BLACKOUT SHEET — PHASE 1 FIELD TEST PLAN

Irradiance Suppression Proof of Concept — Single Shorted Monofacial Module

Item	Detail
Document version	**V18 — October 24, 2026** (supersedes V17.1, October 23, 2026)
Aligned to	Phase 1 Field Trial Log v29 (web form, sunsafepv.com/r+d/trials.html) and v28 (paper). Box numbers [1]–[38] and Side 2 rows 1a–5a are identical in both; v29 adds the photo record and a second copy address.
Test module	Suniva OPT255-60-4-100 (monofacial, backsheet), single module, short-circuit configuration, ≤ 600 VDC. Scope: monofacial modules only; bifacial modules are untested (Section A.5.10).
Trials required	10 valid PASS trials minimum (void trials do not count). 7 completed: 3 on Aug 29 and 4 on Oct 22, 2026 — see Section 14.
Provisional patent	US 64/026,462, filed April 2, 2026 — Casey C. Schuyler
Applicable standards	NEC Article 690 (2023; the 2026 edition keeps the 690.12 limits) • NFPA 70E Articles 120 and 130; 2027 edition PV article (First Draft Article 390 text cited; the issued edition is reported to number it Article 380 — confirm) • IEC 61215-2:2016 • IEC 60904-3

Changes in V18 (no change to the procedure, gates or Side 2)

Scope: monofacial modules only. A front cover cannot suppress rear-side irradiance, so bifacial modules are untested and outside these results.

Section A.5.10 (new): how one trial's measured transmission scales to any monofacial module, with every step shown; largest monofacial module used: Trina Vertex TSM-DE21, Isc 18.62 A [22].

Section 14.5 (new): levels met. Gates stay at 7 W/m² and 125 mA; every trial also met 5 W/m² and 100 mA (the provisional application's levels) on the BT270 and both under-sheet meters, and 40 mA on the BT270.

Changes in V17.1 (no change to the procedure, gates or Side 2)

Sources: β Voc cited to the Suniva datasheet [18]; the 14.00 A large-module case to the Canadian Solar CS6W-585T datasheet [19]; statistics to NIST [20]. The 12 m/s wind limit and the 30% term of the Stage 3 (S3) tolerance are labeled as Sun Safe protocol choices with no published source.

OD by meter pair (Section 14): OD is also worked out from the AH-Sol pair for comparison (2.63–2.83, against DayStar ≥ 2.91–3.02). Scoring still uses the DayStar pair (row 3c).

Voc reduction: renamed from "Voc reduction." It is a measured byproduct, not a claim of voltage collapse; at very low light the cells' shunt resistance sets Voc [17].

40 mA: every Phase 1 result was below the NFPA 70E 2027 draft dc shock threshold. It stays a recorded value, not a Phase 1 gate.

Changes in V17

Video: recorded where available; a visible clock is optional. Video is supporting evidence, not a pass or void condition. Oct 22 filming was limited by practical difficulties (Section 14).

BT270 re-zero: after the short, the BT270 is taken off the conductor, zeroed and re-clamped before [31] (Section 8.4). Done on all seven trials; the Fluke and Seaward were not re-zeroed.

Section 8.5: disconnect with the sheet on; zero check and Voc read before the sheet is removed. Photo slots sit at the end of log sections 2, 3 and 4.

Isc: 8.71 A from the test unit's nameplate retained (Section A.5.1). **Section 14:** all seven trials and recorded deviations. **Section 14.4:** review items under consideration, not adopted.

IMPORTANT — READ BEFORE PROCEEDING

This test plan governs a controlled scientific trial on an intentionally shorted PV module operating at up to 600 VDC.

PV conductors remain energized by photocurrent whenever light reaches the module, regardless of inverter or disconnect status.

All NEC Article 690, NFPA 70E Articles 120 and 130, and site safety requirements remain in effect. This plan does not modify, replace or satisfy any code requirement. Qualified persons only.

SECTION A — PURPOSE AND TECHNICAL JUSTIFICATION

A.1 The Structural Gap — NFPA 70E 120.6 Electrically Safe Work Condition

NFPA 70E 120.6 sets an eight-step process for establishing an Electrically Safe Work Condition (ESWC) before a qualified person contacts a conductor.

#	Required step — NFPA 70E 120.6 (2024 edition)
1	Determine all possible sources of electrical supply to the specific equipment.
2	After properly interrupting the load current, open the disconnecting device(s) for each source.
3	Wherever possible, visually verify that all blades of disconnecting devices are fully open.
4	Release stored electrical energy.
5	Block or relieve stored nonelectrical energy.
6	Apply lockout/tagout devices in accordance with a documented and established procedure.
7	Use an adequately rated portable test instrument to test each conductor or circuit part for absence of voltage; verify the instrument on a known source before and after.
8	Where induced voltages or stored electrical energy may exist, ground the circuit conductors and parts before touching them.

WARNING — Steps 4 and 7 cannot be completed on an illuminated PV source circuit

Step 4: a PV module is an active current generator, not stored energy. No disconnect, rapid-shutdown device or LOTO device interrupts the light reaching the cells.

Step 7: a voltmeter across an illuminated module reads Voc. Under the Blackout Sheet in Phase 1, Voc fell from 34.6–36.8 V to 6.7–8.3 V per module ([12] → [35], Phase 1 trials with a baseline) — reduced, not zero. A long string still reads tens to hundreds of volts.

Conclusion: absence of voltage cannot be shown on an illuminated PV source circuit. The quantity the sheet controls is current, and current is what Stage 1 (S1) verifies.

A.2 Why Current — Not Voltage — Is the Operative Gate

In conventional circuits voltage and current collapse together when the source is disconnected. On a PV source circuit, voltage persists while light is present. Covering the module removes the light, and short-circuit current falls in proportion to irradiance [5]. Stage 1 (S1) therefore verifies collapse by current: an 8–9.5 A short must fall to the clamp meter's own floor.

