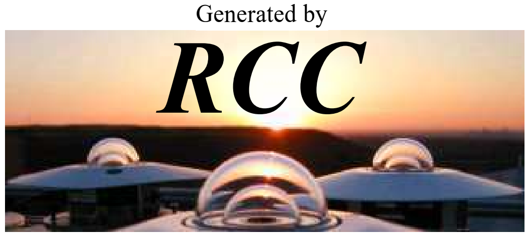
Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2023-02

Generated by



Radiometer Calibration and Characterization

Customer

Craig Webb

Organization: ARM CRF SGP Site

Address: 109596 Coal Rd, Billings, OK 74630

Phone: 580-388-4053

Calibration Facility

Solar Radiation Research Laboratory

Latitude: 39.742°N

Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Calibration date

06/19/2023

Report Date

June 20, 2023

NREL

NOTICE

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

This report compiles the calibration results from a Broadband Outdoor Radiometer Calibration (BORCAL). The work was accomplished at the Radiometer Calibration Facility shown on the front of this report. The calibration results reported here are traceable to the International System (SI) Units of Measurement.

This report includes these sections:

- Control Instruments - a group of instruments included in each BORCAL event that provides a measure of process consistency.
- Results Summary - a table of all instruments included in this report summarizing their calibration results and uncertainty.
- Instrument Details - the calibration certificates for each instrument.
- Environmental and Sky Conditions - meteorological conditions and reference irradiance during the calibration event.

BORCAL Notes or Comments

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

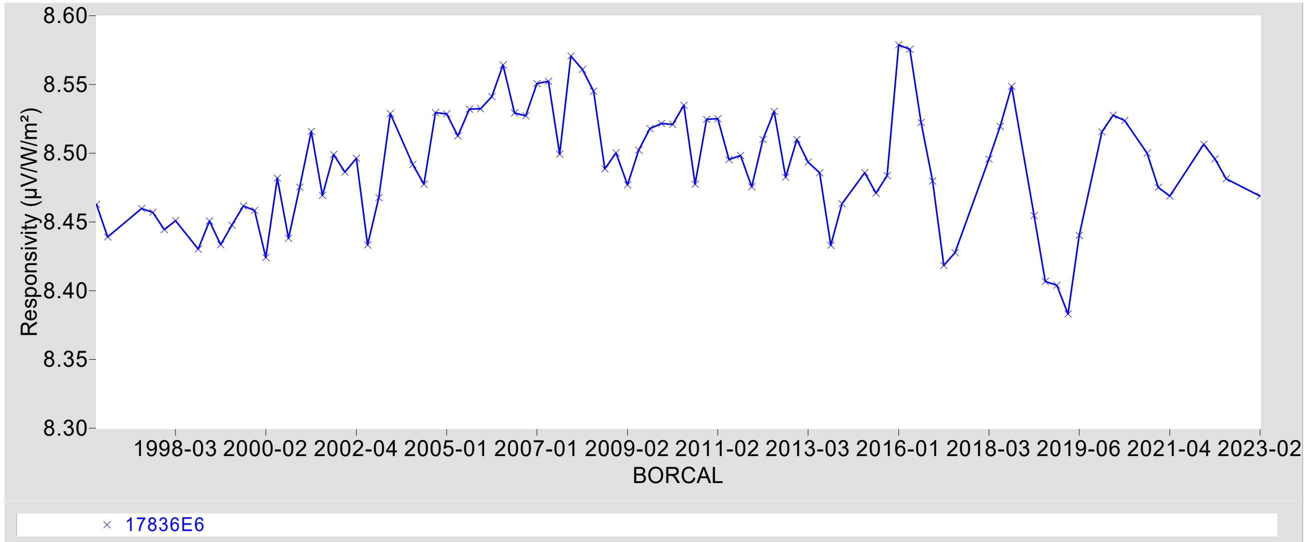


Figure 2. Eppley PSP Control Instrument History

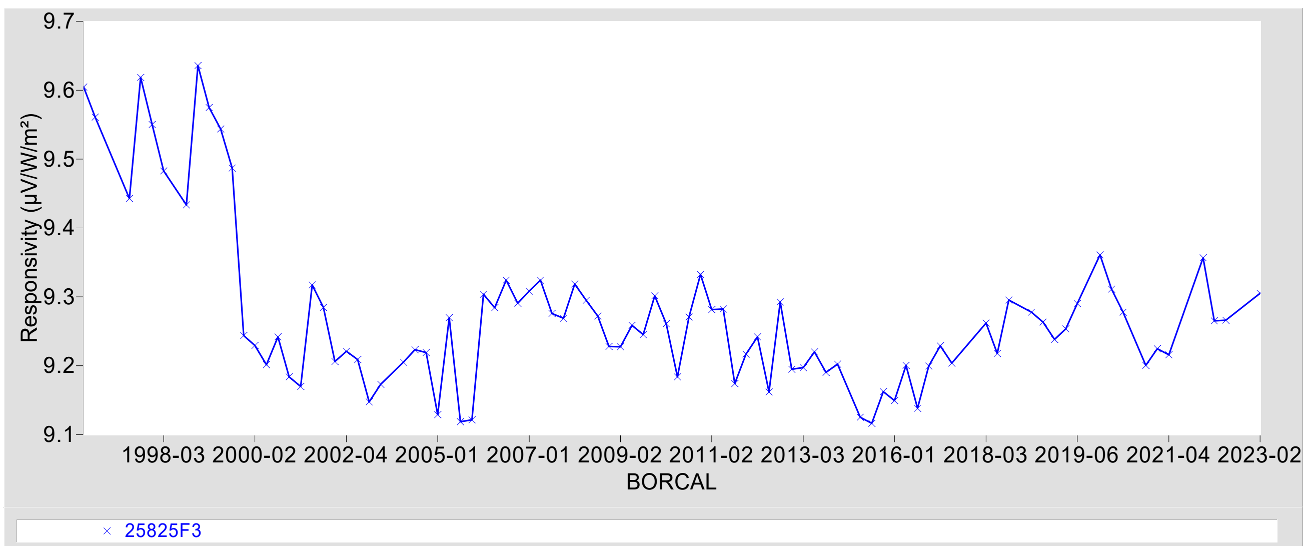
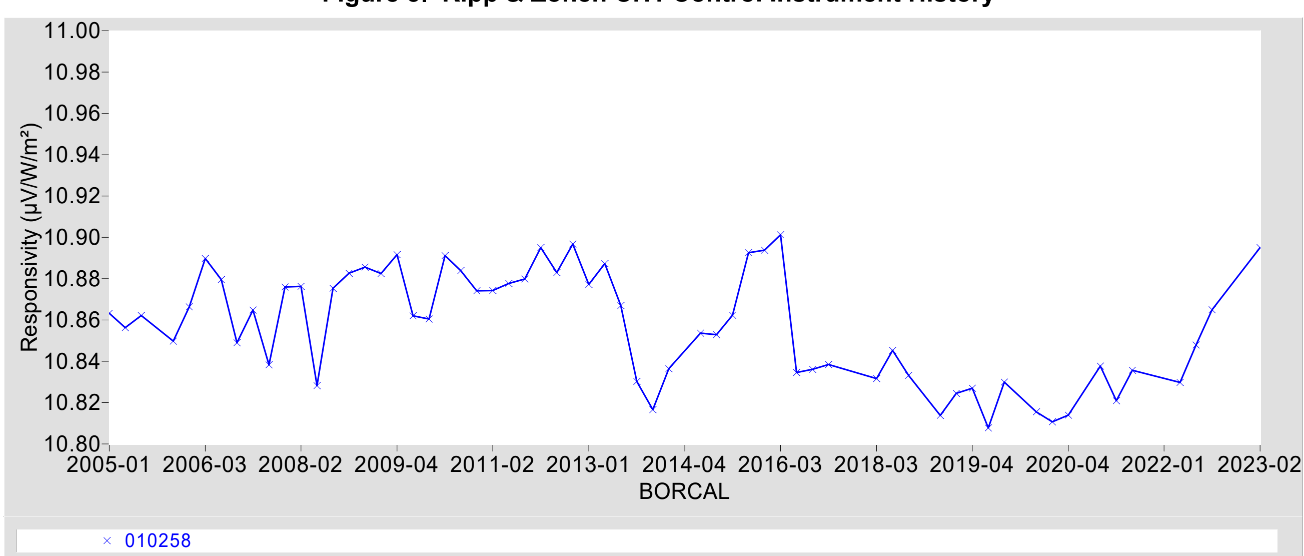


Figure 3. Kipp & Zonen CH1 Control Instrument History



Control Instrument History

Figure 4. Kipp & Zonen CHP1 Control Instrument History

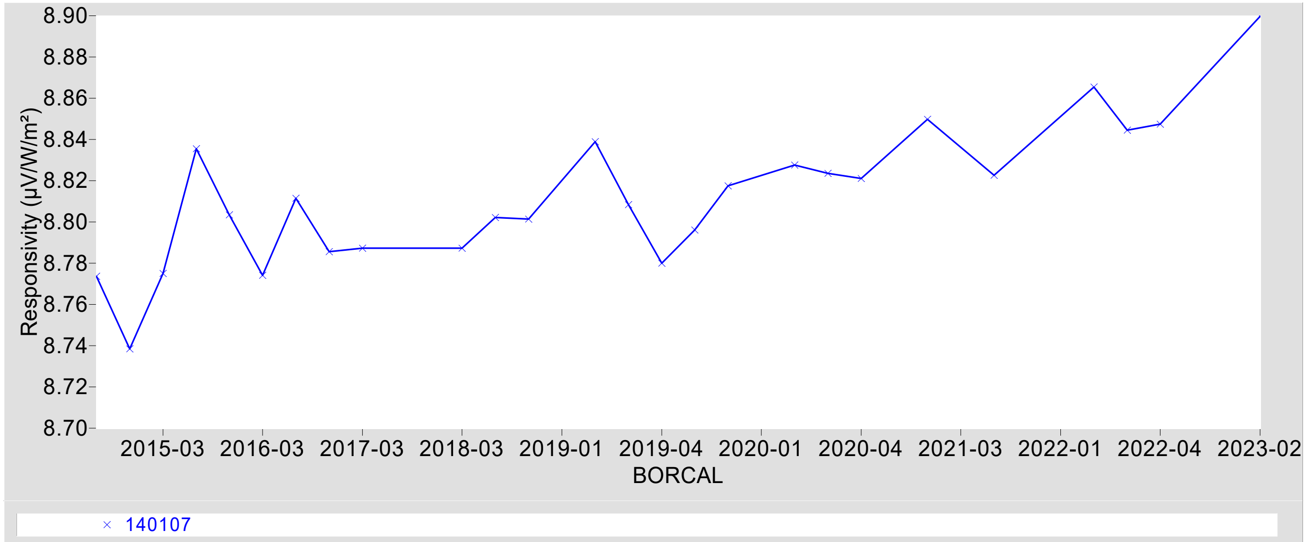


Figure 5. Kipp & Zonen CM22 Control Instrument History

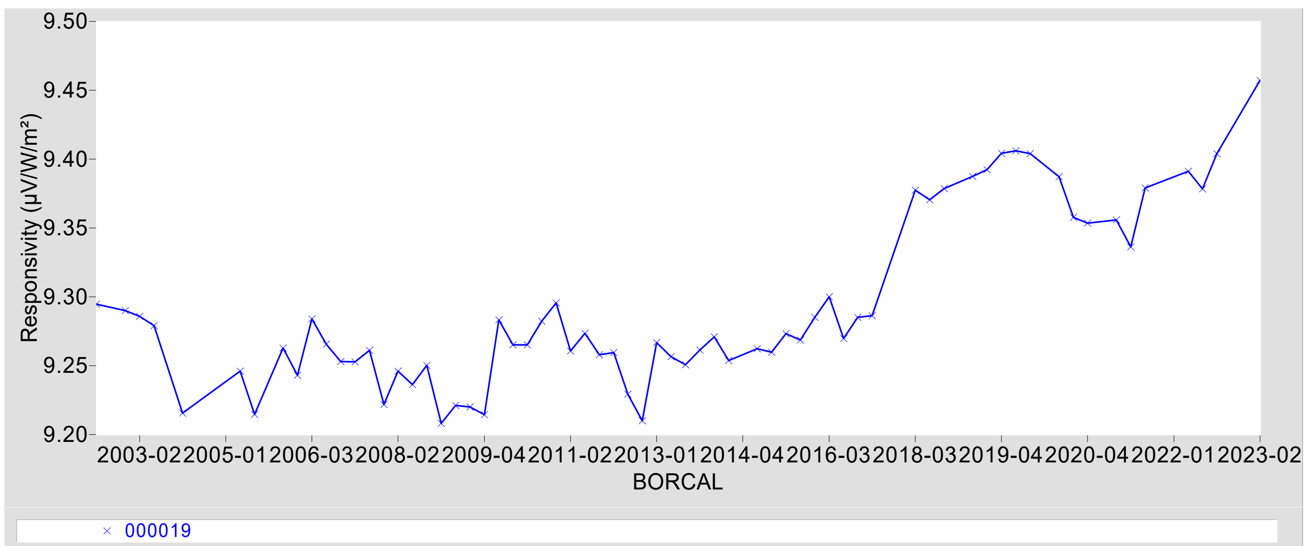
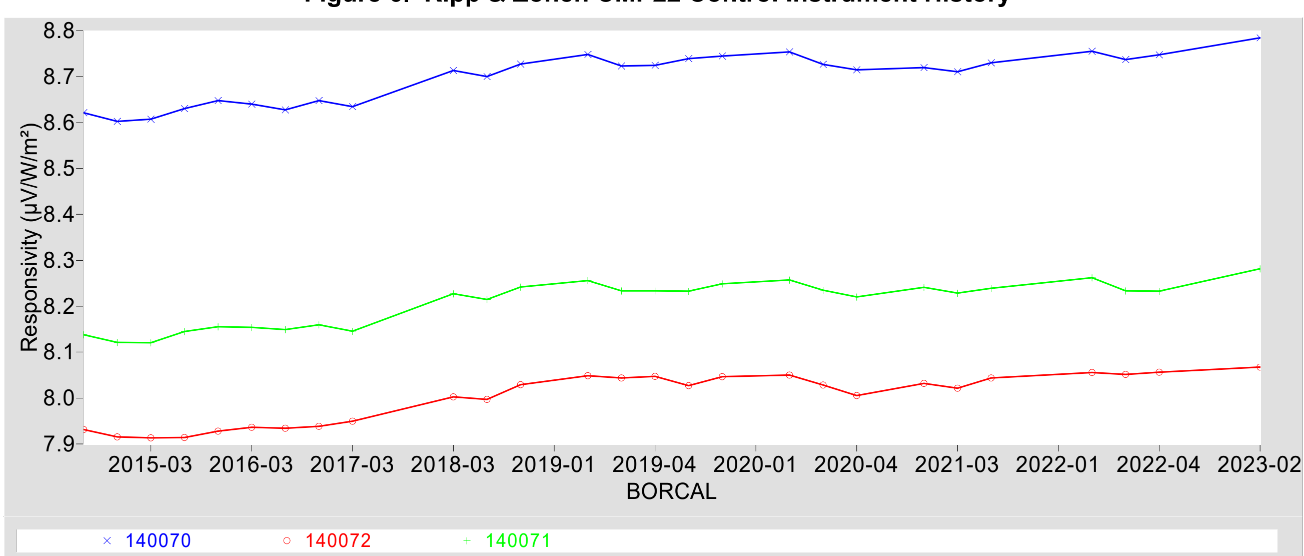


