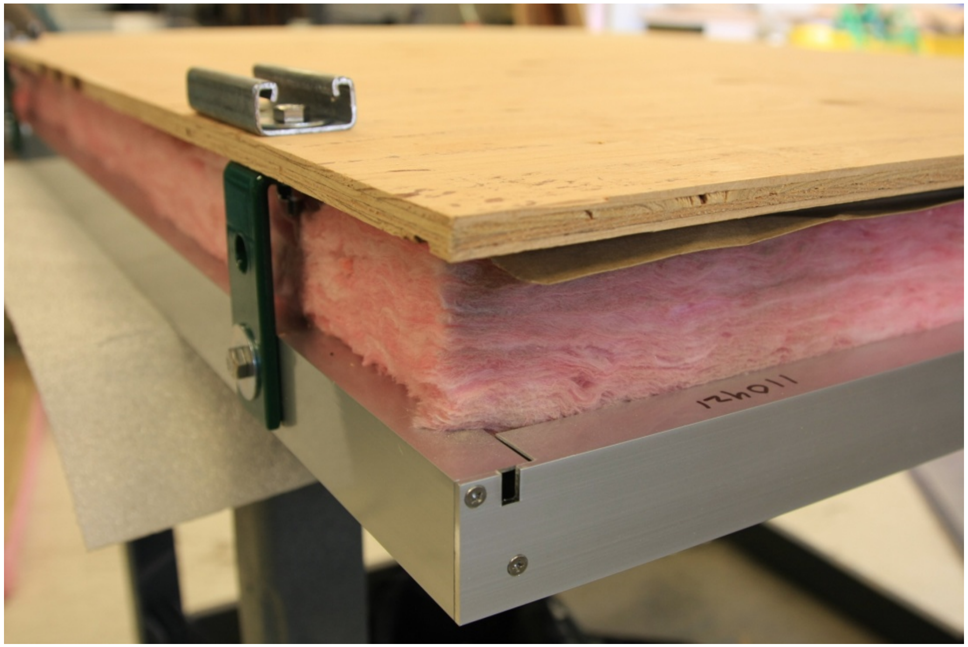
Crystalline Silicon Module Setup

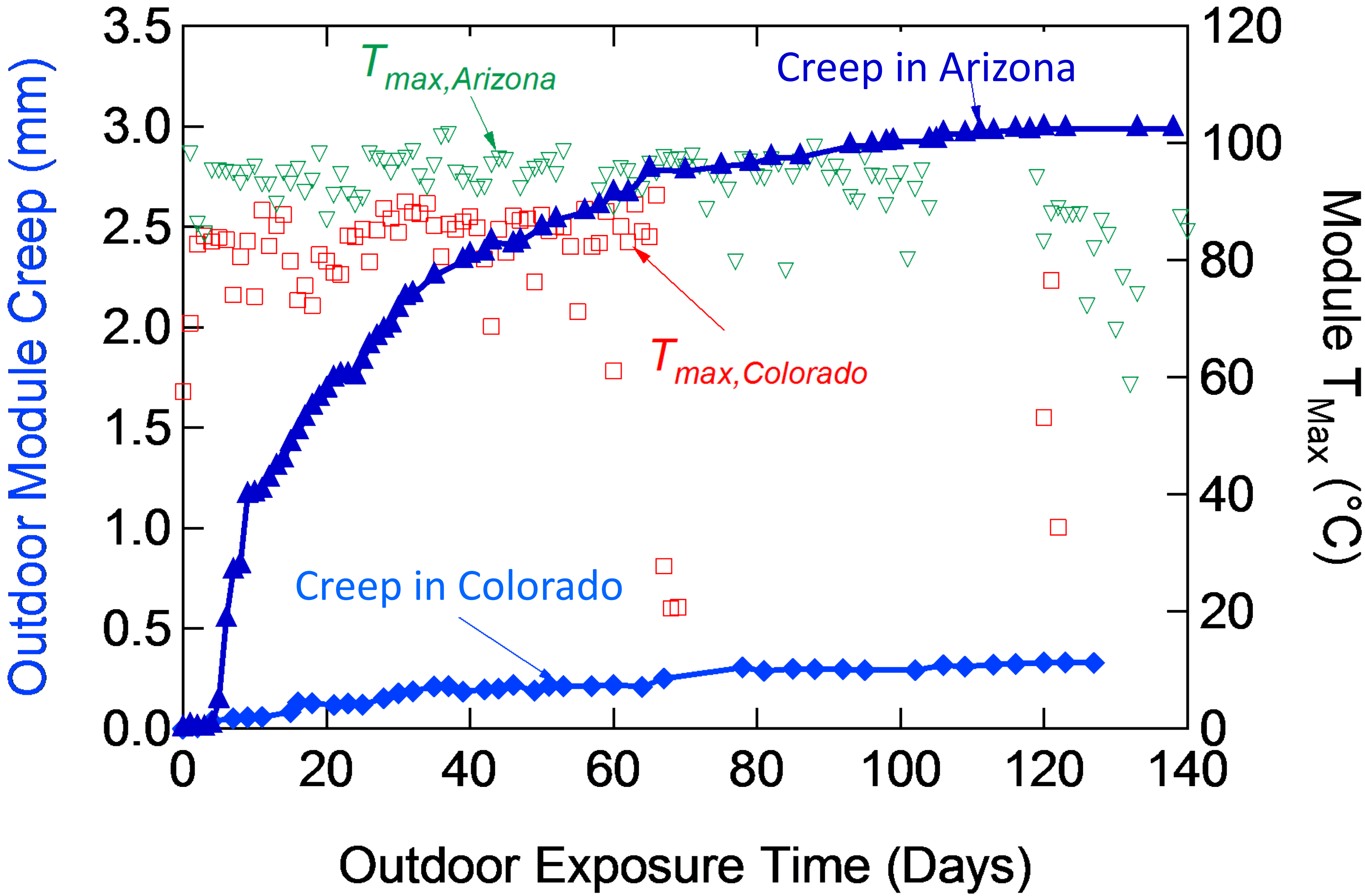


(1) 3.18 mm glass
(2) Encapsulant
(3) UMG polycrystalline Si Solar Cells
(4) Encapsulant
(5) PVF/PET/PVF backsheet
(6) 9 cm Fiberglass matte insulation, 104 m^2K/W^2 (R 15)
(7) 1.3 cm plywood