Available power scales with current: at 125 mA and 1,500 VDC the source can deliver at most 187.5 W, against 13,500 W at 9 A. This is a statement about available energy only; the plan makes no claim that an arc cannot form below any particular current (see A.5.2).

A.3 Historical Precedent — Lineman Rubber Goods and ASTM D120

Background context, not part of the test protocol. The concept "insulate the hands" was obvious long before a standard defined glove classes, proof-test voltages and periodic retest. The concept "cover the modules with something opaque" is likewise obvious; what this program defines is a measured performance threshold (OD, under-sheet irradiance, current) and an instrument-verified pass criterion. Dates and figures for the lineman history are being re-sourced and are not repeated here; see the separate Lineman/PV Gap document.

A.4 Deployment Context

UL/FSRI documented the tarp problem in 2011 [1]. US PV capacity has grown many-fold since. Capacity figures will be cited to SEIA/Wood Mackenzie or EIA in the next revision; V14's unsourced year-by-year table is withdrawn.

A.5 Threshold Derivation — 125 mA, 40 mA, 7 W/m², 800 W/m², OD 2.3 / 2.5

All thresholds are inventor-defined test criteria, not NEC values. Each is traced to a measurement or a cited source.

A.5.1 Test Module Reference Data

Parameter	Value	Source / basis
Module	Suniva OPT255-60-4-100	Phase 1 test article
Isc at STC	8.71 A (8,710 mA)	Test-unit nameplate (verified Oct 2026)
Voc at STC	38.0 V	Test-unit nameplate
Pmax / Imp / Vmp	255 W / 8.21 A / 31.1 V	Test-unit nameplate
Cells in series	60	Suniva datasheet
β Voc	−0.335 %/°C × 38.0 V = −0.127 V/°C	Suniva Optimus datasheet SAMD_0016 Rev. 16 [18]
STC	1,000 W/m², 25 °C, AM1.5G	IEC 60904-3 [13]
UL 2011 tarp-test modules	8.11 A Isc, 37.08 V Voc (4 in series)	UL 2011 §9.1.2 [1]

Isc constant — resolved for Phase 1

Side 2 keeps 8.71 A, the value on the test unit's own nameplate (serial SJWSH00011106130567; photo at sunsafepv.com/r+d/docs/Suniva-OPT255-test-module-nameplate.jpg). The Suniva datasheet lists 9.05 A for this model. Baseline shorted current normalized to 1,000 W/m² gives about 9.0–9.5 A across the seven trials. Using 8.71 A makes 4a read slightly high, which is conservative; no pass/fail outcome changes.

A.5.2 Why 125 mA Is the Current Threshold

- **Measurement-noise gate (basis).** On a DC clamp meter reading in amps, 0.10 A is noise, 0.11 A (110 mA) still passes and 0.13 A fails. A pass shows that an 8–9.5 A short has collapsed to the meter's own floor — an unambiguous reading, not a value inside the instrument's uncertainty.
- **Read against each meter's zero.** A correctly zeroed Fluke 393 reads 0–100 mA at true zero; 200 mA indicates a zeroing error. The zero check [32]–[34], taken after disconnecting with the sheet still on, is recorded on every trial so each clamp's floor is documented.
- **Re-zero after the short.** A dc clamp's jaw stays slightly magnetised after carrying amps, so its zero shifts (the BT270 read −31 mA after a 9 A short collapsed). The BT270 is re-zeroed off the conductor before [31]; [34] then shows how well that zero held.
- **Decisive clamp.** Near zero, the Fluke 393 (±0.5 A class) and Seaward clamp (±0.2 A class) cannot resolve 125 mA on their own. The AUTOOL BT270 (1 mA resolution) is the clamp that resolves the gate.
- **What 125 mA is not.** It is not an arc limit and not a shock limit. Minimum arc current is material-specific (carbon contacts 10–30 mA) and intermittent arcing has been reported below traditional minimums [11]. PPE is required at all times.

A.5.3 Why 40 mA Is Recorded (Shock Reference Tier)

- NFPA 70E 2027 First Draft, FR-102, proposed 390.2(2): dc electric-shock hazard threshold "100 volts and 40 milliamperes" [7]. The 2027 edition has since been issued and its PV article is reported as Article 380; confirm the section number in the issued edition.
- UL 2011 body-current bands (PDF p. 23) [1]: 0–2 mA Safe • 2.1–40 mA Perception • 40.1–240 mA Lock On • > 240 mA Electrocution.
- A source cannot drive more current through a person than its short-circuit current. A BT270 reading under 40 mA therefore bounds any body current under 40 mA. Recorded on every trial (row 2c-2); not part of the Stage 1 (S1) pass.

A.5.4 Why 7 W/m² and 800 W/m²

7 W/m² keeps every in-scope module under 125 mA and sits above the noise floor of the field irradiance meters (~2–5 W/m²). Check: CS6W-585T at 14.00 A [19] → 14.00 × 7 ÷ 1,000 = 98 mA; Suniva at 8.71 A → 61.0 mA. 7 W/m² was chosen over 5 W/m² because some photodiode meters approach their noise floor near 5 W/m².

800 W/m² is the reference irradiance for nominal module operating temperature (NMOT: 800 W/m², 20 °C ambient, 1 m/s wind), IEC 61215-2:2016 §4.5, p. 13 [12]. Ambient references DayStar #1 [26] and AH-Sol #1 [27] must read ≥ 800 W/m² with the sheet deployed, or the trial is VOID, not FAIL.

A.5.5 Linear Irradiance-to-Current Model

Isc(G) = Isc_STC × G ÷ 1,000 — King, Boyson & Kratochvil, Sandia SAND2004-3535, pp. 9–12, Eqs. (1), (3), (7), Figs. 3–4 [5]. Used for row 4a: G_I = [31] × 1,000 ÷ 8,710. BT270 resolution 1 mA ≈ 0.115 W/m².

A.5.6 Optical Density (Beer-Lambert)

T = G_under ÷ G_ambient • OD = $-\log_{10}(T)$ • T = 10^(−OD) [13]. Required OD for the 7 W/m² criterion: OD_req = $-\log_{10}(7 \div G_{ambient})$. At the 1,400 W/m² design basis OD_req = 2.301.