Figure 6. Kipp & Zonen CMP22 Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	R@45 [1] (μV/W/m²)	CF@45 [1] (W/m²/mV)	U [2] (%)	Rnet [3] (μV/W/m²)	Page
15286 Hukseflux SR20-T2	16.672	59.982	+1.3 / -1.5	0.18000	A1-2
15287 Hukseflux SR20-T2	16.755	59.685	+1.1 / -1.8	0.18000	A1-5
15288 Hukseflux SR20-T2	17.140	58.342	+1.3 / -2.1	0.18000	A1-8
15357 Hukseflux SR20-T2	17.051	58.649	+1.2 / -1.2	0.18000	A1-11
15360 Hukseflux SR20-T2	16.468	60.723	+1.7 / -1.7	0.18000	A1-14
15364 Hukseflux SR20-T2	17.067	58.591	+1.4 / -1.7	0.18000	A1-17
15366 Hukseflux SR20-T2	16.833	59.407	+1.2 / -2.0	0.18000	A1-20
2549 Hukseflux SR25	9.1595	109.18	+1.8 / -1.5	0.043000	A1-23
2550 Hukseflux SR25	8.7792	113.91	+1.5 / -1.7	0.043000	A1-26
31121E6 Eppley NIP	8.7770	113.93	+1.6 / -1.1	0	A1-29
31146F3 Eppley PSP	7.4713	133.85	+3.1 / -3.6	0.56000	A1-32
31147F3 Eppley PSP	7.4244	134.69	+3.2 / -4.1	0.59000	A1-35
31148F3 Eppley PSP	7.3491	136.07	+3.6 / -3.1	0.55000	A1-38
31155F3 Eppley PSP	7.6684	130.41	+2.7 / -3.2	0.54000	A1-41
31156F3 Eppley PSP	7.6425	130.85	+2.9 / -2.9	0.56000	A1-44
31157F3 Eppley PSP	7.5745	132.02	+2.7 / -3.8	0.56000	A1-47
37947E6 Eppley sNIP	8.7791	113.91	+0.94 / -0.76	0	A1-50
65089 Hukseflux DR20-A1-T2	18.666	53.573	+0.85 / -0.89	0	A1-53
65090 Hukseflux DR20-A1-T2	20.201	49.502	+0.84 / -0.96	0	A1-56
65091 Hukseflux DR20-A1-T2	19.668	50.844	+0.90 / -0.95	0	A1-59

[1] CF = 1000 / R [2] See certificate for valid zenith angle range [3] Instrument's Effective Net IR Response

Note: Environmental Conditions for BORCAL starts on page A1-62.

Appendix 1
Instrument Details

Calibration Certificates: 3 pages for each radiometer (4 including Environmental Conditions)
Environmental Conditions for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15286
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

____________________________ ____________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

15286 Hukseflux SR20-T2

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \quad [1]$$

where,

- *V* = radiometer output voltage (microvolts),
- *Rnet* = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- *Wnet* = effective net infrared measured by pyrgeometer (W/m²),
  = *Win - Wout* = $Win - \sigma * Tc^4$
  - where, *Win* = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - *Tc* = case temperature of radiometer (K).
- *I* = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - *Z* = zenith angle (degrees),
  - *D* = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

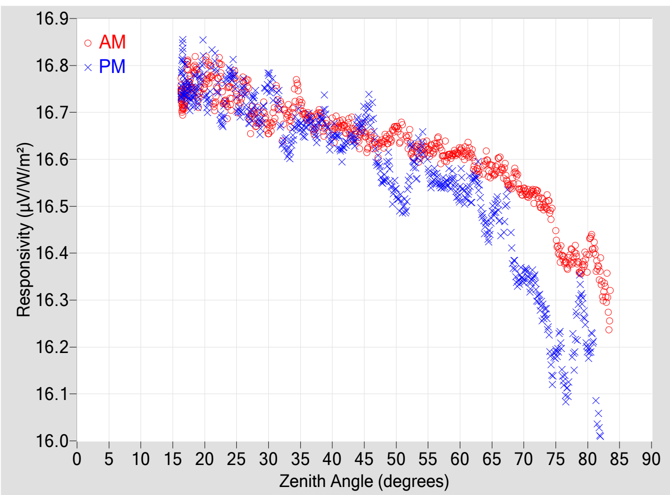


Figure 2. Responsivity vs Local Standard Time

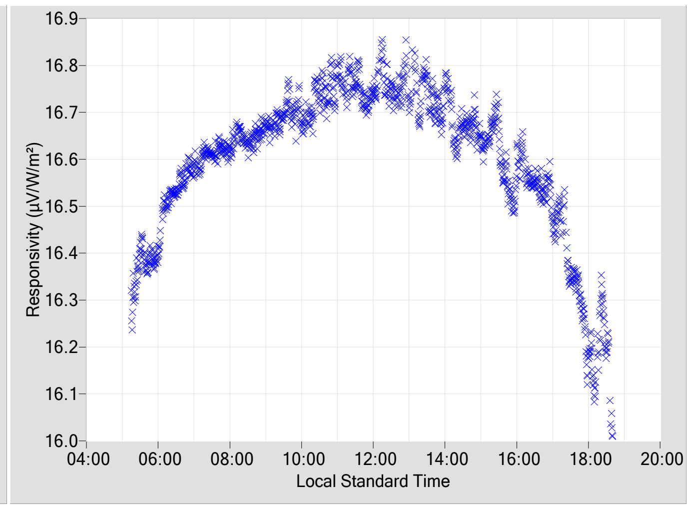


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	16.645	0.33	94.83	16.705	0.33	265.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.638	0.32	93.03	16.555	0.33	266.99
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.667	0.32	91.29	16.533	0.34	268.69
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.642	0.33	89.63	16.566	0.33	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.620	0.33	87.98	16.627	0.34	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.622	0.34	86.37	16.564	0.34	273.62
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.605	0.35	84.80	16.554	0.35	275.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.620	0.36	83.25	16.541	0.36	276.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.600	0.37	81.73	16.543	0.38	278.25
18	16.760	0.33	152.50	16.733	0.31	207.61	64	16.598	0.38	80.22	16.454	0.39	279.82
20	16.772	0.29	140.73	16.776	0.31	219.34	66	16.591	0.40	78.68	16.491	0.41	281.33
22	16.766	0.30	132.65	16.766	0.31	227.13	68	16.544	0.42	77.18	16.411	0.44	282.91
24	16.732	0.32	126.58	16.781	0.33	233.41	70	16.533	0.45	75.65	16.350	0.47	284.37
26	16.754	0.30	121.75	16.744	0.31	238.34	72	16.528	0.48	74.12	16.312	0.51	285.90
28	16.685	0.32	117.49	16.712	0.31	242.49	74	16.494	0.53	72.53	16.206	N/A	287.45
30	16.665	0.30	113.92	16.769	0.31	246.12	76	16.394	N/A	70.98	16.157	N/A	289.05
32	16.693	0.30	110.82	16.663	0.35	249.16	78	16.397	N/A	69.36	16.214	N/A	290.67
34	16.718	0.30	108.01	16.663	0.32	251.98	80	16.384	N/A	67.73	16.194	N/A	292.30
36	16.692	0.30	105.31	16.679	0.30	254.70	82	16.356	N/A	66.03	16.016	N/A	293.90
38	16.698	0.30	102.99	16.682	0.31	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	16.663	0.32	100.72	16.651	0.31	259.23	86	N/A	N/A	N/A	N/A	N/A	N/A
42	16.667	0.31	98.67	16.633	0.31	261.37	88	N/A	N/A	N/A	N/A	N/A	N/A
44	16.647	0.31	96.71	16.676	0.31	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

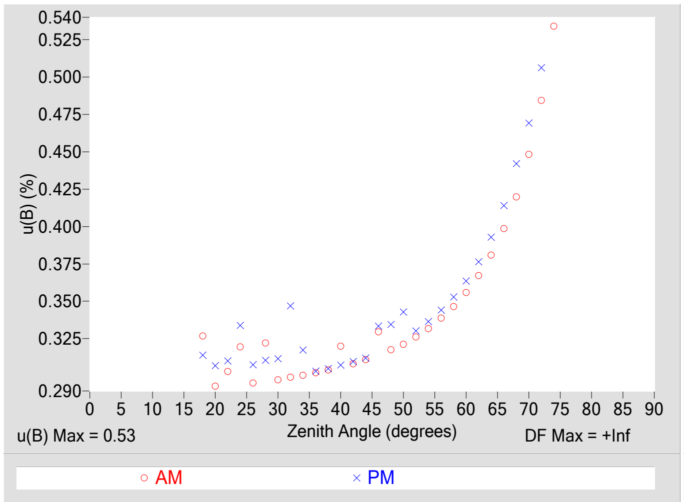


Figure 4. Residuals from Spline Interpolation

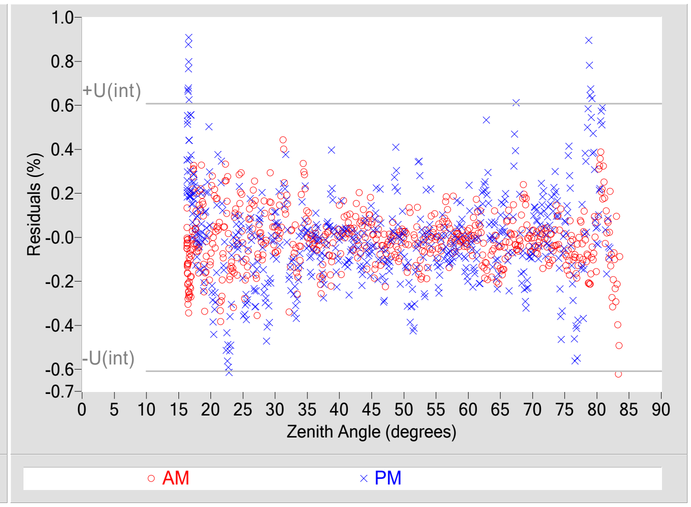


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	18292
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

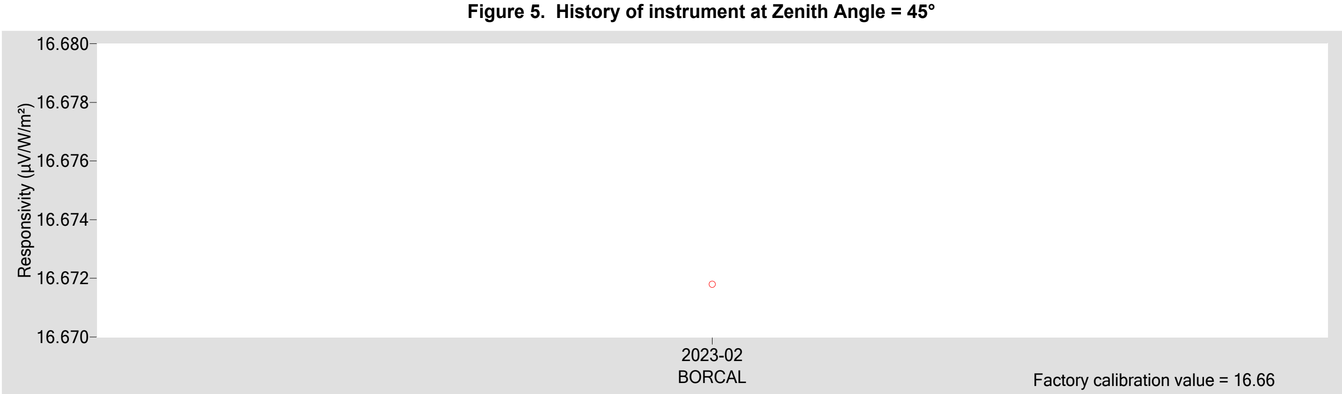
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
16.672	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.58 / -0.83
Expanded Uncertainty, U (%)	+1.3 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15287
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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Measurement Type	Instrument	Calibration Date	Calibration Due Date
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Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

________________________________ ________________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

15287 Hukseflux SR20-T2

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^{4}$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of radiometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