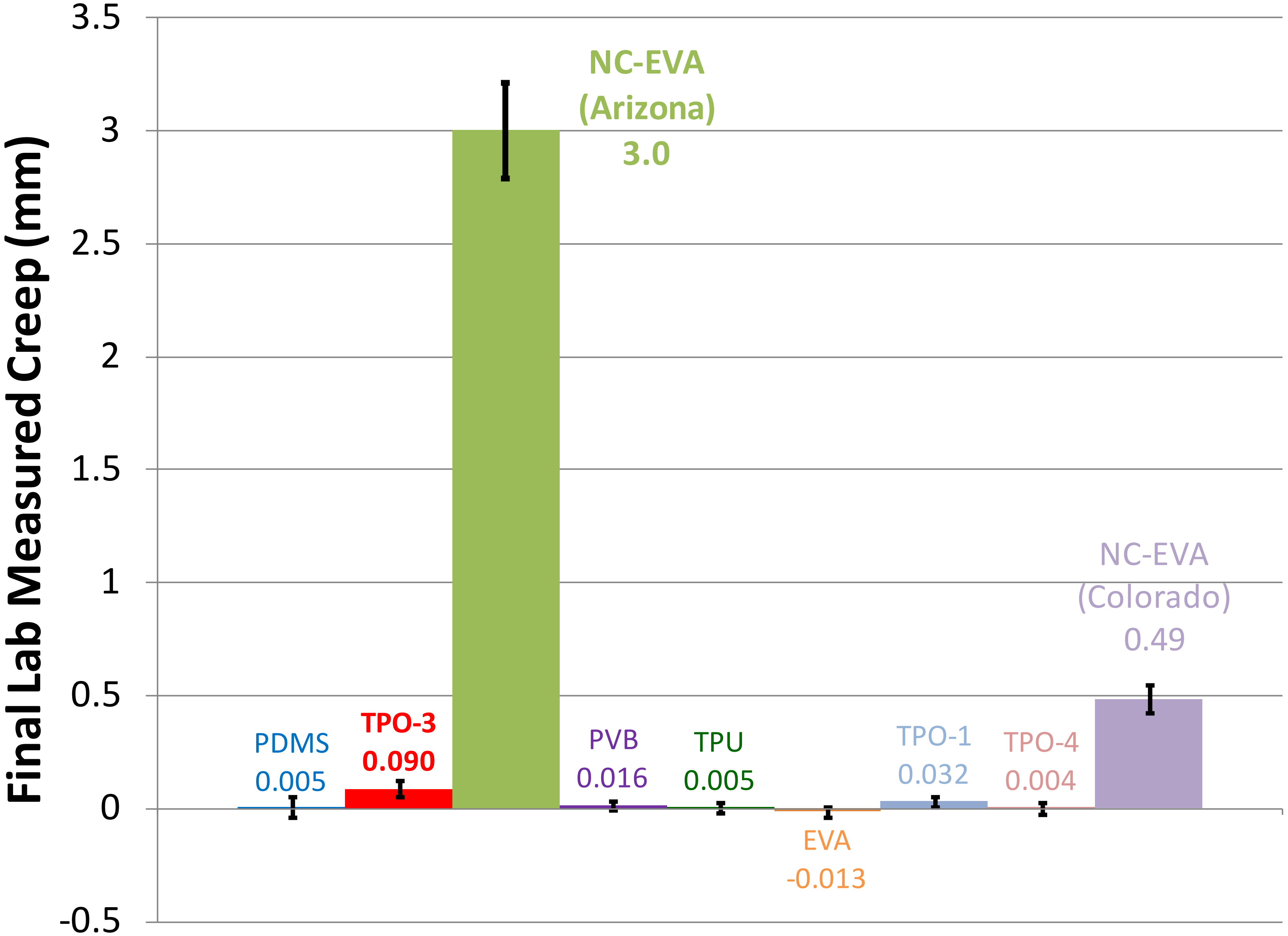
Deployed in Arizona Summer 2011

- Modules mounted in Mesa Arizona from May to September, 2011.
- Array oriented at a 33^{o} tilt and an azimuth of 255^{o} south so that the array more directly faced the sun at the hottest part of the day.
- A single no-cure-EVA mock module was deployed in Golden Colorado.