Note on "OD 2.3"

OD 2.3 is 2.301 rounded down. A sheet at exactly OD 2.300 passes 7.02 W/m² at 1,400 W/m² and reaches 7 W/m² at 1,397 W/m². State the minimum as OD ≥ 2.3 (2.301 at the design basis), or treat 1,400 W/m² as AT LIMIT. Phase 1 measured OD is ≥ 2.92, so results are unaffected.

A.5.7 Required OD as a Function of Ambient Irradiance

Ambient G (W/m²)	Source	T = 7 ÷ G	OD required
1,000	STC, IEC 60904-3 [13]	7.00e-3	2.155
1,250	1.25 × STC (the NEC 690.8(A)(1) current multiplier, shown for comparison only)	5.60e-3	2.252
1,400	Design basis: UL 2011, "can approach 1400 W/m²", PDF p. 56 [1]	5.00e-3	2.301
1,466	San Diego, CA — Lappalainen & Kleissl 2020 [2]	4.77e-3	2.321
1,528	Norway — Yordanov et al. 2013 [3]	4.58e-3	2.339
1,832	Andes, 3,400 m — Emck & Richter 2008, p. 2828 [4]	3.82e-3	2.418
2,214	OD 2.5 limit for 7 W/m²	3.16e-3	2.500

The irradiance peaks above are reported cloud-enhancement measurements, not absolute maxima. OD 2.5 holds 7 W/m² to about 2,214 W/m².

A.5.8 Verification Table — Both Thresholds

Ambient	OD	G under (W/m²)	Suniva 8.71 A (mA)	CS6W 14.00 A (mA)	vs 7 W/m²	CS6W vs 125 mA
800 (Test floor)	2.3	4.01	34.9	56.1	PASS	PASS
800 (Test floor)	2.5	2.53	22.0	35.4	PASS	PASS
1,000 (STC)	2.3	5.01	43.7	70.2	PASS	PASS
1,000 (STC)	2.5	3.16	27.5	44.3	PASS	PASS
1,400 (Design basis)	2.3	7.02	61.1	98.2	AT LIMIT	PASS
1,400 (Design basis)	2.5	4.43	38.6	62.0	PASS	PASS
1,466 (San Diego)	2.3	7.35	64.0	102.9	FAIL	PASS
1,466 (San Diego)	2.5	4.64	40.4	64.9	PASS	PASS
1,528 (Norway)	2.3	7.66	66.7	107.2	FAIL	PASS
1,528 (Norway)	2.5	4.83	42.1	67.6	PASS	PASS
1,832 (Andes)	2.3	9.18	80.0	128.5	FAIL	FAIL
1,832 (Andes)	2.5	5.79	50.5	81.1	PASS	PASS

A.5.9 Ceilings

	7 W/m² reached at	125 mA reached at (CS6W, 14.00 A)	125 mA reached at (Suniva, 8.71 A)
OD 2.3	1,397 W/m²	1,781 W/m²	2,863 W/m²
OD 2.5	2,214 W/m²	2,823 W/m²	4,538 W/m²

A.5.10 Scaling to Any Monofacial Module

Monofacial only

The sheet blocks light from the front. A bifacial module also collects rear-side light, which a front cover cannot suppress. Bifacial modules are untested; every module used in this section has an opaque backsheet.

Step 1 — what the sheet lets through. The trial measures the sheet on the 8.71 A test module: light under the sheet G_under = [31] ÷ 8.71 (W/m², row 4a), and transmission T = G_under ÷ [26]. The 8.71 is used only to read the sheet; it is never applied to another module. Trial 005: 11 ÷ 8.71 = 1.263 W/m²; T = 1.263 ÷ 847 = 0.00149.

Step 2 — the same sheet on another monofacial module. Short-circuit current is proportional to irradiance [5] and a passive cover passes a fixed fraction (Beer-Lambert [13]), so I (mA) = Isc (A) × T × G_sun (W/m²), using the other module's datasheet Isc. Trial 005 on an 18.62 A module at 1,400 W/m²: 18.62 × 0.00149 × 1,400 = 38.9 mA.

Step 3 — sun level that reaches a limit. G_sun for 5 W/m² under the sheet = 5 ÷ T; G_sun for 40 mA = 40 ÷ (Isc × T).

Trial	[31] mA	Ambient [26]	G_under W/m²	T	OD	Sun for 5 W/m²	Sun for 40 mA, 14.00 A [19]	Sun for 40 mA, 18.62 A [22]
1	7 (5–7)	1,041	0.80	0.00077	3.11	6,477	3,701	2,783
2	8	1,020	0.92	0.00090	3.05	5,553	3,173	2,386
3	2	836	0.23	0.00027	3.56	18,204	10,402	7,821
004	7	890	0.80	0.00090	3.04	5,537	3,164	2,379
005	11	847	1.26	0.00149	2.83	3,353	1,916	1,441
006	8	816	0.92	0.00113	2.95	4,442	2,538	1,909
007	4	818	0.46	0.00056	3.25	8,906	5,089	3,826

Compare: 1,400 W/m² design day [1]; 1,466–1,528 W/m² measured cloud-edge peaks [2] [3]; 1,832 W/m² highest in the cited literature [4].

Requirement	Worked out at the 1,400 W/m² design day
5 W/m² under the sheet	5 ÷ 1,400 = 0.00357 → OD = $-\log_{10}(0.00357) = 2.45$
100 mA	18.62 A × 5 W/m² = 93.1 mA on the largest monofacial module used; 14.00 A × 5 = 70.0 mA
40 mA	40 ÷ 18.62 = 2.15 W/m² under the sheet → 2.15 ÷ 1,400 = 0.00153 → OD 2.81
Worst trial (005)	T = 0.00149 → OD 2.83; 40 mA on 18.62 A reached at 1,441 W/m², just above the design day

Sun, light under the sheet and module current describe one requirement three ways: 1,400 W/m², 5 W/m² and 100 mA on the largest monofacial module agree within about 7%. The worst trial sits at the next level, 40 mA on that module at the design day, with no margin to spare.