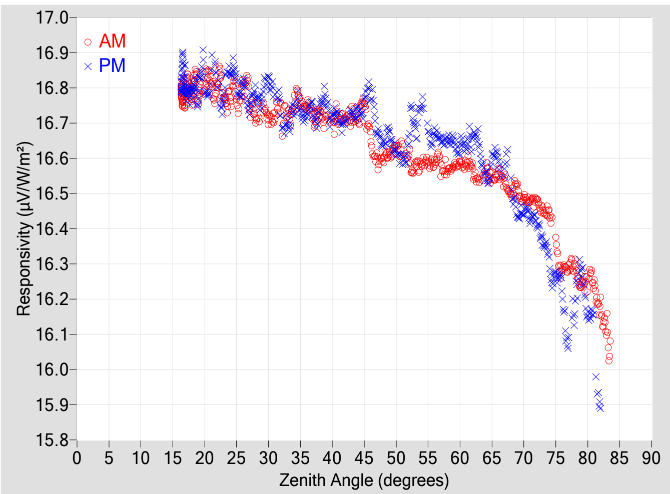


Figure 2. Responsivity vs Local Standard Time

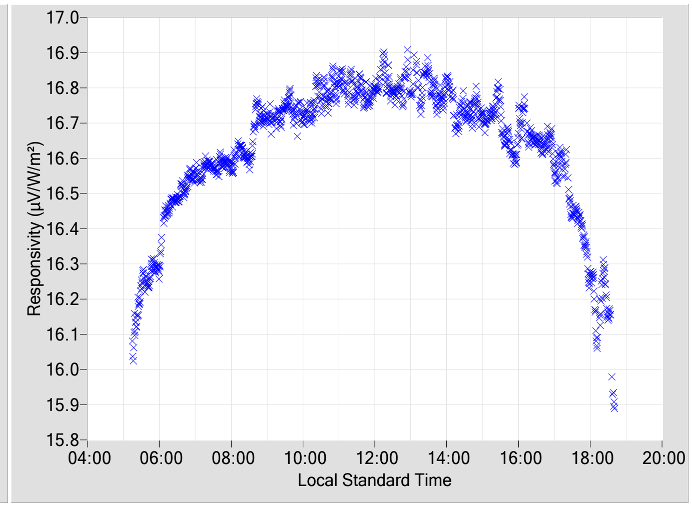


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	16.660	0.33	94.83	16.788	0.33	265.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.601	0.32	93.03	16.642	0.33	266.99
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.634	0.32	91.29	16.622	0.34	268.69
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.600	0.33	89.63	16.670	0.33	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.587	0.33	87.98	16.751	0.34	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.583	0.34	86.37	16.670	0.34	273.62
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.564	0.35	84.80	16.654	0.35	275.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.588	0.36	83.25	16.636	0.36	276.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.565	0.37	81.73	16.651	0.38	278.25
18	16.782	0.33	152.50	16.791	0.31	207.61	64	16.566	0.38	80.22	16.550	0.39	279.82
20	16.811	0.29	140.73	16.831	0.31	219.34	66	16.558	0.40	78.68	16.592	0.41	281.33
22	16.817	0.30	132.65	16.822	0.31	227.13	68	16.501	0.42	77.18	16.513	0.44	282.91
24	16.773	0.32	126.58	16.843	0.33	233.41	70	16.487	0.45	75.65	16.446	0.47	284.37
26	16.797	0.30	121.75	16.809	0.31	238.34	72	16.480	0.48	74.12	16.412	0.51	285.90
28	16.721	0.32	117.49	16.777	0.31	242.49	74	16.437	0.53	72.53	16.299	N/A	287.45
30	16.714	0.30	113.92	16.820	0.31	246.12	76	16.284	N/A	70.98	16.214	N/A	289.05
32	16.726	0.30	110.82	16.716	0.35	249.16	78	16.294	N/A	69.36	16.187	N/A	290.67
34	16.751	0.30	108.01	16.743	0.32	251.98	80	16.248	N/A	67.73	16.155	N/A	292.30
36	16.750	0.30	105.31	16.729	0.30	254.70	82	16.172	N/A	66.03	15.898	N/A	293.90
38	16.736	0.30	102.99	16.745	0.30	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	16.703	0.32	100.72	16.722	0.31	259.23	86	N/A	N/A	N/A	N/A	N/A	N/A
42	16.712	0.31	98.67	16.708	0.31	261.37	88	N/A	N/A	N/A	N/A	N/A	N/A
44	16.711	0.31	96.71	16.739	0.31	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

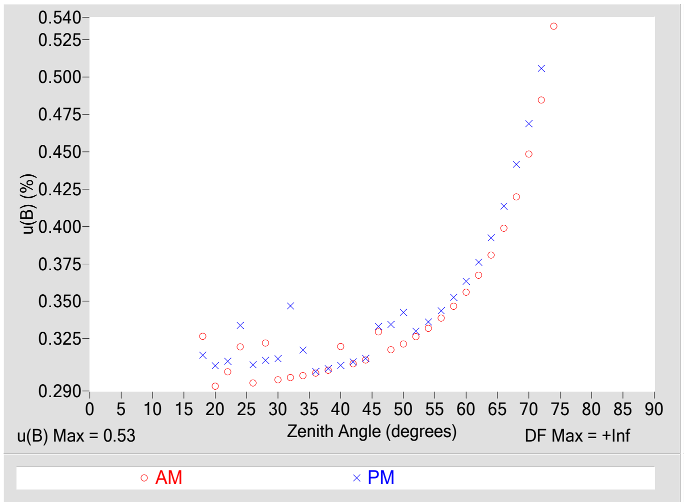


Figure 4. Residuals from Spline Interpolation

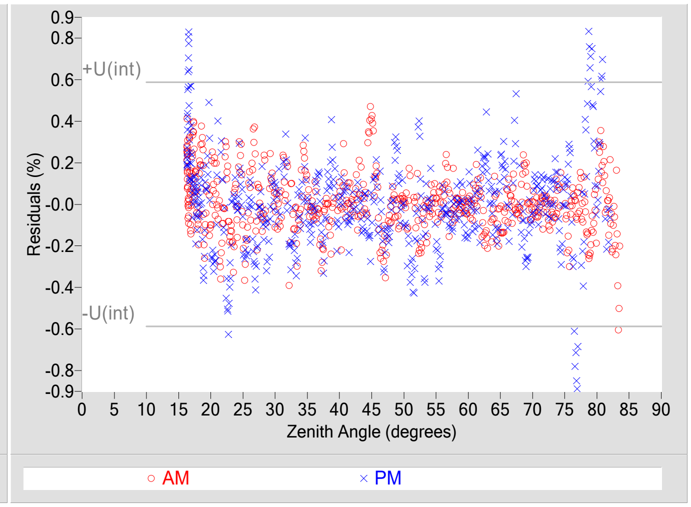


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	20267
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

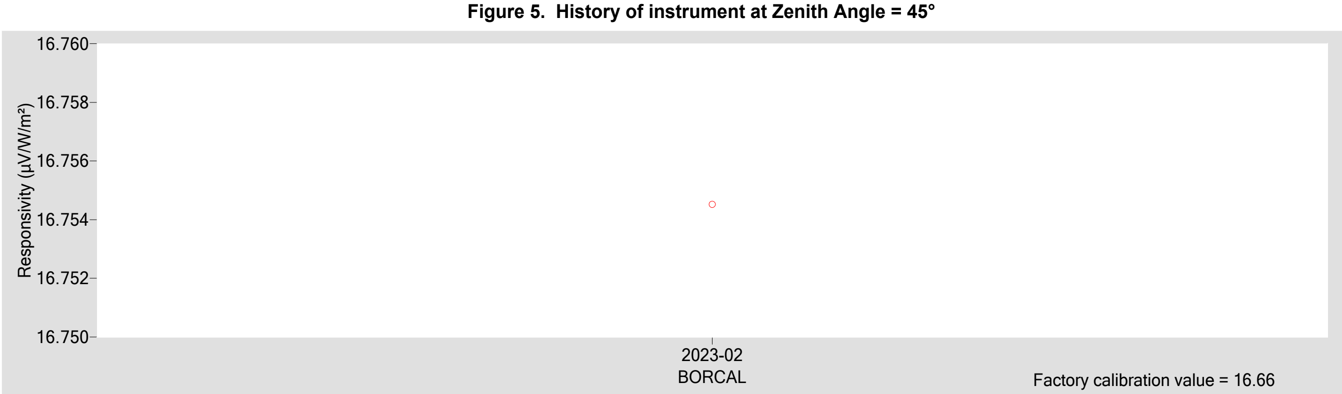
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
16.755	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.39 / -1.1
Expanded Uncertainty, U (%)	+1.1 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15288
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR)   ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

____ ________________

Afshin M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

15288 Hukseflux SR20-T2

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \quad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of radiometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

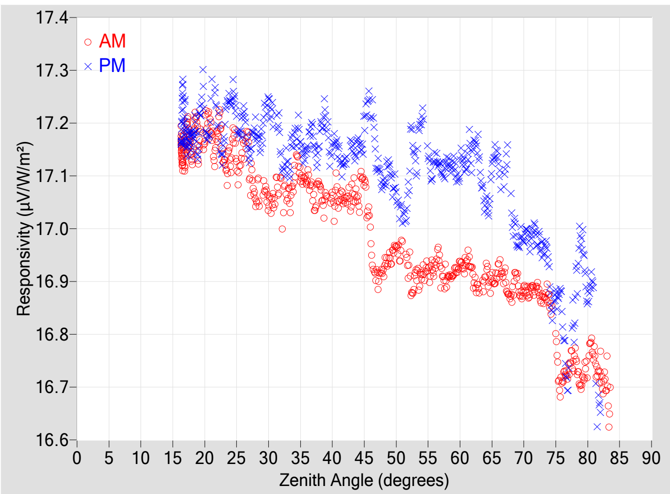


Figure 2. Responsivity vs Local Standard Time

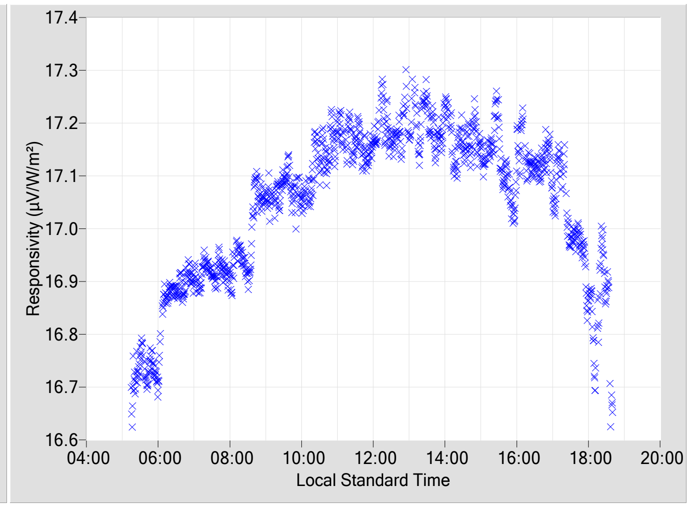


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	16.987	0.33	94.83	17.234	0.33	265.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.924	0.32	93.03	17.085	0.33	266.99
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.964	0.32	91.29	17.069	0.34	268.69
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.927	0.33	89.63	17.104	0.33	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.916	0.33	87.98	17.210	0.34	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.924	0.34	86.37	17.129	0.34	273.62
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.904	0.35	84.80	17.126	0.35	275.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.935	0.36	83.25	17.122	0.36	276.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.910	0.37	81.73	17.142	0.38	278.25
18	17.150	0.33	152.50	17.172	0.31	207.61	64	16.915	0.38	80.22	17.047	0.39	279.82
20	17.180	0.29	140.73	17.225	0.31	219.34	66	16.923	0.40	78.68	17.123	0.41	281.33
22	17.183	0.30	132.65	17.215	0.31	227.13	68	16.874	0.42	77.18	17.033	0.44	282.91
24	17.132	0.32	126.58	17.241	0.33	233.41	70	16.883	0.45	75.65	16.984	0.47	284.37
26	17.153	0.30	121.75	17.211	0.31	238.34	72	16.888	0.48	74.12	16.978	0.51	285.90
28	17.060	0.32	117.49	17.181	0.31	242.49	74	16.860	0.53	72.53	16.905	N/A	287.45
30	17.052	0.30	113.92	17.235	0.31	246.12	76	16.709	N/A	70.98	16.834	N/A	289.05
32	17.064	0.30	110.82	17.139	0.35	249.16	78	16.752	N/A	69.36	16.857	N/A	290.67
34	17.091	0.30	108.01	17.174	0.32	251.98	80	16.742	N/A	67.73	16.872	N/A	292.30
36	17.096	0.30	105.31	17.156	0.30	254.70	82	16.728	N/A	66.03	16.663	N/A	293.90
38	17.082	0.30	102.99	17.174	0.30	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	17.050	0.32	100.72	17.156	0.31	259.23	86	N/A	N/A	N/A	N/A	N/A	N/A
42	17.055	0.31	98.67	17.130	0.31	261.37	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.054	0.31	96.71	17.162	0.31	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

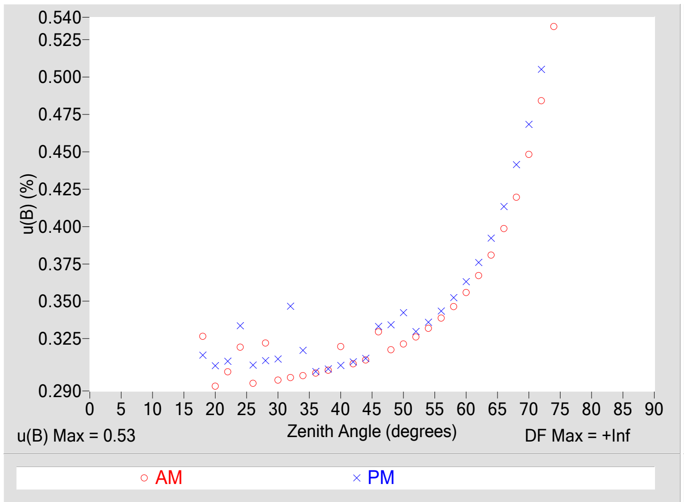


Figure 4. Residuals from Spline Interpolation

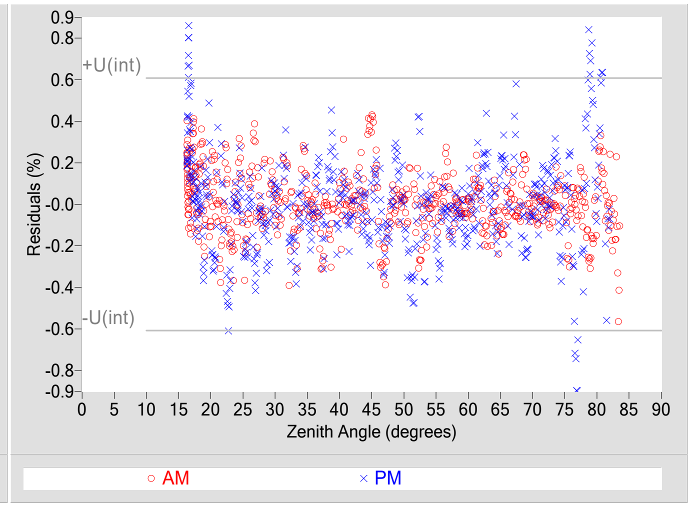


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	18263
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