Only the No-Cure-EVA Module Crept Significantly



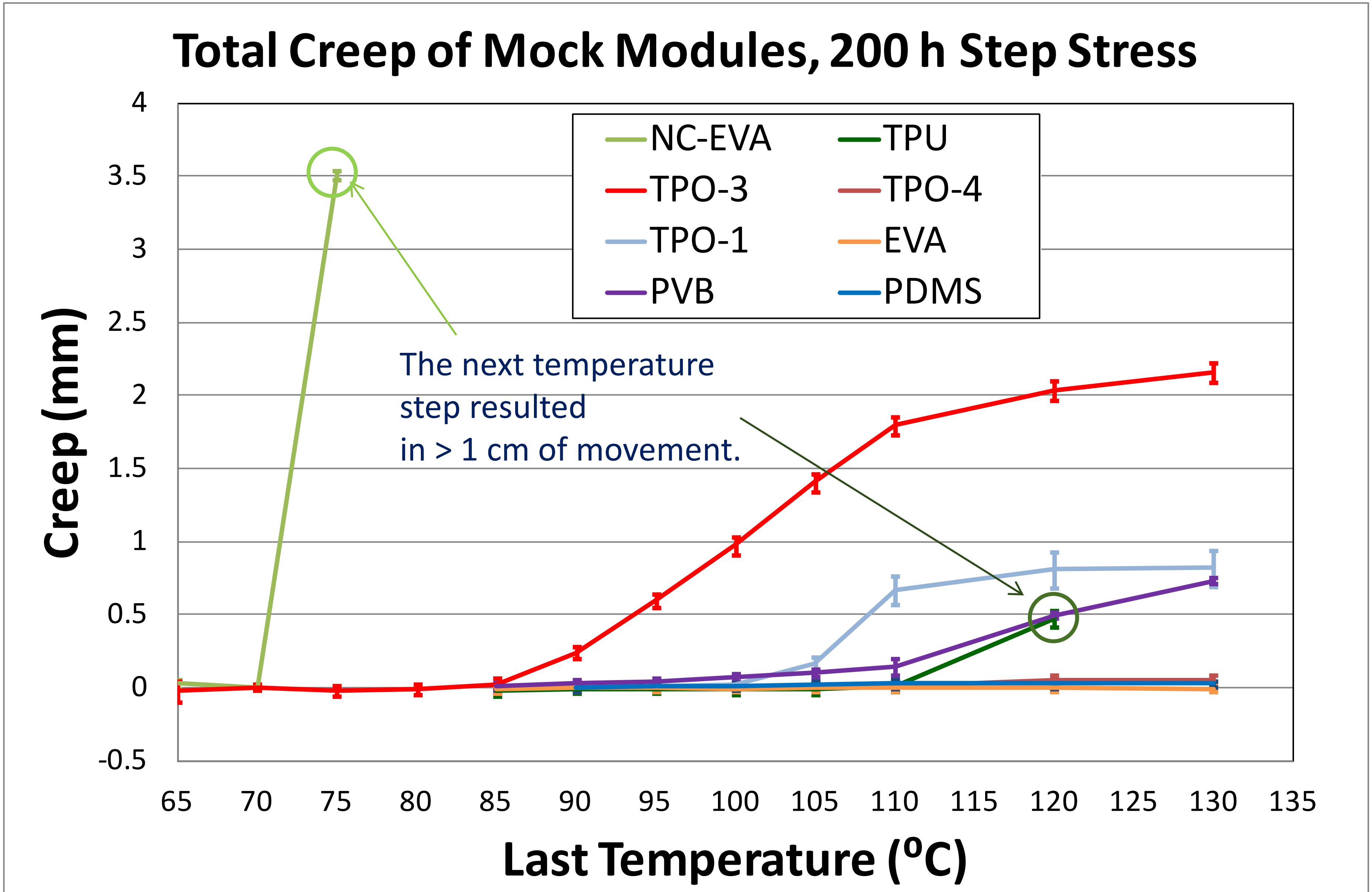
Minor Creep in TPO-3 and TPO-1



Outdoor Results Summary

- **Crystalline Si Modules**
  - No Signs of Creep
  - All Passed Wet High Pot
  - Only TPO-4 showed performance loss attributable to cell breakage. Probably from the lamination process.
- **Thin Fim Mock Modules**
  - The NC-EVA Module Crept 3 mm.
  - The NC-EVA appears to be crosslinking as it ages.
  - The TPO-1, and TPO-3 crept 32 and 90 microns, respectively.
  - All Passed the Wet High Pot Test.

Step Stress Test Parallels Outdoor Data



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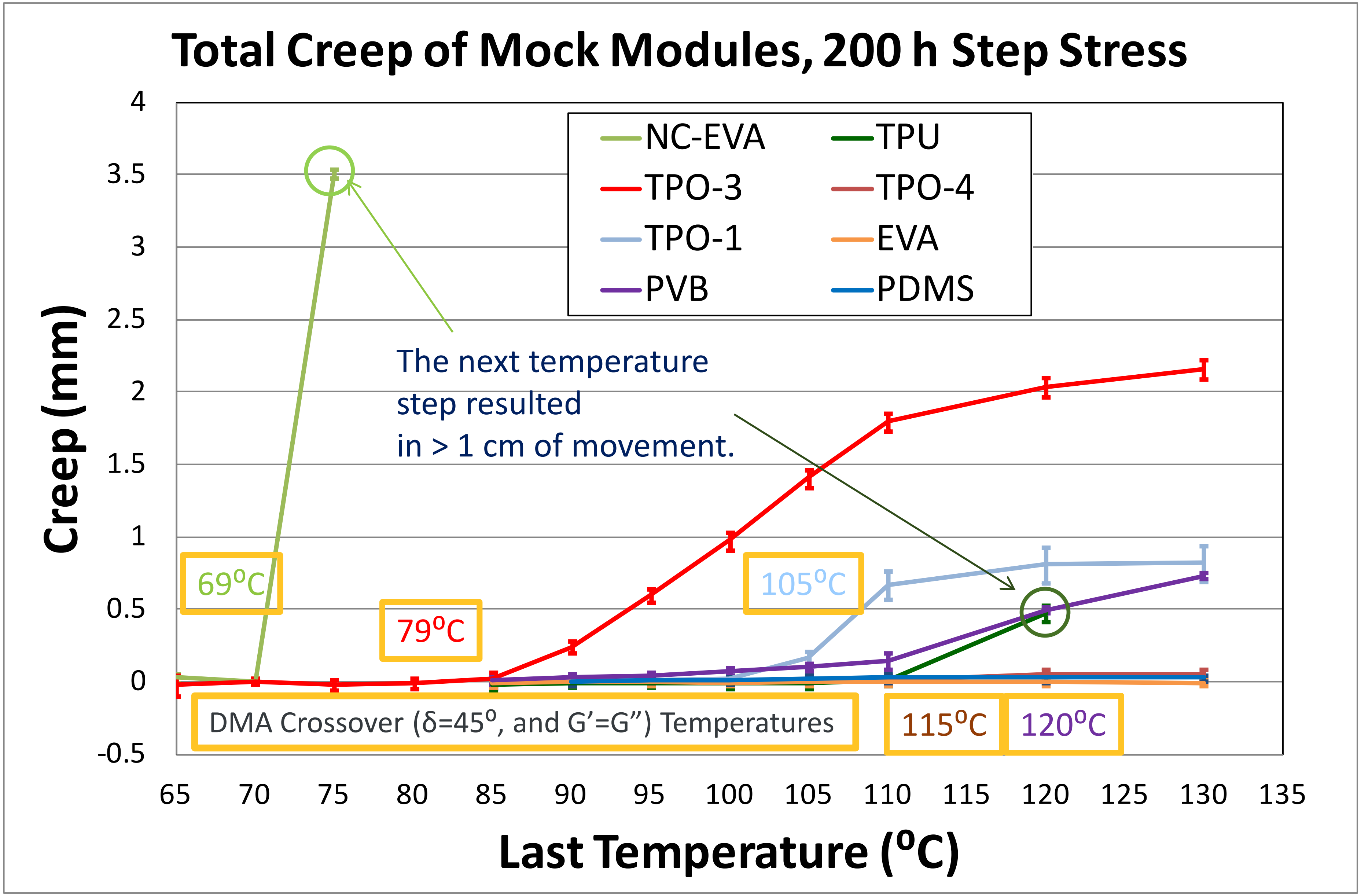