- Transmission is assumed constant at any sun level; Phase 1 tested to 1,055 W/m² only.
- Cell types respond slightly differently to the filtered light under the sheet; not measured here.

- Trial 005's 11 mA is on a clamp good to about ±5 mA (Section 14.3), so 1,441 W/m² could fall either side of the design day.
- Largest monofacial module used: Trina Vertex TSM-DE21, 650–670 W, white backsheet, Isc 18.44–18.62 A at STC (670 W: 18.62 A) [22]. The CS6W-585T backsheet construction is to be confirmed from its datasheet [19].

A.6 What Phase 1 Establishes

- That the sheet collapses short-circuit current on a shorted monofacial module to < 125 mA on all three clamps under ambient ≥ 800 W/m² (Stage 1, S1; the Fluke may instead read at or below its own zero [32]).
- That under-sheet irradiance is < 7 W/m² on two meters of two technologies and OD ≥ 2.3 on the matched DayStar pair (Stage 2, S2).
- That light inferred from current (BT270) agrees with the under-sheet DayStar within tolerance (Stage 3, S3).
- Mean, SD and CV of OD, BT270 current, Voc reduction and the 4b gap across ≥ 10 valid trials (Section 11).

A.7 Data Record

- **Primary record:** Trial Log v29 on the web form, or v28 on paper (same boxes). Readings are entered at the time of measurement; the web form timestamps each box.
- **Side 2:** computed on the web form with the same formulas and criteria as the paper Side 2 (Section 8.6). Paper logs are worked by hand.
- **Output:** a searchable PDF per trial: Side 1, Side 2, and a page 3 photo record when condition photos were taken. It carries technician and supervisor signatures and photos, is emailed to Sun Safe and up to two more addresses, and is saved to the device archive.
- **Photos:** three condition photos (sky, instruments shorted, instruments with the sheet on) and two portraits (technician, supervisor/witness), each with its capture time. Instrument photos are kept at 1,280 px on the long side so meter displays stay readable; they are stored in the device photo store and included in archive backups.
- **Historical trials:** paper originals are transcribed into the archive; values are locked and only comments can be edited.
- **Video:** recorded where available, file ID in [3]; a visible clock is optional. Video is supporting evidence, not a pass condition. Where video exists, readings are cross-checked against it; a discrepancy over ±5% is flagged in [38] and the trial reviewed.
- **Analysis:** the Results page computes summary statistics from the archive and exports every box and Side 2 result as CSV.

1. Purpose and Scientific Framework

1.1 Objective

Establish, under controlled and documented conditions, that the Blackout Sheet collapses short-circuit current on a single shorted monofacial module to the clamp meter floor in full sun, with independent optical and current-derived confirmation.

1.2 Hypotheses — SC-1

Null and alternative hypotheses

H_0: deployment of the sheet does not reduce module current below 125 mA or under-sheet irradiance below 7 W/m² under ambient ≥ 800 W/m².

H_1: deployment reduces current to < 125 mA and under-sheet irradiance to < 7 W/m² under ambient ≥ 800 W/m².

A PASS requires instrument-verified evidence against H_0 on every trial. Trials where a controlled variable cannot be confirmed are VOID, not FAIL.

1.3 Scientific Method Framework

Requirement	Protocol element
Controlled conditions	Fixed module, fixed short, ambient floor, wind limit, dry modules — Section 2

Requirement	Protocol element
Independent variable	Sheet deployment only
Dependent variables	Current on three clamps; under-sheet irradiance on two meters; OD; current-derived irradiance (BT270); Voc reduction (record)
Measurement independence	Three clamps of three makes; five irradiance meters of two technologies (three ambient, two under-sheet); current-derived irradiance channel
Reproducibility	10-trial minimum; identical sequence; standardized log; video where available
Convergent validation	Stage 3 (S3): optical and electrical paths agree within tolerance — SC-6
Statistics	Mean, SD, CV at Phase 1 completion — SC-9

1.4 Verification Hierarchy and Pass Criteria

STAGE 1 — CURRENT (PRIMARY, BINDING)

Fluke 393 [24], Seaward clamp [25] and BT270 [31] each < 125 mA with the sheet deployed. Fluke exception: a reading at or below its own open-string zero [32] is meter floor, not current. Single- or dual-clamp pass is not valid. Recorded tier: BT270 < 40 mA (row 2c-2).

STAGE 2 — LIGHT

DayStar #2 [29] < 7 W/m² AND AH-Sol #2 [30] < 7 W/m² AND OD = $-\log_{10}([29] \div [26]) \geq 2.3$ (target 2.5). Validity: DayStar #1 [26] and AH-Sol #1 [27] each ≥ 800 W/m², else VOID.

STAGE 3 — AGREEMENT

G_I = [31] × 1,000 ÷ 8,710 (row 4a). PASS when |G_I − [29]| ≤ the larger of 2.0 W/m² or 0.30 × [29] (row 4b). The 2.0 W/m² term follows the DayStar's 1 W/m² resolution; the 30% term is a Sun Safe protocol choice with no published source.

Voc reduction (row 5a) is recorded, not a pass criterion.

The 12 m/s wind limit is a Sun Safe protocol choice, set before testing; no published source.

Overall F: VOID if 1a or 1b fails, wind [10] > 12 m/s, or the protocol-void box is marked; otherwise PASS when Stage 1 (S1), Stage 2 (S2) and Stage 3 (S3) all pass, FAIL if any stage fails.