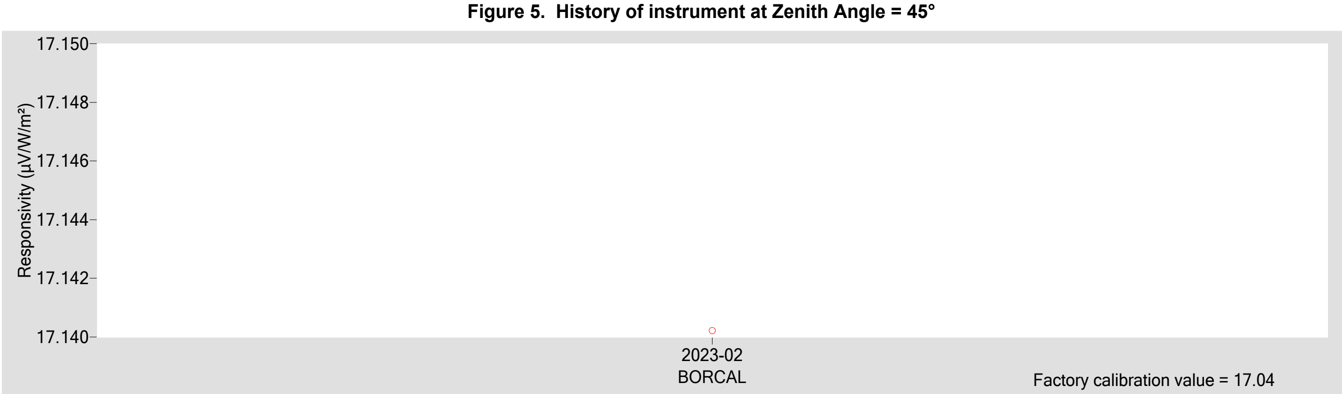
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
17.140	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.56 / -1.4
Expanded Uncertainty, U (%)	+1.3 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15357
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 38520F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

__________________________________ ________________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

15357 Hukseflux SR20-T2

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

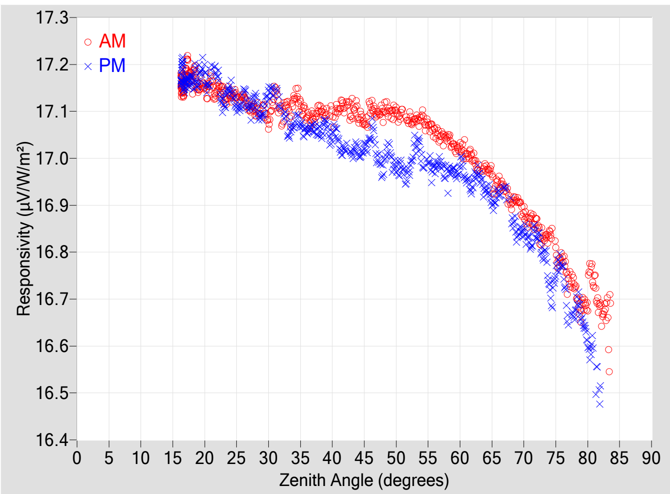


Figure 2. Responsivity vs Local Standard Time

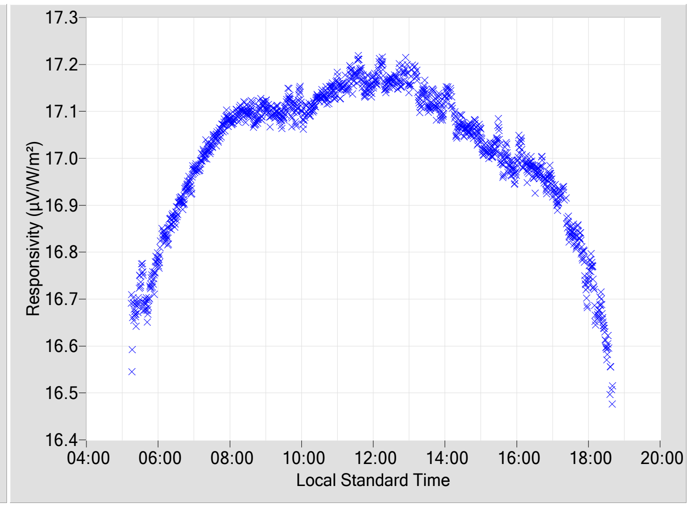


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	17.111	0.33	94.80	17.055	0.33	265.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	17.100	0.32	93.00	16.978	0.33	266.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	17.100	0.32	91.31	16.984	0.32	268.72
6	N/A	N/A	N/A	N/A	N/A	N/A	52	17.085	0.33	89.60	16.974	0.33	270.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	17.090	0.33	87.96	16.996	0.36	272.02
10	N/A	N/A	N/A	N/A	N/A	N/A	56	17.055	0.34	86.39	16.980	0.34	273.60
12	N/A	N/A	N/A	N/A	N/A	N/A	58	17.045	0.35	84.82	16.978	0.35	275.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	17.021	0.36	83.27	16.988	0.36	276.73
16	N/A	N/A	N/A	N/A	N/A	N/A	62	17.002	0.37	81.75	16.943	0.38	278.27
18	17.171	0.33	152.44	17.165	0.33	207.87	64	16.981	0.38	80.20	16.934	0.39	279.79
20	17.153	0.30	140.69	17.175	0.32	219.93	66	16.946	0.40	78.70	16.927	0.41	281.31
22	17.148	0.31	132.72	17.177	0.33	227.22	68	16.903	0.42	77.16	16.875	0.44	282.93
24	17.136	0.32	126.65	17.149	0.35	233.47	70	16.882	0.45	75.63	16.844	0.47	284.34
26	17.132	0.32	121.69	17.138	0.30	238.41	72	16.863	0.48	74.10	16.834	0.50	285.92
28	17.104	0.31	117.54	17.122	0.31	242.44	74	16.835	0.53	72.51	16.725	N/A	287.47
30	17.080	0.31	113.88	17.137	0.30	246.07	76	16.786	N/A	70.96	16.766	N/A	289.03
32	17.092	0.30	110.83	17.109	0.34	248.98	78	16.726	N/A	69.34	16.673	N/A	290.65
34	17.129	0.33	107.90	17.075	0.30	252.08	80	16.706	N/A	67.73	16.607	N/A	292.27
36	17.088	0.30	105.34	17.059	0.32	254.66	82	16.677	N/A	66.01	16.500	N/A	293.88
38	17.106	0.30	102.96	17.058	0.30	257.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	17.092	0.33	100.75	17.050	0.31	259.27	86	N/A	N/A	N/A	N/A	N/A	N/A
42	17.109	0.33	98.65	17.021	0.34	261.34	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.094	0.31	96.68	17.015	0.31	263.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

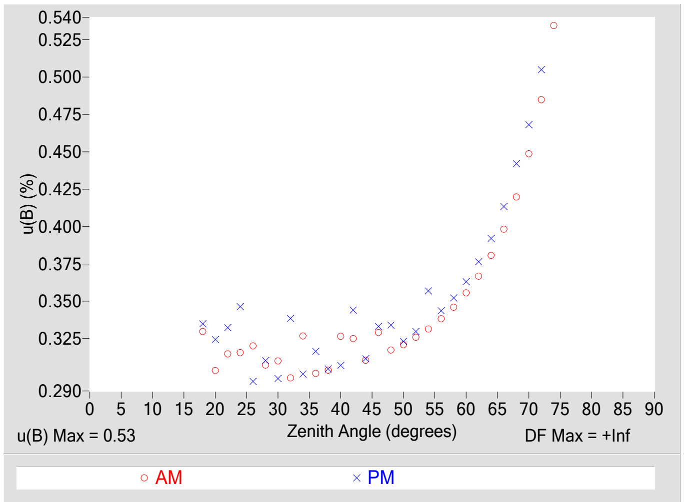


Figure 4. Residuals from Spline Interpolation

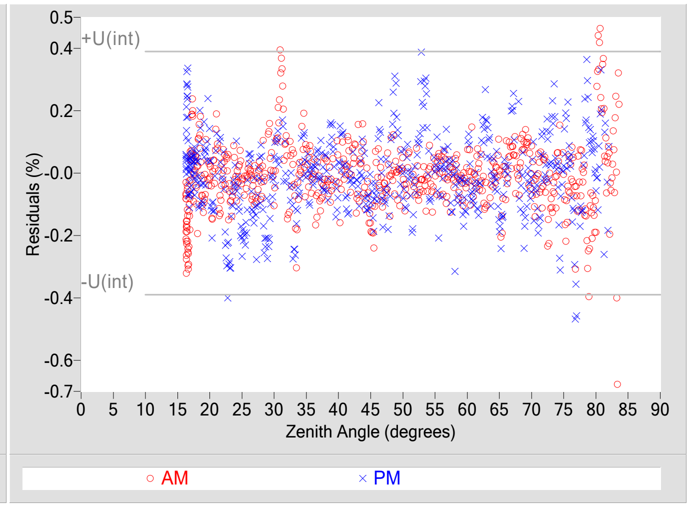


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	79945
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

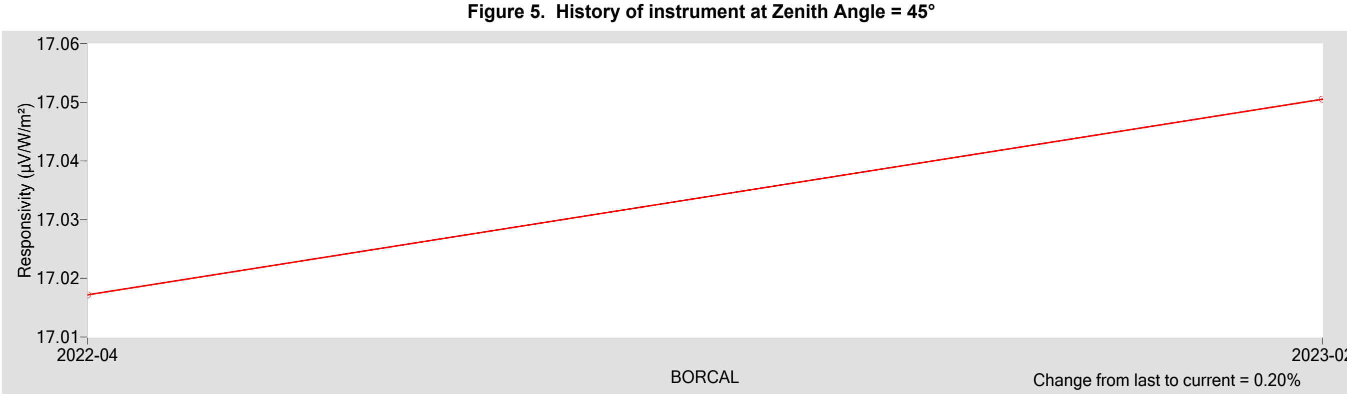
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
17.051	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.50 / -0.45
Expanded Uncertainty, U (%)	+1.2 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15360
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________________ ________________

Afshin M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

15360 Hukseflux SR20-T2

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

*R = (V - Rnet * Wnet) / I* [1]

where,

V = radiometer output voltage (microvolts),
Rnet = radiometer net infrared responsivity (µV/W/m²), see Table 4,
Wnet = effective net infrared measured by pyrgeometer (W/m²),
= *Win - Wout* = *Win - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, *G = B * COS(Z) + D,*
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