TPU Thin Film Mock Module Formed Bubbles Upon Heating

TPU after 100^{o}C
No Creep
Pass Wet Hi-Pot

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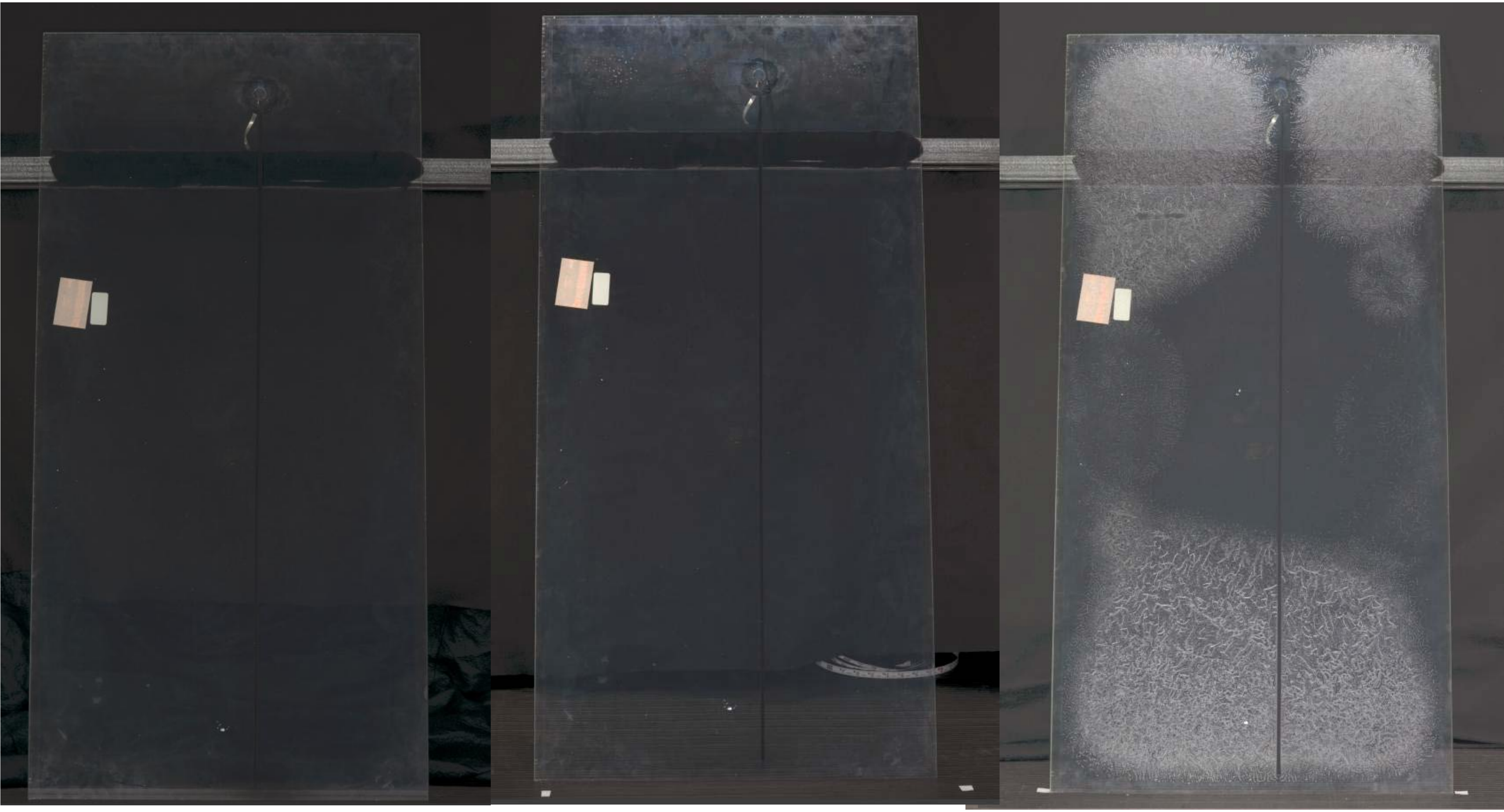
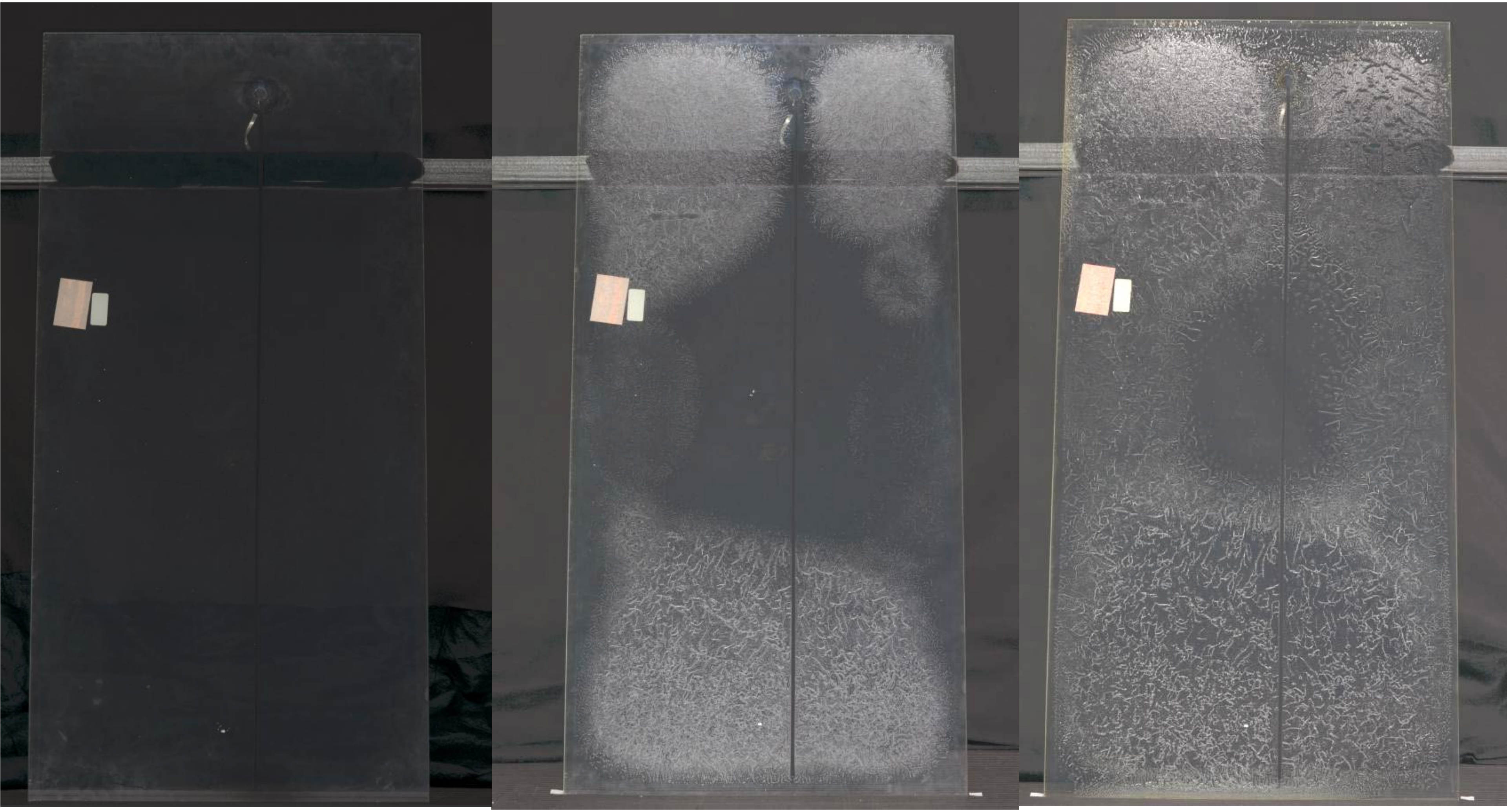
TPU Thin Film Mock Module Formed Bubbles Upon Heating