2. Controlled and Measured Variables — SC-2

Variable	Status	Control / measurement
Module identity	Controlled	Same Suniva OPT255 unit every trial
Tilt and azimuth	Controlled / recorded	Set on the day for best plane-of-array irradiance; recorded every trial [4] [5]
Short circuit	Controlled	MC4 jumper at the module leads; confirmed by baseline current [16] [17] [23]
Sheet	Controlled / recorded	Same prototype unit; unit [6] and condition [7] recorded every trial
Deployment	Controlled	Lateral advance, zero point-load, white up, black down
Under-sheet meter positions	Controlled	Marked positions on the module glass
Stabilization	Controlled	10 s minimum after full coverage
Ambient irradiance	Measured	DayStar #1, AH-Sol #1, Seaward 200R at plane of array, never moved
Wind	Measured	Maximum gust [10]; VOID above 12 m/s

Variable	Status	Control / measurement
Module dryness	Recorded	[11] Yes/No
Temperatures	Measured	Seaward 200R cell and air at baseline [15] and at Voc [36] [37]
Time	Recorded	Start [8] and end [9]
Video	Where available	File ID [3]; visible clock optional
Photos	Recorded	Sky, instruments shorted, instruments with sheet on; technician and witness portraits — each with capture time

3. Electrical Safety Requirements

3.1 Personnel

Qualified persons only (NEC Article 100, NFPA 70E Article 100). Two-person team. Supervisor signs the log; record “NA” and the reason in [38] if no supervisor was present.

3.2 Required PPE — NFPA 70E Article 130

PPE item	Requirement
Arc flash PPE	Per the site arc flash risk assessment for a 600 VDC PV circuit
Insulated gloves	Class 00 minimum at ≤ 600 VDC (ASTM D120 Class 00: 750 V dc max use); leather protectors
Face shield / hood	Arc-rated for the assessed incident energy
Arc-rated clothing	Per the risk assessment
Footwear	Dielectric-rated where required by the site PPE program

4. Instruments — SC-4 / SC-5

Each instrument carries a colored tape that matches the Trial Log tape key. Datasheet links are on the web form Tools tab and the R&D Method page.

4.1 Current — Stage 1 (S1)

Tape	Instrument	Rating	Role	Boxes
Blue	Fluke 393 FC	CAT III 1500 V dc	Clamp 1. Zero floor 0–100 mA when correctly zeroed	[16] [24] [32]
Green	Seaward Solar Power Clamp	CAT III 1000 V dc	Clamp 2, different make	[17] [25] [33]
Brown	AUTOOL BT270	CAT III 600 V	Clamp 3, 1 mA resolution — resolves the gate; row 2c-2 and 4a	[23] [31] [34]

4.2 Irradiance — Stage 2 (S2)

Tape	Instrument	Technology	Position	Boxes
Yellow	DayStar DS-05A #1	Si reference cell	Ambient, never moved	[13] [18] [26]
Orange	AquaHorti AH-SOL #1	Si photodiode	Ambient, never moved	[14] [19] [27]
Purple	Seaward Solar Survey 200R	Si reference cell + temperature probes	Ambient, never moved; cell and air temperature	[15] [20] [28] [36] [37]
White	DayStar DS-05A #2	Si reference cell	Module face, then under the sheet; matched to #1 for OD	[21] [29]

Tape	Instrument	Technology	Position	Boxes
Red	AquaHorti AH-SOL #2	Si photodiode	Module face, then under the sheet	[22] [30]

4.3 Voltage, Wind and Other Equipment

Item	Purpose
Rated multimeter	Voc baseline [12] and Voc under the sheet [35]
Aiomest AI-881M anemometer	Maximum gust [10]; VOID above 12 m/s
Inclinometer and compass	Tilt [4] and azimuth [5]
Video camera on tripod (GoPro, phone or glasses)	Video where available; file ID [3]; visible clock optional
Adjustable ground mount, 30–60°	Test module and adjacent control module
Suniva control module	Electrically isolated mount for the three ambient meters
Blackout Sheet prototype, paracord, weighted leaders	Test article and edge tensioning

5. Zeroing and Daily Instrument Verification — SC-4

5.1 Clamp Zeroing — every test day

Step 01 Jaws closed, no conductor inside: Fluke 393, Seaward clamp, BT270.

Step 02 Press ZERO / auto-zero on each.

Step 03 Confirm the zero: Seaward 0.00 A, BT270 0 mA, Fluke 0–100 mA. A Fluke reading of 200 mA is a zeroing error — re-zero. Remove any clamp that cannot reach its zero.

5.2 Irradiance Meter Zeroing — every test day

Step 01 Power on all five meters; allow 30–60 s warm-up.

Step 02 Cover each sensor completely.

Step 03 Confirm 0 W/m² (±2–3 W/m²) on each; re-zero if outside.

5.3 Daily Cross-Check — every test day

Step 01 Record instrument serial numbers on the daily verification sheet (one per test day).

Step 02 Point all five irradiance meters at the same plane-of-array location at the same time.

Step 03 Record readings. Tolerance ±5–8% between any two meters; over 8% suspends testing until resolved.

Step 04 Record wind, module temperature and time.

6. Electrical Isolation

6.1 Phase 1 test circuit

The Phase 1 circuit is one module, shorted at its own MC4 leads, not connected to any inverter, combiner or other module. There is no fuse to extract and no other source to isolate. Confirm before every test day that the test module is disconnected from all other equipment and that the control module is electrically isolated.

6.2 Field deployment reference (not performed in Phase 1)

Step	Action	Code basis
1	Initiate rapid shutdown via the listed initiation device; confirm it has occurred	NEC 690.12
2	Open inverter ac and dc disconnects	NEC 690.15
3	At the combiner, isolate all strings other than the affected string; do not expose energized busbars	NEC 690.15

Step	Action	Code basis
4	Apply LOTO to all opened disconnects per the written energy control procedure	NFPA 70E Article 120
5	Deploy the sheet; confirm Stage 1 (S1) before any fuse or conductor work; then extract the affected string fuse with PPE	—

7. Test Setup

Step 01 Confirm PPE per Section 3.2.

Step 02 Confirm daily verification (Section 5) is complete.

Step 03 Confirm wind < 12 m/s and modules dry.

Step 04 Confirm ambient ≥ 800 W/m² on DayStar #1, AH-Sol #1 and Seaward 200R.

Step 05 Start video if available (a visible clock is optional). If there is no video, note it in [38]; it does not void the trial.

Step 06 Confirm sheet orientation: white side up, black side down. Same sheet every trial.