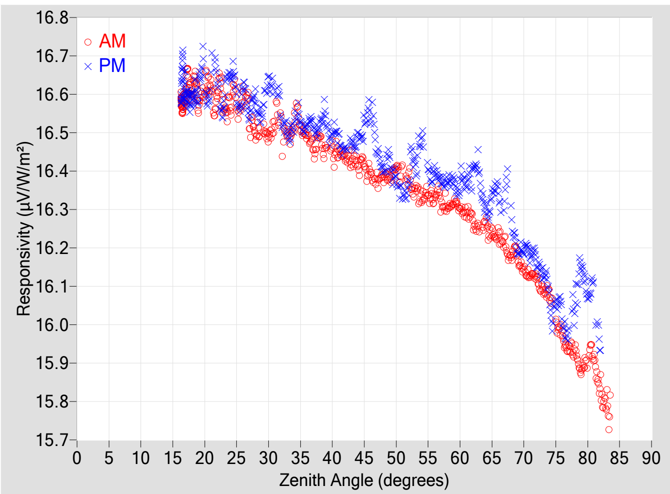


Figure 2. Responsivity vs Local Standard Time

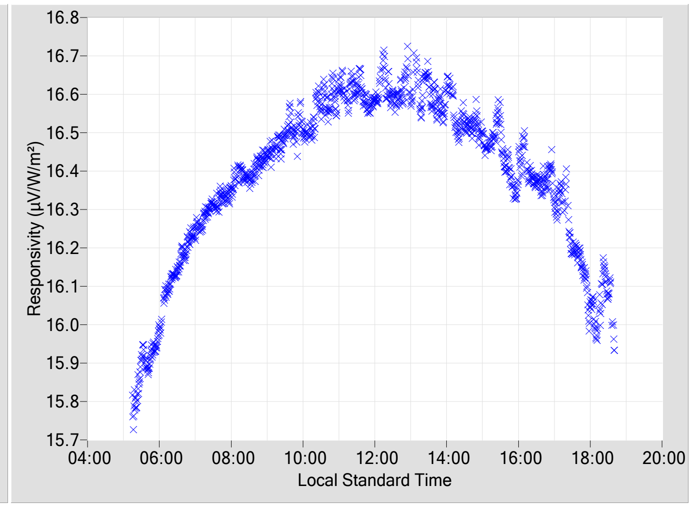


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	16.397	0.33	94.83	16.556	0.33	265.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.386	0.32	93.03	16.405	0.33	266.99
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.408	0.32	91.29	16.380	0.34	268.69
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.384	0.33	89.63	16.385	0.33	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.336	0.33	87.98	16.481	0.34	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.328	0.34	86.37	16.397	0.34	273.62
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.303	0.35	84.80	16.378	0.35	275.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.302	0.36	83.25	16.373	0.36	276.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.271	0.37	81.73	16.390	0.38	278.25
18	16.610	0.33	152.50	16.587	0.31	207.61	64	16.266	0.38	80.22	16.302	0.39	279.82
20	16.617	0.29	140.73	16.645	0.31	219.34	66	16.233	0.40	78.68	16.343	0.41	281.33
22	16.604	0.30	132.65	16.641	0.31	227.13	68	16.178	0.42	77.18	16.276	0.44	282.91
24	16.570	0.32	126.58	16.647	0.33	233.41	70	16.143	0.45	75.65	16.194	0.47	284.37
26	16.593	0.30	121.75	16.610	0.31	238.34	72	16.122	0.48	74.12	16.160	0.51	285.90
28	16.499	0.32	117.49	16.579	0.31	242.49	74	16.075	0.53	72.53	16.065	N/A	287.45
30	16.491	0.30	113.92	16.632	0.31	246.12	76	15.975	N/A	70.98	16.019	N/A	289.05
32	16.511	0.30	110.82	16.543	0.35	249.16	78	15.930	N/A	69.36	16.056	N/A	290.67
34	16.521	0.30	108.01	16.525	0.32	251.98	80	15.905	N/A	67.73	16.076	N/A	292.30
36	16.495	0.30	105.31	16.521	0.30	254.70	82	15.832	N/A	66.03	15.943	N/A	293.90
38	16.489	0.30	102.99	16.523	0.31	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	16.449	0.32	100.72	16.500	0.31	259.23	86	N/A	N/A	N/A	N/A	N/A	N/A
42	16.435	0.31	98.67	16.460	0.31	261.37	88	N/A	N/A	N/A	N/A	N/A	N/A
44	16.414	0.31	96.71	16.492	0.31	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

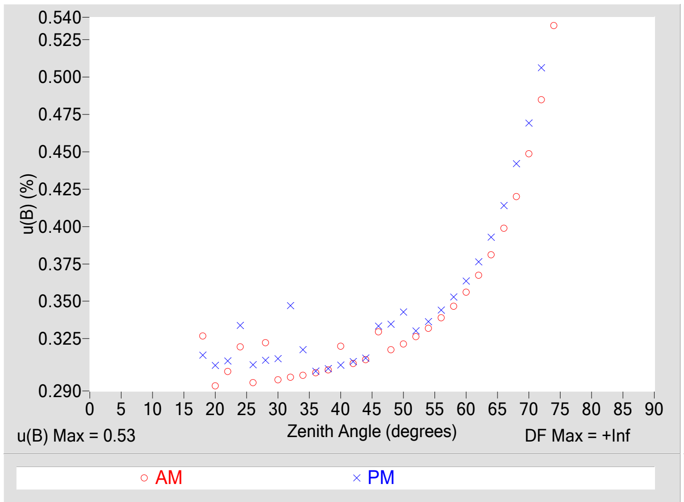


Figure 4. Residuals from Spline Interpolation

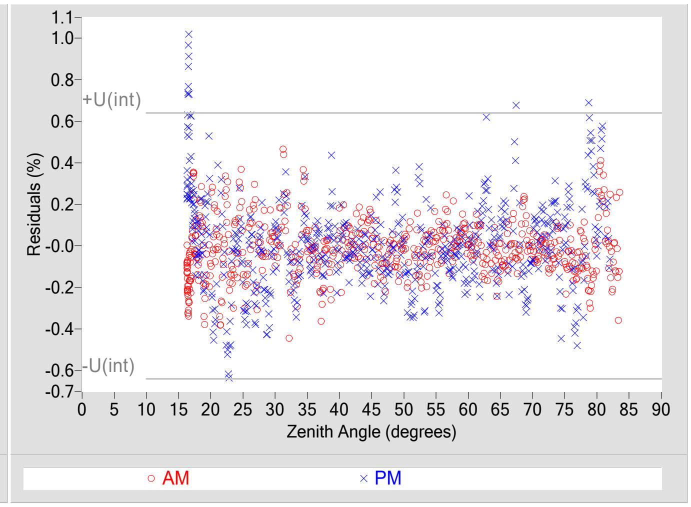


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	15742
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

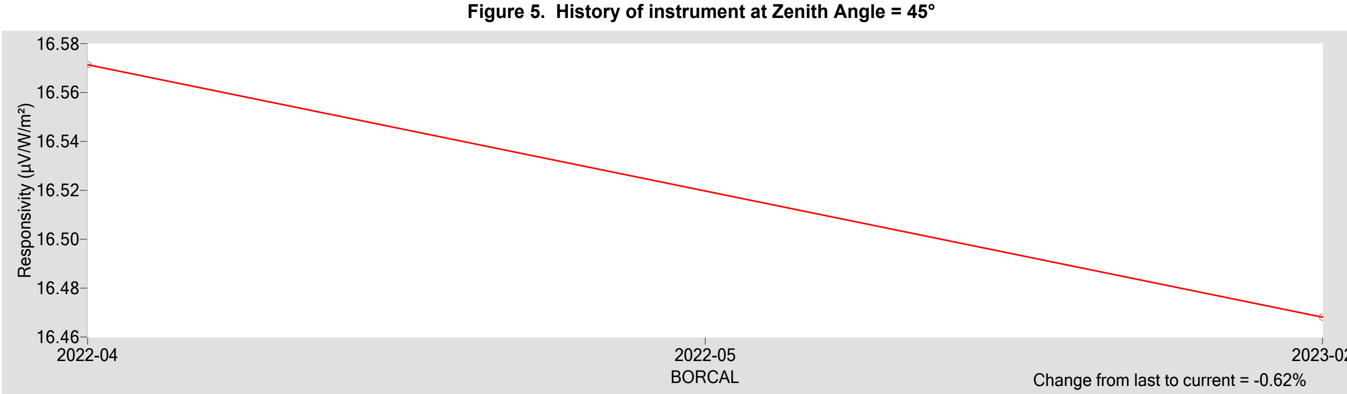
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
16.468	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.00 / -1.0
Expanded Uncertainty, U (%)	+1.7 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

ACCREDITED
Calibration CERT #1239.02

Test Instrument: Pyranometer (Ventilated)

Manufacturer: Hukseflux

Model: SR20-T2

Serial Number: 15364

Calibration Date: 6/19/2023

Due Date: 6/19/2024

Customer: Craig Webb

Environmental Conditions: see page 4

Test Dates: 6/19

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 38520F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________________ ________________

Afshin M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

15364 Hukseflux SR20-T2

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

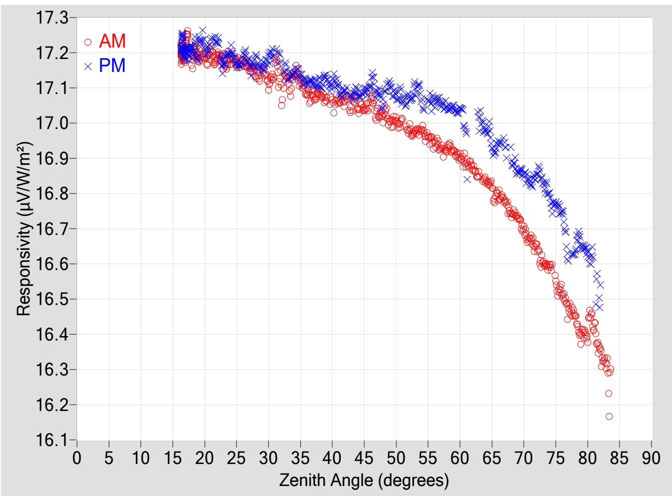


Figure 2. Responsivity vs Local Standard Time

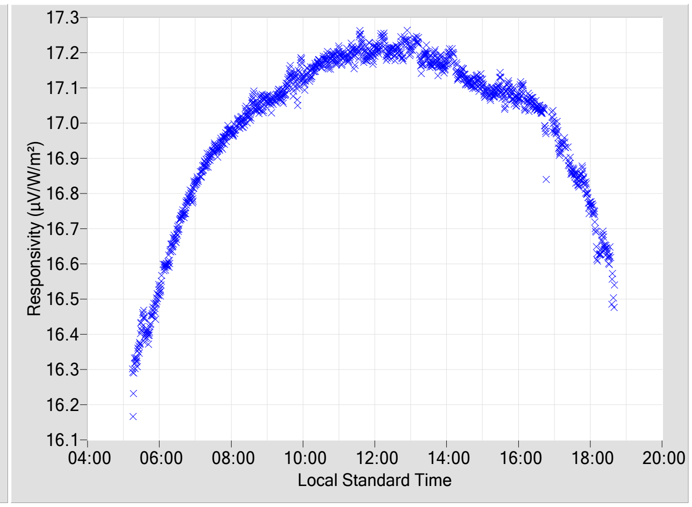


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	17.073	0.33	94.80	17.118	0.33	265.20
2	N/A	N/A	N/A	N/A	N/A	N/A	48	17.025	0.32	93.00	17.064	0.33	266.96
4	N/A	N/A	N/A	N/A	N/A	N/A	50	17.007	0.32	91.31	17.081	0.32	268.72
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.982	0.33	89.60	17.073	0.33	270.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.982	0.33	87.96	17.060	0.36	272.02
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.940	0.34	86.39	17.063	0.34	273.60
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.929	0.35	84.82	17.046	0.35	275.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.901	0.36	83.27	17.039	0.36	276.73
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.873	0.37	81.75	N/A	N/A	N/A
18	17.193	0.33	152.44	17.208	0.33	207.87	64	16.838	0.38	80.20	16.980	0.39	279.79
20	17.190	0.30	140.69	17.213	0.32	219.93	66	16.795	0.40	78.70	16.942	0.41	281.31
22	17.188	0.31	132.72	17.230	0.33	227.22	68	16.742	0.42	77.16	16.896	0.44	282.93
24	17.186	0.32	126.65	17.203	0.35	233.47	70	16.696	0.45	75.63	16.857	0.47	284.34
26	17.177	0.32	121.69	17.191	0.30	238.41	72	16.649	0.48	74.10	16.853	0.50	285.92
28	17.145	0.31	117.54	17.180	0.31	242.44	74	16.591	0.53	72.51	16.792	N/A	287.47
30	17.114	0.31	113.88	17.183	0.30	246.07	76	16.518	N/A	70.96	16.741	N/A	289.03
32	17.101	0.30	110.83	17.184	0.34	248.98	78	16.453	N/A	69.34	16.641	N/A	290.65
34	17.140	0.33	107.90	17.144	0.30	252.08	80	16.409	N/A	67.73	16.630	N/A	292.27
36	17.084	0.30	105.34	17.117	0.32	254.66	82	16.346	N/A	66.01	16.507	N/A	293.88
38	17.087	0.30	102.96	17.116	0.30	257.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	17.057	0.33	100.75	17.120	0.31	259.27	86	N/A	N/A	N/A	N/A	N/A	N/A
42	17.062	0.33	98.65	17.092	0.34	261.34	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.049	0.31	96.68	17.086	0.31	263.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

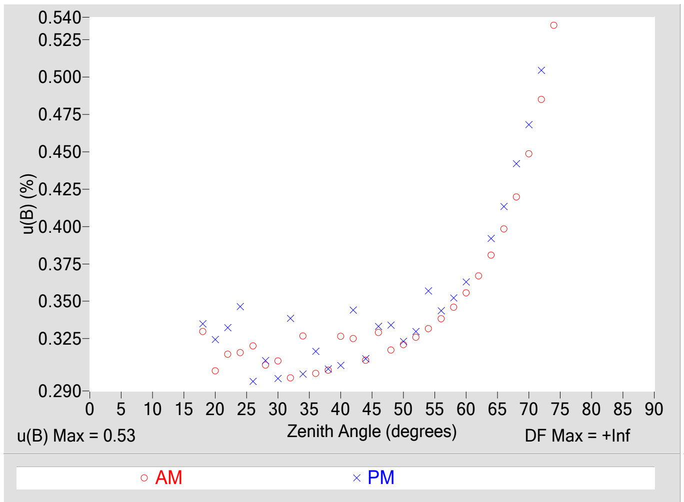


Figure 4. Residuals from Spline Interpolation

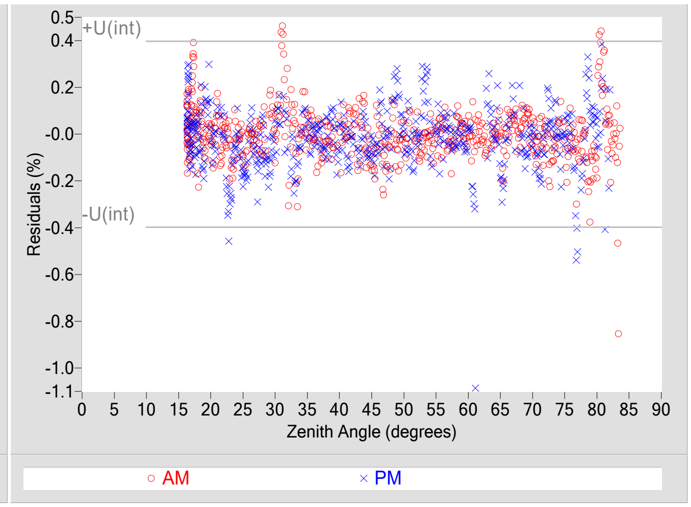


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	73788
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