TPU after 100^oC	TPU After 105^oC	TPU after 110^oC
No Creep	No Creep	0.023 mm Creep
Pass Wet Hi-Pot	Pass Wet Hi-Pot	Pass Wet Hi-Pot

TPU Thin Film Mock Module Formed Bubbles Upon Heating



TPU after 100°C	TPU after 110°C	TPU after 120°C
No Creep	0.023 mm Creep	0.482 mm Creep
Pass Wet Hi-Pot	Pass Wet Hi-Pot	Pass Wet Hi-Pot

TPU Thin Film Mock Module Formed Bubbles Upon Heating

TPU after 100^oC
No Creep
Pass Wet Hi-Pot

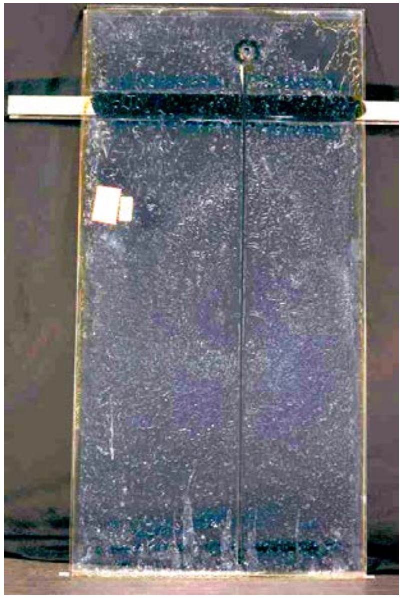
TPU after 110^oC
0.023 mm Creep
Pass Wet Hi-Pot