7.1 Racking

- Test module and control module on the adjustable carbon-steel ground mount (30–60° tilt), same plane of array.
- Tilt and azimuth set on the day and held for every trial that day; recorded in [4] and [5].
- Ambient meters mounted on the control module and never moved during a trial.

8. Trial Execution — Repeat for 10 Valid Trials

Each trial follows this sequence, which matches the Trial Log sections. A deviation is recorded in [38]; if it affects a controlled variable, mark the protocol-void box.

8.1 Log section 1 — Trial identification

Step 01 Record Trial # [1] (any whole number), date [2], video file ID [3], tilt [4], azimuth [5], sheet unit [6] and sheet condition [7].

8.2 Log section 2 — Conditions (before the short and sheet)

Step 02 Record start time [8] and maximum wind gust [10]; confirm modules dry [11].

Step 03 With the module open-circuit, measure Voc baseline [12].

Step 04 Record ambient on DayStar #1 [13], AH-Sol #1 [14] and Seaward 200R [15], with cell and air temperature. Each should read ≥ 800 W/m²; the log flags any that do not.

Step 05 **Photo 1 — sky / sun:** photograph the sky toward the sun and the array to document conditions (photo slot at the end of log section 2).

8.3 Log section 3 — Baseline, shorted, no sheet (SC-3)

Step 06 Install the MC4 jumper. Clamp the Fluke, Seaward and BT270 on the shorted conductor; they stay on for the whole trial.

Step 07 Record shorted current on all three clamps: Fluke [16], Seaward [17], BT270 [23] (amps). Expected ≈ 8.71 × G ÷ 1,000 (7.0–8.7 A at 800–1,000 W/m²); measured 7.8–9.5 A in Trials 1–3. Near zero — stop and investigate.

Step 08 Record irradiance on all five meters: ambient [18] [19] [20], module face [21] [22].

Step 09 **Photo 2 — instruments, module shorted, no sheet:** photograph the instrument board so the clamp and meter displays are readable (photo slot at the end of log section 3).

8.4 Log section 4 — Sheet deployed (Stages 1 and 2 data)

Step 10 Deploy the sheet laterally, zero point-load, white up. Tension edges; weighted leaders on free edges; 250 mm standoff beyond the frame.

Step 11 Wait 10 s.

Step 12 Slide DayStar #2 and AH-Sol #2 under the sheet edge to their marked positions, sensors flat on the glass.

Step 13 Re-zero the BT270: take it off the conductor, zero it away from the wire, and clamp it back on. After carrying the 8–9.5 A short its jaw holds a residual offset (−31 mA observed). The Fluke and Seaward are not re-zeroed here.

Step 14 Record simultaneously: Fluke [24] and Seaward [25] (amps), ambient [26] [27] [28], under-sheet [29] [30], BT270 [31] (mA). If a meter fluctuates, record the range (e.g. 5–7); Side 2 scores the higher value.

Step 15 **Photo 3 — instruments, module shorted, sheet on:** photograph the instrument board with the sheet deployed, displays readable (photo slot at the end of log section 4).

8.5 Log section 5 — Disconnect, sheet on: meter zero check and Voc

Step 16 Disconnect: with the sheet on and current collapsed below the gate, remove the MC4 jumper. This is the safe disconnection the sheet is for. The sheet and clamps stay in place for every reading in this section.

Step 17 Meter zero check: record each clamp on the disconnected conductor, a known 0 A: Fluke [32], Seaward [33] (amps), BT270 [34] (mA). Each reading is that meter's offset, the floor its Section 4 reading is judged against. Fluke 200 mA = re-zero before the next trial; note in [38].

Step 18 Measure Voc under the sheet [35] with cell [36] and air [37] temperature from the Seaward 200R.

Step 19 Remove the sheet once all section 5 readings are recorded.

Step 20 Record end time [9]. Record observations, anomalies and any VOID reason in [38].

Step 21 Work Side 2 (Section 8.6). Copy the overall result to Side 1; technician and supervisor sign and date, and take the technician and supervisor/witness photos.

Step 22 Complete the trial in the log and email the PDF (up to two copy addresses).

Step 23 Before the next trial, re-install the jumper and confirm current returns on all three clamps.

8.6 Side 2 — Analysis Row by Row

Row	Check	Formula / input	Criterion
1a	DayStar #1 ambient, sheet on	[26]	≥ 800 W/m², else VOID
1b	AH-Sol #1 ambient, sheet on	[27]	≥ 800 W/m², else VOID
2a	Fluke, sheet on	[24] × 1,000 vs [32] × 1,000	< 125 mA, or ≤ its own zero [32]
2b	Seaward clamp, sheet on	[25] × 1,000	< 125 mA
2c	BT270, sheet on	[31]	< 125 mA
2c-2	BT270 shock tier (record)	[31]	< 40 mA — recorded, not in S1
2d	Meter zero check (record)	[32] [33] [34]	each < 125 mA; Fluke 200 = re-zero
S1	Stage 1 (S1)	2a, 2b, 2c	all three PASS
3a	DayStar #2 under sheet	[29]	< 7 W/m²
3b	AH-Sol #2 under sheet	[30]	< 7 W/m²
3c	Optical density	R = [29] ÷ [26]; OD = $-\log_{10}(R)$. If [29] = 0, use 1 and report "≥"	≥ 2.3 (target 2.5)
S2	Stage 2 (S2)	3a, 3b, 3c	all three PASS
4a	Light from current (record)	[31] × 1,000 ÷ 8,710	W/m²
4b	Agreement with DayStar #2	|4a − [29]|	≤ max(2.0 W/m², 0.30 × [29])
S3	Stage 3 (S3)	4b	PASS
5a	Voc reduction (record)	(1 − [35] ÷ [12]) × 100	% — not a pass criterion
F	Overall	VOID first (1a/1b fail, wind > 12 m/s, protocol void); then Stage 1 (S1) + Stage 2 (S2) + Stage 3 (S3)	PASS / FAIL / VOID

Notes the log adds without changing F: pre-sheet ambient [13]/[14] under 800 W/m²; modules not dry; 2d over 125 mA; OD between 2.3 and 2.5; protocol void marked with no reason in [38].