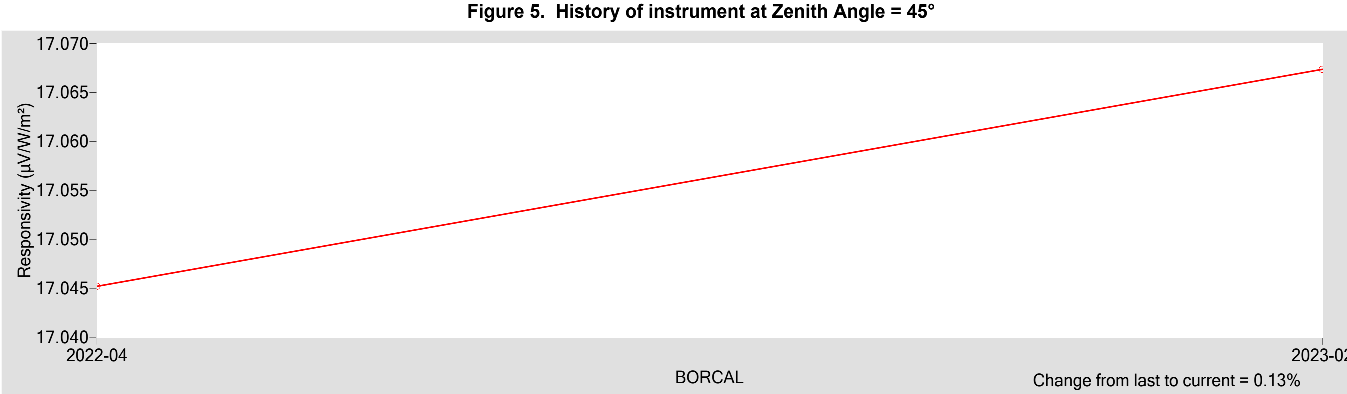
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
17.067	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.68 / -0.97
Expanded Uncertainty, U (%)	+1.4 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15366
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR)   ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

____ ______________

Afshin M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

15366 Hukseflux SR20-T2

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

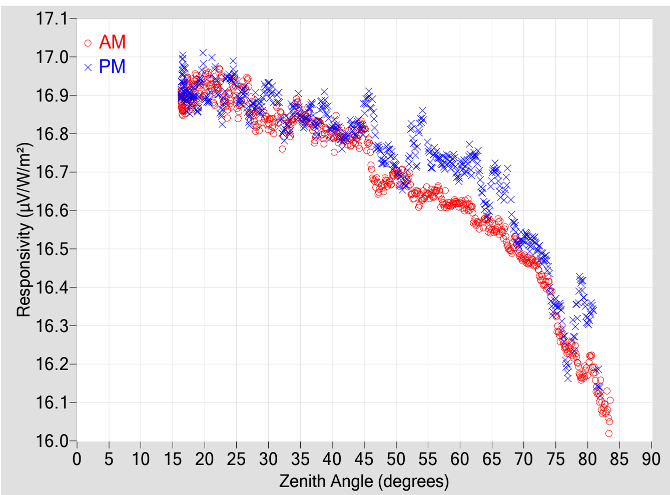


Figure 2. Responsivity vs Local Standard Time

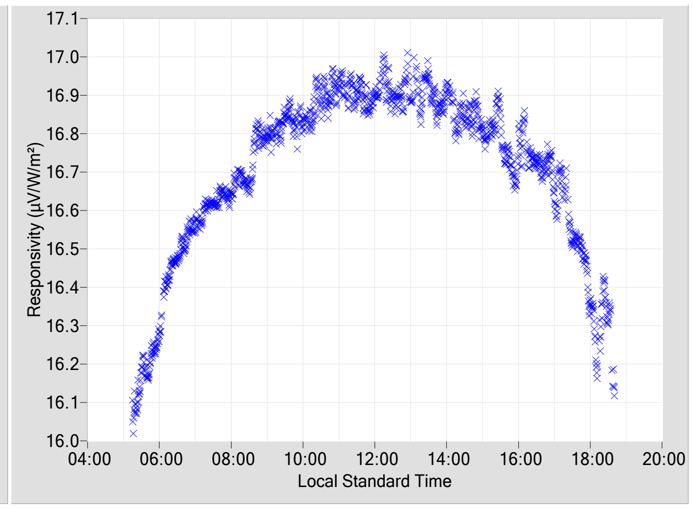


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	16.737	0.33	94.83	16.887	0.33	265.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.666	0.32	93.03	16.728	0.33	266.99
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.699	0.32	91.29	16.712	0.34	268.69
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.678	0.33	89.63	16.743	0.33	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.635	0.33	87.98	16.841	0.34	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.645	0.34	86.37	16.749	0.34	273.62
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.614	0.35	84.80	16.736	0.35	275.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.619	0.36	83.25	16.705	0.36	276.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.591	0.37	81.73	16.727	0.38	278.25
18	16.893	0.33	152.50	16.892	0.31	207.61	64	16.581	0.38	80.22	16.608	0.39	279.82
20	16.920	0.29	140.73	16.934	0.31	219.34	66	16.560	0.40	78.68	16.678	0.41	281.33
22	16.933	0.30	132.65	16.921	0.31	227.13	68	16.498	0.42	77.18	16.597	0.44	282.91
24	16.889	0.32	126.58	16.944	0.33	233.41	70	16.476	0.45	75.65	16.525	0.47	284.37
26	16.908	0.30	121.75	16.907	0.31	238.34	72	16.460	0.48	74.12	16.504	0.51	285.90
28	16.826	0.32	117.49	16.874	0.31	242.49	74	16.398	0.53	72.53	16.414	N/A	287.45
30	16.829	0.30	113.92	16.920	0.31	246.12	76	16.268	N/A	70.98	16.304	N/A	289.05
32	16.824	0.30	110.82	16.831	0.35	249.16	78	16.229	N/A	69.36	16.298	N/A	290.67
34	16.844	0.30	108.01	16.862	0.32	251.98	80	16.188	N/A	67.73	16.313	N/A	292.30
36	16.850	0.30	105.31	16.842	0.30	254.70	82	16.113	N/A	66.03	16.132	N/A	293.90
38	16.829	0.30	102.99	16.854	0.30	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	16.790	0.32	100.72	16.820	0.31	259.23	86	N/A	N/A	N/A	N/A	N/A	N/A
42	16.787	0.31	98.67	16.791	0.31	261.37	88	N/A	N/A	N/A	N/A	N/A	N/A
44	16.785	0.31	96.71	16.825	0.31	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

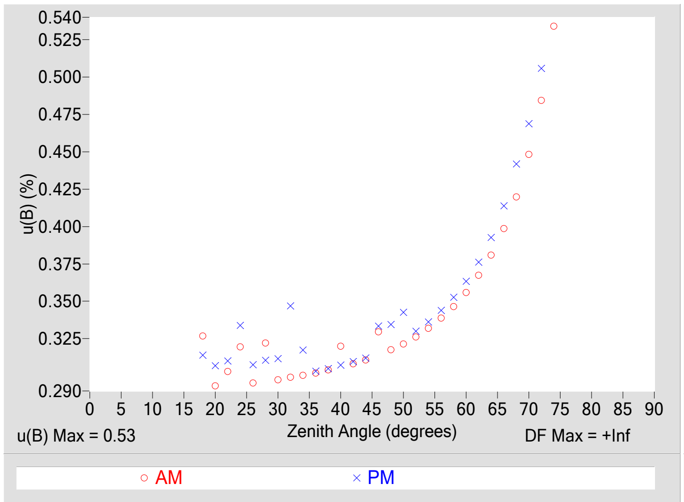


Figure 4. Residuals from Spline Interpolation

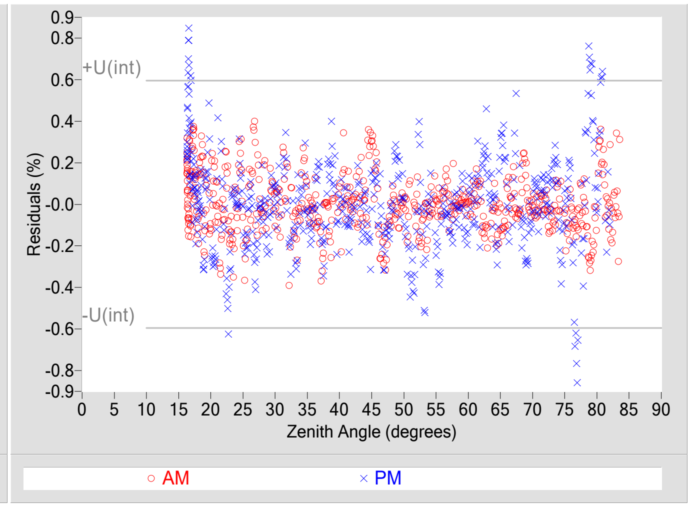


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	19455
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

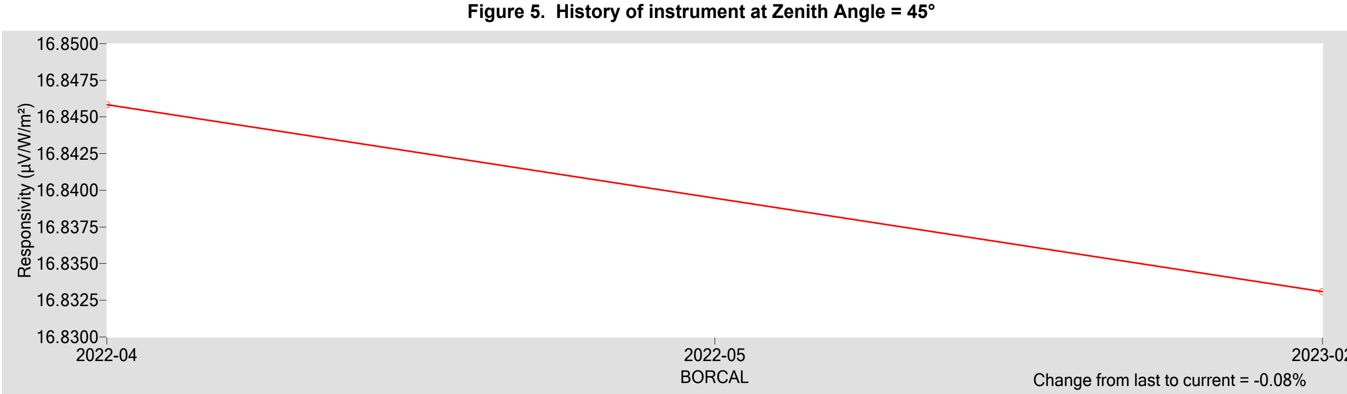
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
16.833	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.52 / -1.3
Expanded Uncertainty, U (%)	+1.2 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2549
Calibration Date:	6/19/2023	**Due Date:**	6/19/2025
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________________ ________________
Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

2549 Hukseflux SR25

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

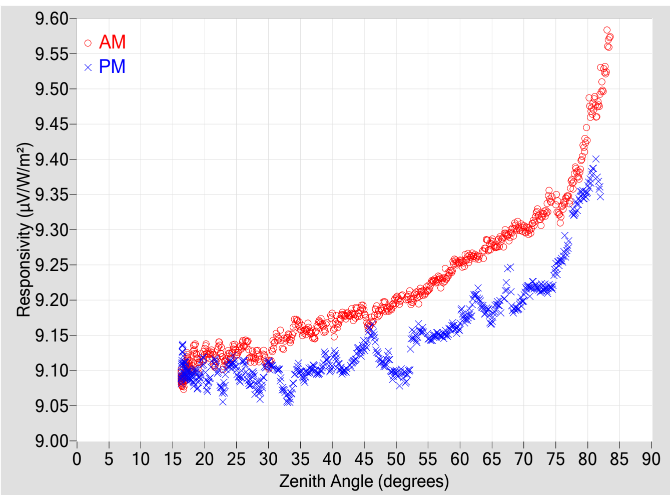


Figure 2. Responsivity vs Local Standard Time

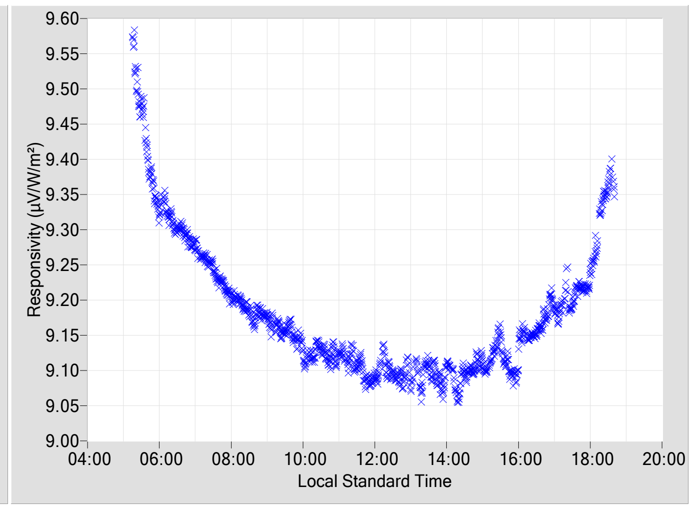


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1677	0.33	94.83	9.1571	0.33	265.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1920	0.32	93.03	9.1095	0.34	266.99
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2012	0.32	91.29	9.0966	0.34	268.69
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2057	0.33	89.63	9.1050	0.33	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2121	0.33	87.98	9.1562	0.34	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2274	0.34	86.37	9.1489	0.34	273.62
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2333	0.35	84.80	9.1524	0.35	275.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2544	0.36	83.25	9.1712	0.36	276.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2632	0.37	81.73	9.1940	0.38	278.25
18	9.1094	0.33	152.50	9.0887	0.31	207.61	64	9.2776	0.38	80.22	9.1833	0.39	279.82
20	9.1261	0.29	140.73	9.1013	0.31	219.34	66	9.2814	0.40	78.68	9.1953	0.42	281.33
22	9.1258	0.30	132.65	9.1026	0.31	227.13	68	9.2943	0.42	77.18	9.2089	0.44	282.86
24	9.1207	0.32	126.58	9.1085	0.33	233.41	70	9.3014	0.45	75.65	9.2054	0.47	284.37
26	9.1358	0.30	121.75	9.1077	0.31	238.34	72	9.3215	0.49	74.12	9.2185	0.51	285.90
28	9.1209	0.32	117.49	9.0798	0.31	242.49	74	9.3421	0.54	72.53	9.2171	N/A	287.45
30	9.1083	0.30	113.92	9.1097	0.31	246.12	76	9.3271	N/A	70.98	9.2596	N/A	289.05
32	9.1437	0.30	110.82	9.0849	0.35	249.16	78	9.3772	N/A	69.36	9.3277	N/A	290.67
34	9.1611	0.30	108.01	9.0854	0.32	251.98	80	9.4532	N/A	67.73	9.3568	N/A	292.30
36	9.1585	0.30	105.31	9.0976	0.30	254.70	82	9.4969	N/A	66.03	9.3550	N/A	293.90
38	9.1684	0.30	102.99	9.0978	0.31	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1675	0.32	100.72	9.1112	0.31	259.23	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1779	0.31	98.67	9.0996	0.31	261.37	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1823	0.31	96.71	9.1289	0.31	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