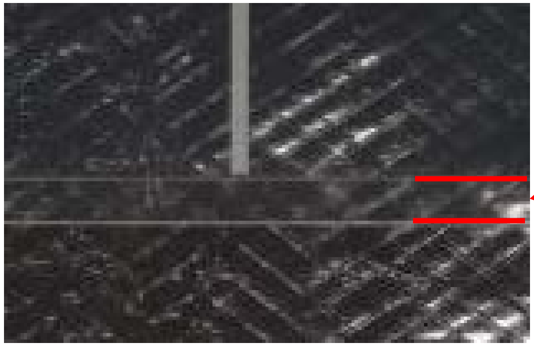
TPU after 130^oC
>1 cm Creep
Fail Wet Hi-Pot

NC-EVA Did not Form Bubbles

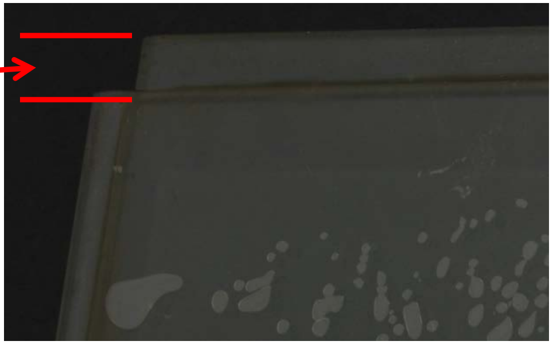
NC-EVA Mock Module
After 80^{o}C Exposure.

TPU Mock Module
After 130^{o}C exposure.