No voltage-collapse claim

Voc under the sheet is recorded as evidence of effect, not as a safety indicator. The single-diode model predicts Voc falling about 3.5 V per tenfold drop in light (60 × 0.025693 V × ln 10); at very low light shunt losses dominate and Voc falls much further. Phase 1 measured 6.7–8.3 V under the sheet against 34.6–36.8 V baselines.

9. Void Trial Criteria — SC-7

Void condition	How it is recorded
Ambient [26] or [27] < 800 W/m² with the sheet deployed	Automatic — rows 1a/1b
Wind gust [10] > 12 m/s	Automatic
Baseline current not confirmed on all three clamps	Protocol-void box + reason in [38]
Baseline irradiance not confirmed on all five meters	Protocol-void box + reason
Instrument outside its rated range	Protocol-void box + reason
Video fails or not recorded	Note in [38]; not a void condition
Sheet displaced or coverage lost before readings	Protocol-void box + reason
Daily cross-check deviation > 8% unresolved	No trials that day

10. Expected Results — Suniva OPT255-60-4-100

Measurement	Expected	Pass threshold	Instrument
Baseline shorted current	≈ 8.71 × G ÷ 1,000 A	Not near zero	All three clamps
Clamps, sheet on	floor	< 125 mA each (Fluke ≤ its zero)	Fluke, Seaward, BT270
BT270 shock tier	< 40 mA	Recorded	BT270
Under-sheet irradiance	< 7 W/m²	< 7 W/m² each	DayStar #2, AH-Sol #2
Ambient	≥ 800 W/m²	≥ 800 W/m², else VOID	DayStar #1, AH-Sol #1
OD	≥ 2.5 target	≥ 2.3	DayStar pair
Theoretical Isc at 7 W/m²	61.0 mA	—	Sandia model
4b gap	small	≤ max(2.0, 0.30 × [29]) W/m²	BT270 + DayStar #2
Voc under sheet	well below baseline (measured 6.7–8.3 V)	Recorded	Multimeter

11. Statistical Summary at Phase 1 Completion — SC-9

Computed on the Results page from the selected trials (sample SD, n − 1).

Statistic	Measure	Target / use
n, mean, SD, CV, min, max	BT270 current, sheet on [31]	All < 125 mA; report share < 40 mA
n, mean, SD, CV, min, max	OD (row 3c) — values marked “≥” are lower bounds	Mean ≥ 2.3; CV < 15%
n, mean, SD, CV, min, max	Voc reduction (row 5a)	Record
n, mean, SD, CV, min, max	4b gap	Record

Statistic	Measure	Target / use
Rate	Stage 3 (S3) agreement	Target 100%
Max	Under-sheet irradiance [29] [30]	Document worst case

Resolution limit: DayStar #2 resolves 1 W/m², so at ~1,000 W/m² ambient the largest measurable OD is ≈ 3.0. OD results at that limit are lower bounds.

12. Phase 1 Completion Criteria

- ☐ 10 trials recorded as PASS (void trials do not count)
- ☐ Video file IDs logged in [3] where recorded
- ☐ Baseline confirmed on each passing trial — SC-3
- ☐ Stage 1 (S1), Stage 2 (S2) and Stage 3 (S3) PASS on each passing trial
- ☐ OD and Voc reduction logged on each trial; 2c-2 tier logged
- ☐ Readings cross-checked against video where available
- ☐ Statistical summary per Section 11
- ☐ Tilt and azimuth held constant within each test day

13. Comparative Prior Art Performance Testing

13.1 Purpose

Instrument-verified comparison of the Blackout Sheet with four commercially available cover materials of the classes UL tested in 2011 [1] §9.1, Table 17. UL recorded voltage and current under each tarp but no under-tarp irradiance; this protocol adds OD and under-sheet irradiance using the same Trial Log.

13.2 Materials

Material	Vendor	Price	Purchased	FR status	UL 2011 analog
4-mil black polyethylene	Amazon	$15.00	4/13/2026	Not FR	Tarp #1 — 0 A, Safe
Green fire salvage canvas (brass grommets)	Amazon	$45.00	4/13/2026	FR rated	Tarp #3 — 0 A, Safe
5-mil blue all-purpose poly	Amazon	$8.99	4/13/2026	Not FR	Tarp #2 — 2.1 A / 126 V
18 oz FR vinyl, grey (brass grommets)	Tarps4All	$56.00	4/13/2026	FR certified	Tarp #4 (red vinyl) — 1.8 A / 124 V
Blackout Sheet (positive control)	Sun Safe LLC	—	—	FR target	—

13.3 Protocol

- Identical to Sections 5–8, on the same Trial Log, minimum 3 valid trials per material, on separate test days from Blackout Sheet trials.
- Record in [38]: deployment method (flat, draped, tensioned), full coverage achieved (yes/no), movement during the 10 s stabilization (yes/no), grommet material, FR certification, weight.
- A material that cannot hold coverage for 10 s is recorded as a deployment failure, separate from an optical failure.
- Every result is reported as measured, including any comparison material that meets the current and OD thresholds.

14. Phase 1 Results to Date

Seven valid trials, Rutland, VT; prototype unit 004; Suniva OPT255-60-4-100. Aug 29, 2026: trials 1–3, paper originals transcribed to Trial Log v28 on Oct 19–20 (no photo record). Oct 22, 2026: trials 004–007 on the web log

(v29) with photo record, witnessed and signed on site by Mark Foote, EMS Coordinator / Fire Captain, Killington Fire & Rescue. All trials are locked in the published archive.