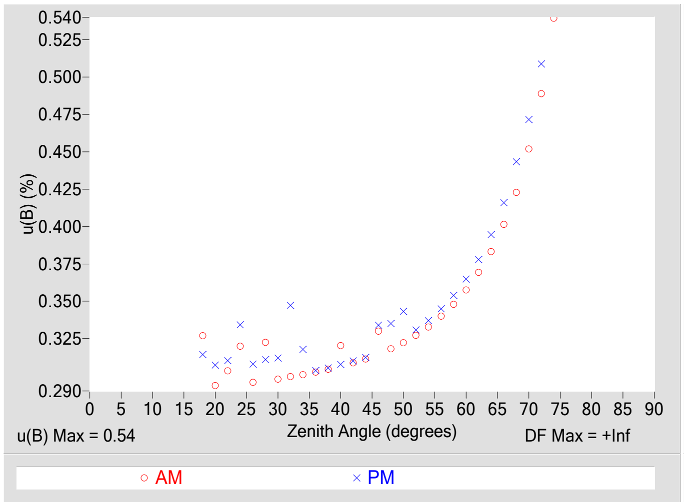


Figure 4. Residuals from Spline Interpolation

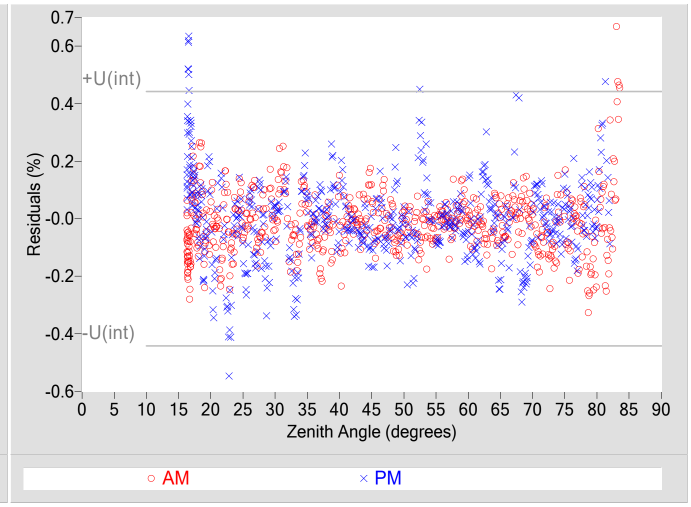


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.54
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	53137
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

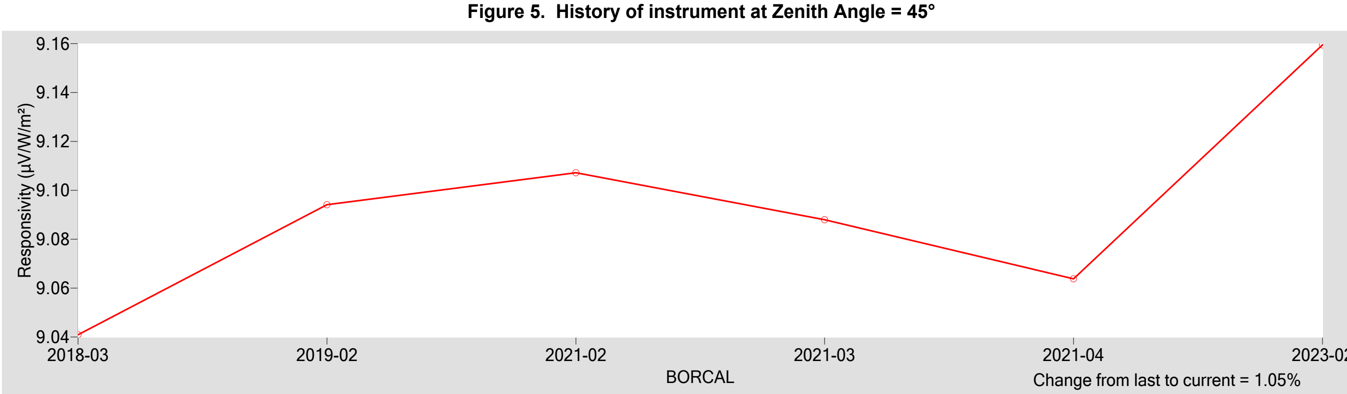
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.1595	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.0 / -0.81
Expanded Uncertainty, U (%)	+1.8 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2550
Calibration Date:	6/19/2023	**Due Date:**	6/19/2025
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

________________________________ ________________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

2550 Hukseflux SR25

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc$^4
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

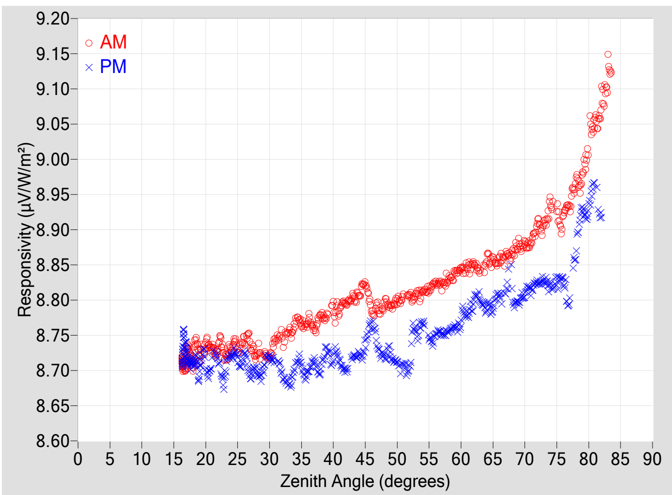


Figure 2. Responsivity vs Local Standard Time

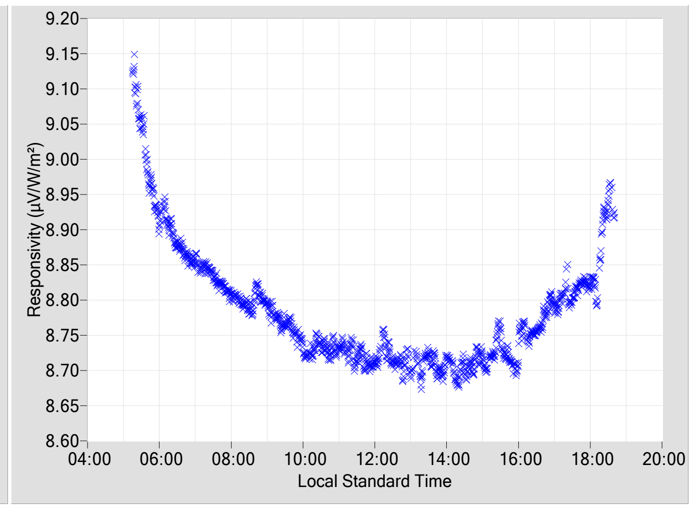


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7873	0.33	94.83	8.7650	0.33	265.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7942	0.32	93.03	8.7198	0.34	266.99
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8001	0.32	91.29	8.7113	0.34	268.69
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8069	0.33	89.63	8.7124	0.33	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8128	0.33	87.98	8.7674	0.34	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8239	0.34	86.37	8.7506	0.35	273.62
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8282	0.35	84.80	8.7554	0.35	275.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8450	0.36	83.25	8.7737	0.37	276.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8514	0.37	81.73	8.7963	0.38	278.25
18	8.7150	0.33	152.50	8.7120	0.31	207.61	64	8.8575	0.38	80.22	8.7887	0.40	279.82
20	8.7355	0.29	140.73	8.7130	0.31	219.34	66	8.8576	0.40	78.68	8.8069	0.42	281.33
22	8.7364	0.30	132.65	8.7133	0.31	227.13	68	8.8649	0.42	77.18	8.8143	0.44	282.86
24	8.7306	0.32	126.58	8.7199	0.33	233.41	70	8.8791	0.45	75.65	8.8090	0.47	284.37
26	8.7414	0.30	121.75	8.7212	0.31	238.34	72	8.9082	0.49	74.12	8.8252	0.51	285.90
28	8.7240	0.32	117.49	8.6981	0.31	242.49	74	8.9327	0.54	72.53	8.8194	N/A	287.45
30	8.7207	0.30	113.92	8.7175	0.31	246.12	76	8.9143	N/A	70.98	8.8255	N/A	289.05
32	8.7455	0.30	110.82	8.6936	0.35	249.16	78	8.9665	N/A	69.36	8.8719	N/A	290.67
34	8.7661	0.30	108.01	8.7043	0.32	251.98	80	9.0276	N/A	67.73	8.9290	N/A	292.30
36	8.7701	0.30	105.31	8.6984	0.30	254.70	82	9.0779	N/A	66.03	8.9193	N/A	293.90
38	8.7775	0.30	102.99	8.7016	0.31	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7848	0.32	100.72	8.7177	0.31	259.23	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7953	0.31	98.67	8.7006	0.31	261.37	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8077	0.31	96.71	8.7237	0.31	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

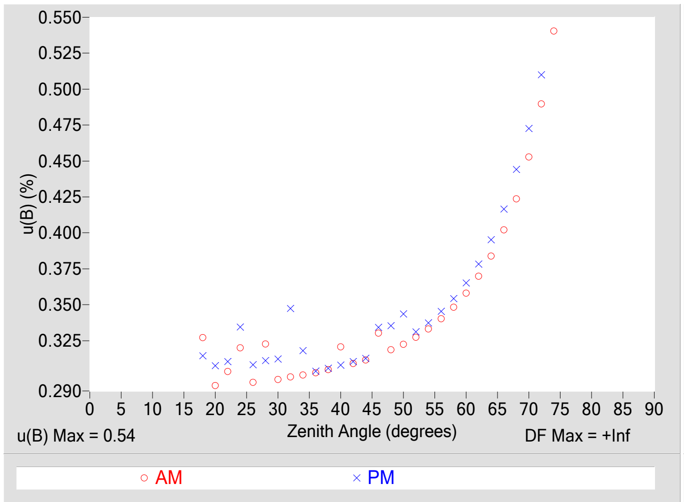


Figure 4. Residuals from Spline Interpolation

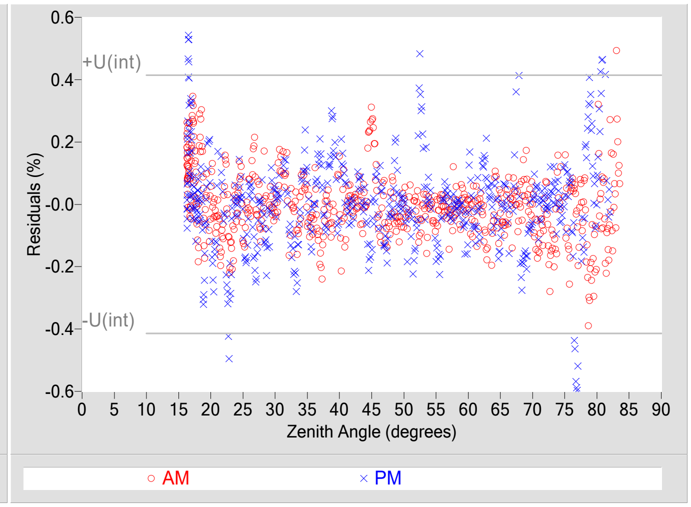


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.54
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	66783
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

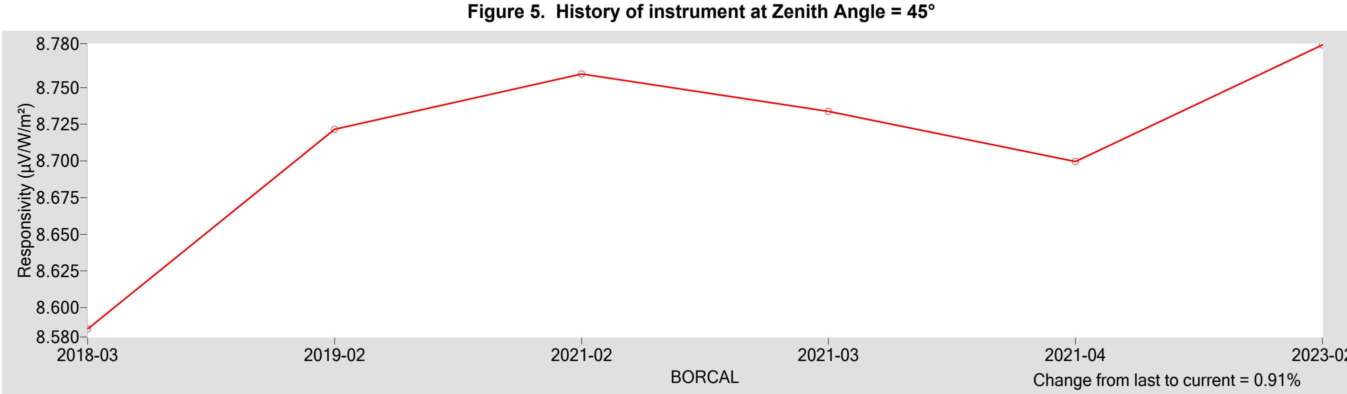
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.7792	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.75 / -0.98
Expanded Uncertainty, U (%)	+1.5 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31121E6
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