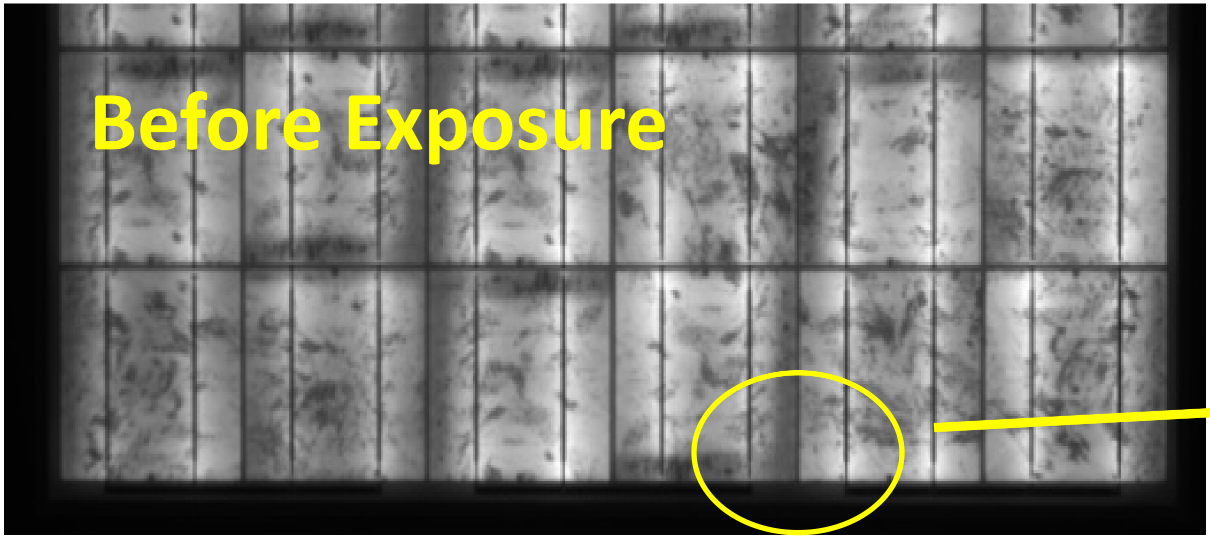


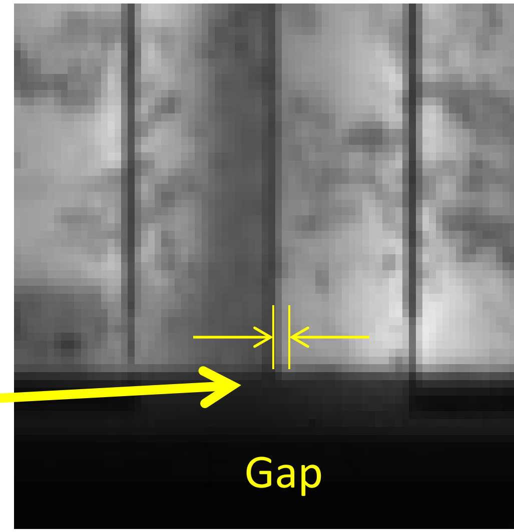
Glass
Displacement

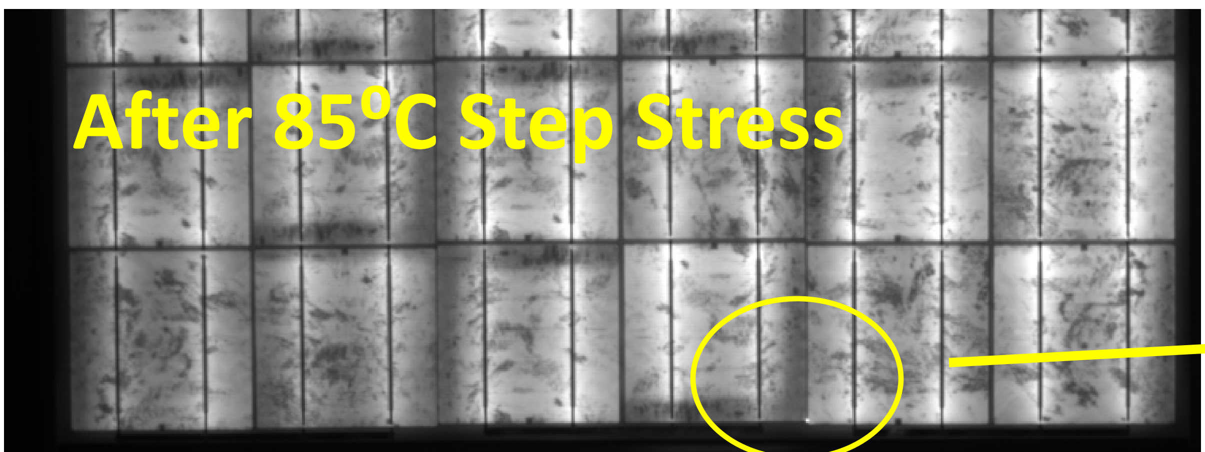


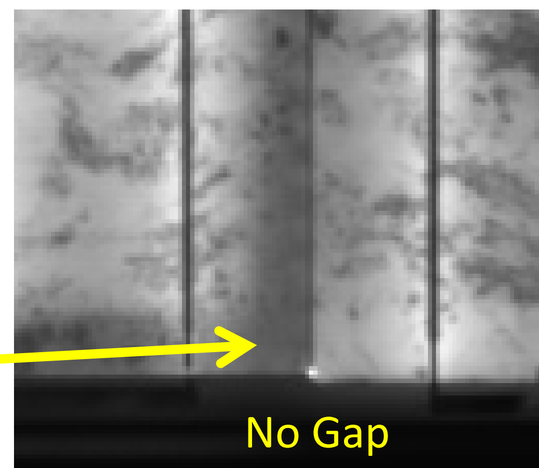
Some Creep in NC-EVA in Chamber at 85^{o}C

NC-EVA Crystalline Si Module (Electroluminescence)