Trial	Ambient [26] / [27]	Under sheet [29] / [30]	Shorted (max clamp) → BT270 [31]	2a Fluke	OD	4a / 4b gap	Voc [12] → [35]	F
1 (Aug 29)	1,041 / 1,055	0 / 2.4	9.5 A → 5–7 mA (scored 7)	200 mA ≤ zero 200	≥ 3.02	0.80 / 0.80	— → 7.6 V	PASS
2	1,020 / 1,043	0 / 2.4	9.3 A → 8 mA	0 mA	≥ 3.01	0.92 / 0.92	34.7 → 7.8 V (77.5%)	PASS
3	836 / 897	1 / 1.8	8.1 A → 2 mA	100 mA	2.92	0.23 / 0.77	34.6 → 6.7 V (80.6%)	PASS
004 (Oct 22)	890 / 923	0 / 1.5	8.2 A → 7 mA	0 mA	≥ 2.95	0.80 / 0.80	35.3 → 7.9 V (77.6%)	PASS
005	847 / 890	0 / 2.1	8.0 A → 11 mA	0 mA	≥ 2.93	1.26 / 1.26	35.4 → 8.1 V (77.1%)	PASS
006	816 / 869	0 / 1.3	7.8 A → 8 mA	0 mA	≥ 2.91	0.92 / 0.92	35.9 → 7.8 V (78.3%)	PASS
007	818 / 851	0 / 1.8	7.8 A → 4 mA	0 mA	≥ 2.91	0.46 / 0.46	36.8 → 8.3 V (77.4%)	PASS

Summary (n = 7): BT270 sheet-on mean 6.7 mA, SD 2.9, range 2–11 mA — all under both 125 mA and 40 mA. OD by meter pair: DayStar ≥ 2.91–3.02 (lower bounds; with the meter reading 0 the OD reflects the ambient level) and AH-Sol 2.63–2.83 (actual values; the more conservative pair). Every trial is above the 2.3 minimum and the 2.5 target on both. Every result was also below 40 mA, the NFPA 70E 2027 draft dc shock threshold [7], which is recorded, not a Phase 1 gate. Voc reduction 77.1–80.6%, mean 78.1% (n = 6; trial 1 has no Voc baseline): a drop this size occurs only at very low light, where the cells' shunt resistance sets the voltage [17], so it independently supports the light and current readings. 4b gap 0.46–1.26 W/m². Three valid trials remain for Phase 1 completion.

14.1 Trial notes

- Trial 1: BT270 read 5 mA on the open conductor (net 2 mA); Fluke read 200 mA on the open conductor (zeroing). Trial 2: BT270 fluctuated 4–8 mA; 8 recorded. Trial 3: ambient 836 W/m².
- Oct 22: the first trial was recorded as #1 and is published as 004, when the 00x numbering was adopted that day. Trials 006 and 007 ran at 816–818 W/m², just above the 800 floor.

14.2 Recorded deviations

None of these changes a result; each is recorded so the record is complete.

- **Video:** Aug 29 recorded on iPhone and Meta glasses, no file IDs logged. Oct 22 filming was limited by practical difficulties: partial video of trial 005 only (Meta glasses clips 5163, 14:03–14:04, and 5155, 14:10–14:11); none for 004, 006 and 007. Under V17 this is not a void condition.
- **BT270 re-zero:** done on all seven trials before [31]; the Fluke and Seaward were not re-zeroed.
- **Fluke zero:** 200 mA on the open conductor in trials 1 and 3; testing continued without re-zeroing the Fluke (Section 5 asks for a re-zero).
- **Tilt and azimuth:** changed within a test day — Aug 29 27° → 28°, 180° → 240°; Oct 22 34–35°, 195° → 218° (Section 7 asks for them held constant).
- **Personnel:** Aug 29 trial 2 run by one person; trials 1–3 have no supervisor signature. Oct 22 trials witnessed by Mark Foote.
- **Meter agreement:** trial 3 module-face readings AH-Sol #2 916 vs DayStar #2 837 W/m² (9.4%, above the 8% cross-check limit).
- **Missing entries:** trial 004 technician print name and photo 3; trial 005 end time [9]; trial 000 (a test run) excluded.

14.3 Instrument note

Near zero the Fluke 393 (±0.5 A class) and Seaward (±0.2 A class) cannot resolve the 125 mA gate; the BT270 (1 mA resolution, ±(2% + 5 digits)) decides Stage 1 (S1) in practice. Its open-conductor zero [34] read 0–5 mA across the seven trials, comparable to the sheet-on readings of 2–11 mA.

14.4 Under review — not adopted in V18

Raised in an independent review of the published data (Oct 23, 2026). Recorded here for decision before further trials; Side 2 remains the v29 worksheet.

- Make the BT270 40 mA line a binding Stage 1 (S1) gate; treat the Fluke and Seaward as gross checks and drop the “at or below its own zero” exception.
- Report OD by channel (DayStar pair, AH-Sol pair, current), since a DayStar reading of 0 sets OD by the ambient level; Section 5 accepts a zero of ±2–3 W/m². V17.1: DayStar and AH-Sol pairs are now reported side by side for comparison; scoring is unchanged.
- Add a second Stage 3 (S3) comparison against AH-Sol #2.
- Run the Section 13 comparison against black poly and canvas before any claim of better performance than a tarp.
- Field procedure: cover every module in the circuit, verify current at the work point, and state residual voltage as N × about 8 V with current under 40 mA.
- Update code citations to the issued NFPA 70E 2027 and the 2026 NEC once section numbers are confirmed.

14.5 Levels met (gates unchanged)

Level	Under-sheet light	Current	Phase 1 result
Phase 1 gate (this plan)	< 7 W/m²	< 125 mA	7 / 7 PASS
Provisional application levels (US 64/026,462)	< 5 W/m²	< 100 mA	7 / 7 on the BT270 and both under-sheet meters
NFPA 70E 2027 draft dc shock threshold [7]	—	< 40 mA	7 / 7 on the BT270 (recorded, not a gate)
Measured worst case	2.4 W/m² (AH-Sol #2, trials 1 and 2)	11 mA (BT270, trial 005)	—

The Fluke 393 resolves 0.1 A and read 0.2 A (trial 1, zero offset) and 0.1 A (trial 3) with the sheet on, so it cannot show < 100 mA; the BT270 (1 mA resolution) is the instrument that resolves these levels (Section 14.3).

15. References

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