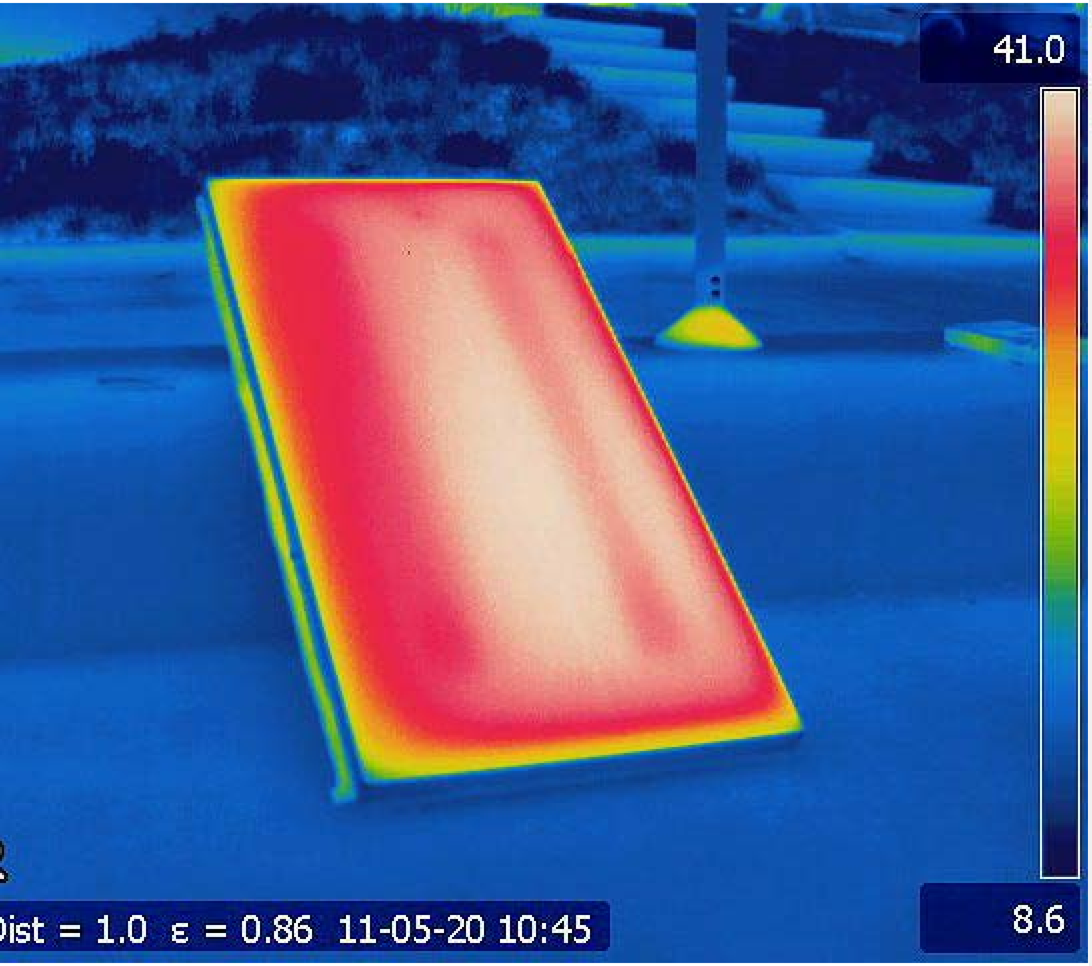


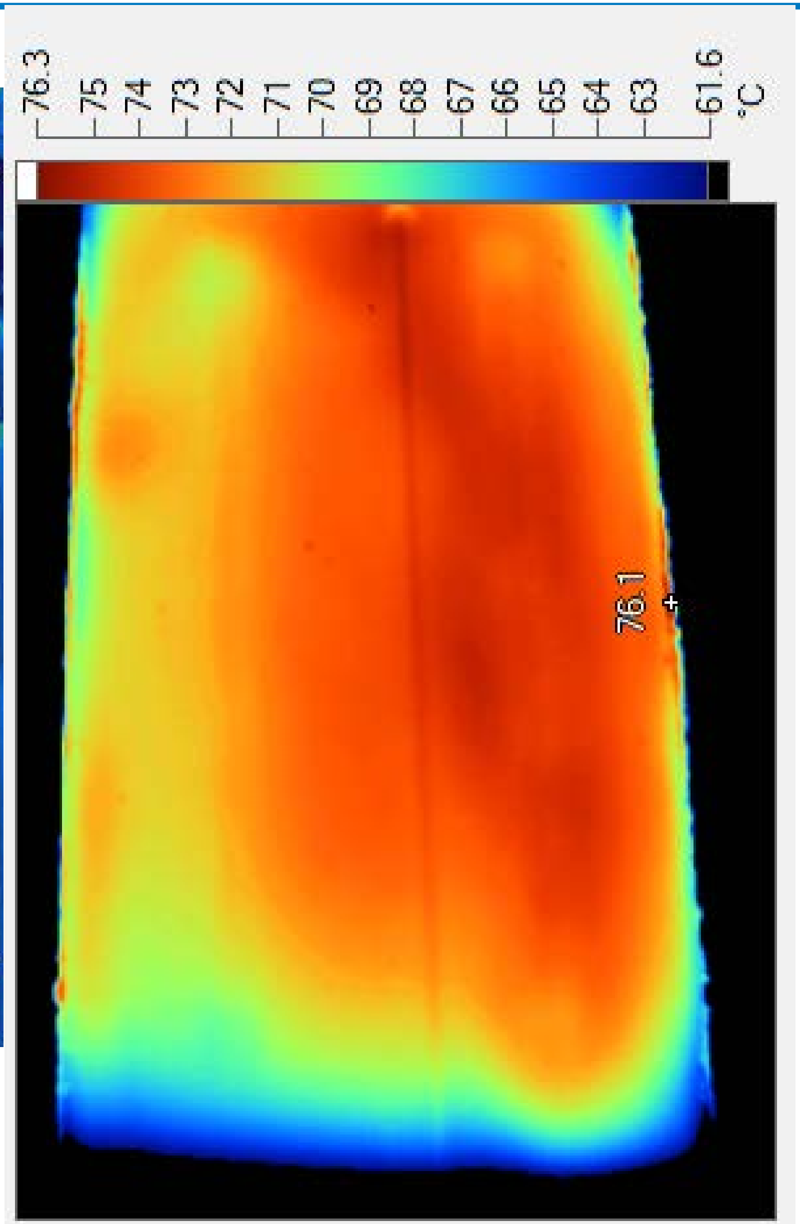




However, there was no performance loss.

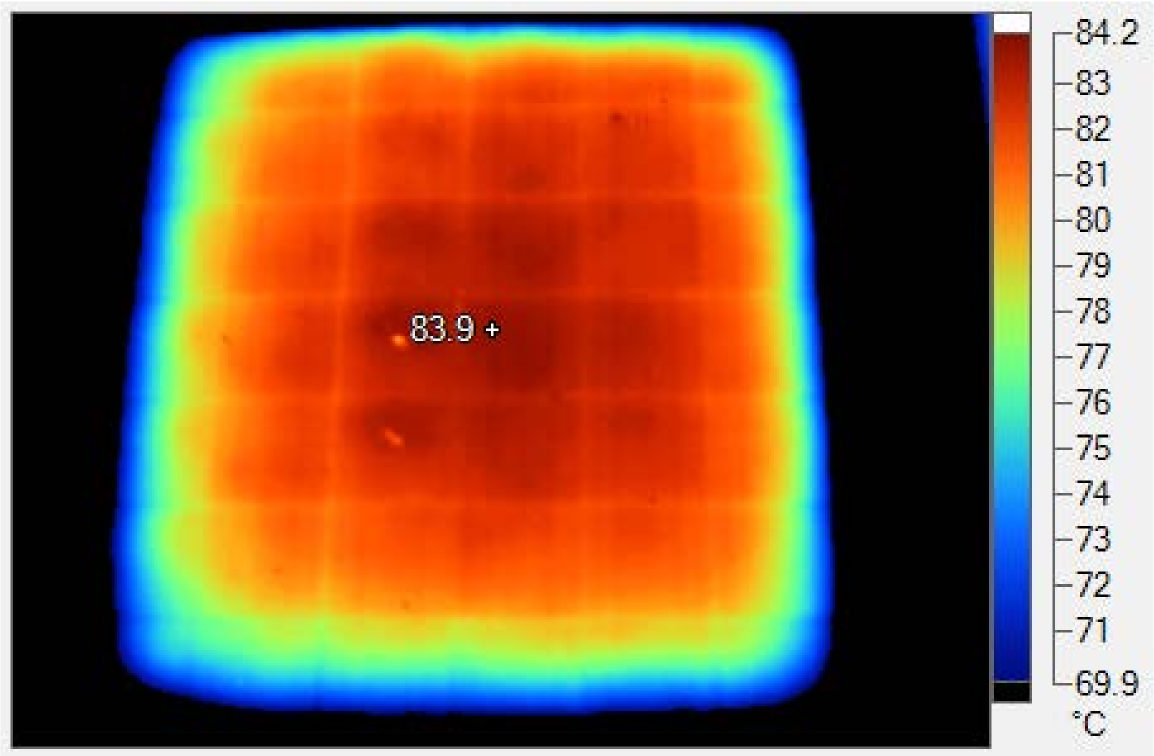
Temperature Non-Uniformity Decreases Creep





Up to a ~15^{o}C temperature variation was seen.

X-Si Modules Show Similar Thermal Gradients



Despite reaching very high temperatures around 102^{o}C, the module tabbing and backsheet were able to prevent large cell movements.

Strings were connected vertically, if it had been mounted with horizontal strings, cells in the center may have been more likely to move.

Conclusions

- Even without any peroxide for curing, NC-EVA, modules are not likely to creep significantly in most environments and mounting configurations.
- A Creep evaluation test should account for the possibility of polymer chain scission or cross-linking.
- Thermal non-uniformities dramatically reduce the propensity for creepage.

- The current proposal for IEC 61730 part 1, is to expose all modules for 200 h to a temperature between 100 and 110 ^{o}C.

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