________________________________ ____________

Afshin M. Andreas, Deputy Technical Manager — Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31121E6 Eppley NIP

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \quad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

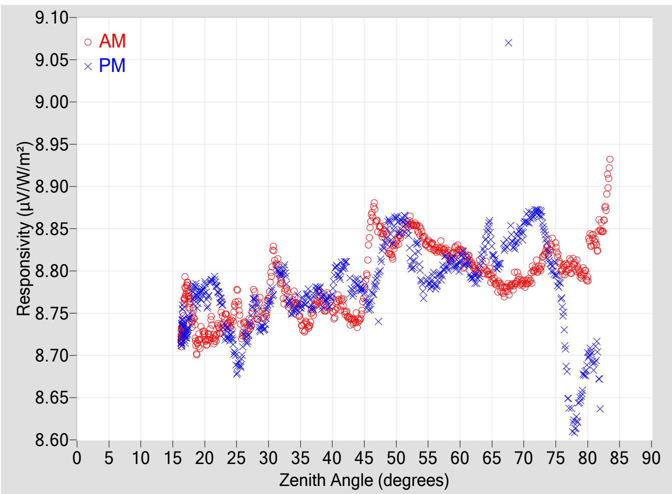


Figure 2. Responsivity vs Local Standard Time

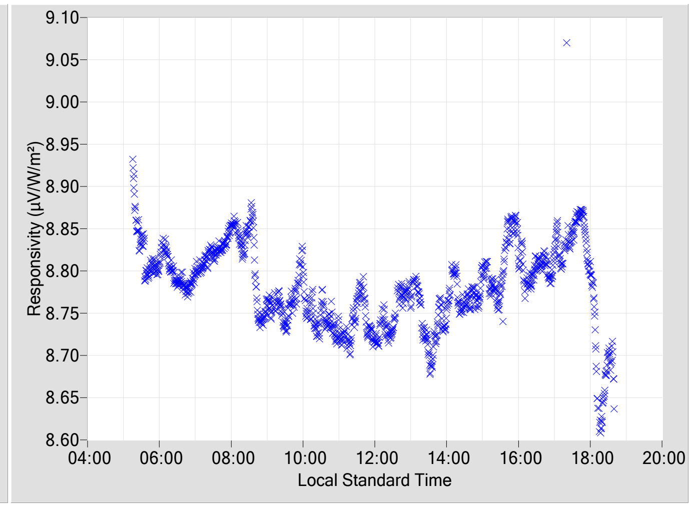


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8570	0.30	94.82	8.7639	0.29	265.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8459	0.29	93.02	8.8285	0.29	266.98
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8344	0.29	91.28	8.8623	0.29	268.73
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8573	0.29	89.62	8.8327	0.29	270.38
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8431	0.29	87.97	8.7842	0.29	272.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8260	0.29	86.36	8.7870	0.29	273.61
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8222	0.29	84.83	8.8074	0.29	275.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8228	0.29	83.29	8.8114	0.30	276.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8064	0.29	81.71	8.7911	0.30	278.29
18	8.7481	0.30	152.34	8.7737	0.31	208.64	64	8.8024	0.30	80.21	8.8369	0.30	279.81
20	8.7221	0.30	140.63	8.7777	0.32	219.47	66	8.7839	0.30	78.67	8.8069	0.30	281.32
22	8.7293	0.28	132.63	8.7777	0.31	227.35	68	8.7830	0.30	77.18	8.8418	0.31	282.90
24	8.7371	0.31	126.57	8.7227	0.29	233.39	70	8.7851	0.30	75.64	8.8508	0.31	284.36
26	8.7310	0.29	121.62	8.7121	0.29	238.21	72	8.8033	0.30	74.11	8.8713	0.31	285.90
28	8.7583	0.29	117.47	8.7621	0.31	242.44	74	8.8279	0.31	72.57	8.8108	N/A	287.48
30	8.7679	0.30	113.99	8.7602	0.32	246.02	76	8.8008	N/A	70.97	8.7581	N/A	289.04
32	8.7863	0.30	110.85	8.7970	0.32	249.24	78	8.8055	N/A	69.36	8.6179	N/A	290.62
34	8.7662	0.31	107.92	8.7536	0.31	252.18	80	8.8056	N/A	67.70	8.6951	N/A	292.32
36	8.7353	0.30	105.36	8.7694	0.29	254.62	82	8.8512	N/A	65.98	8.6603	N/A	293.85
38	8.7714	0.29	102.98	8.7762	0.29	257.03	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7547	0.30	100.71	8.7785	0.30	259.29	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7541	0.29	98.66	8.8086	0.29	261.30	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7414	0.29	96.70	8.7829	0.29	263.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

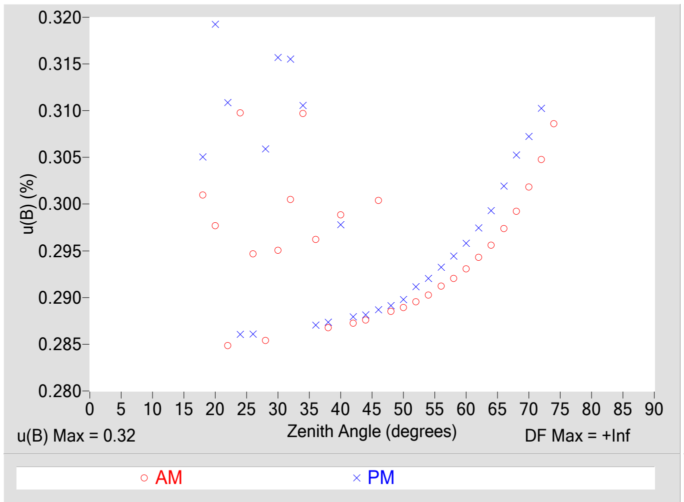


Figure 4. Residuals from Spline Interpolation

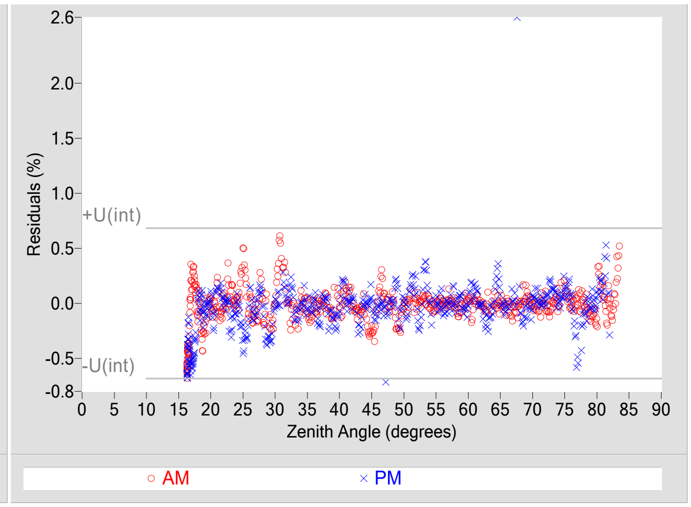


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	3894
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.92
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

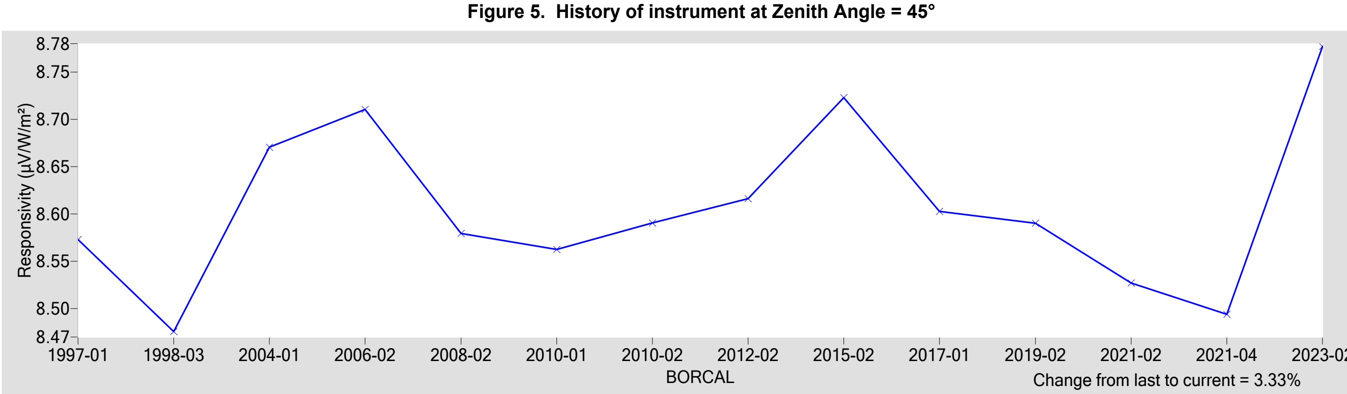
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7770	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.97 / -0.48
Expanded Uncertainty, U (%)	+1.6 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 31146F3

Calibration Date: 6/19/2023

Due Date: 6/19/2024

Customer: Craig Webb

Environmental Conditions: see page 4

Test Dates: 6/19

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________ ______________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31146F3 Eppley PSP

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

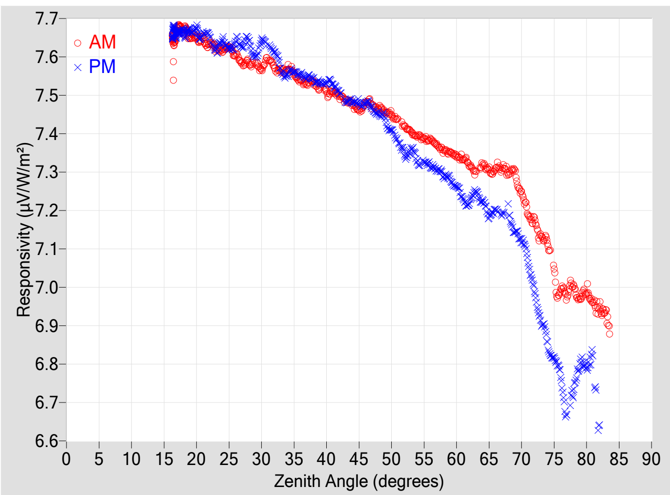


Figure 2. Responsivity vs Local Standard Time

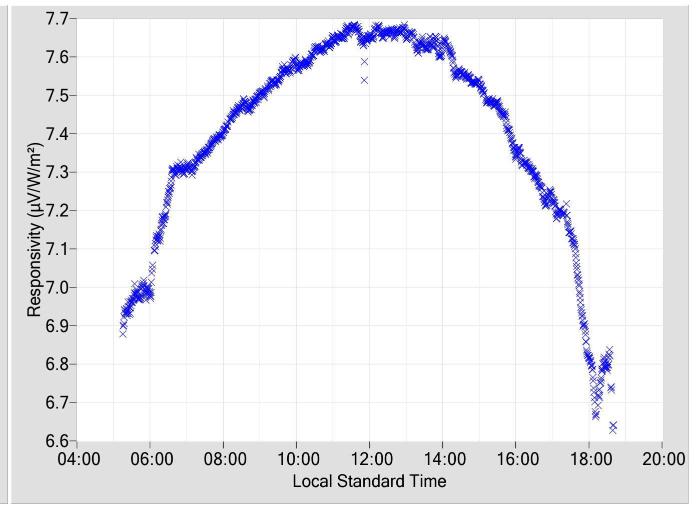


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4806	0.38	94.79	7.4794	0.34	265.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4655	0.34	93.04	7.4508	0.34	267.01
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4501	0.34	91.31	7.4088	0.35	268.71
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4191	0.35	89.59	7.3463	0.36	270.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3945	0.35	88.00	7.3254	0.37	272.01
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3837	0.36	86.39	7.3159	0.38	273.63
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3565	0.37	84.81	7.2899	0.39	275.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3420	0.38	83.27	7.2624	0.40	276.73
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3184	0.40	81.74	7.2211	0.42	278.27
18	7.6706	0.32	152.29	7.6628	0.33	207.83	64	7.3191	0.41	80.19	7.2229	0.44	279.79
20	7.6515	0.31	140.55	7.6722	0.32	219.52	66	7.3083	0.43	78.69	7.2025	0.46	281.30
22	7.6342	0.32	132.70	7.6535	0.33	227.25	68	7.2955	0.46	77.16	7.1905	0.50	282.92
24	7.6176	0.33	126.63	7.6409	0.32	233.54	70	7.2462	0.49	75.67	7.1213	0.54	284.38
26	7.6050	0.32	121.68	7.6430	0.31	238.35	72	7.1722	0.54	74.09	6.9862	0.59	285.92
28	7.5852	0.33	117.53	7.6434	0.33	242.49	74	7.1142	0.59	72.55	6.8524	N/A	287.46
30	7.5685	0.31	113.95	7.6410	0.32	246.06	76	6.9913	N/A	70.95	6.7707	N/A	289.02
32	7.5721	0.34	110.82	7.6109	0.34	249.28	78	7.0005	N/A	69.34	6.7331	N/A	290.64
34	7.5693	0.31	107.89	7.5542	0.32	252.08	80	6.9887	N/A	67.72	6.7934	N/A	292.26
36	7.5385	0.32	105.33	7.5541	0.35	254.65	82	6.9425	N/A	66.00	6.6361	N/A	293.87
38	7.5338	0.32	102.95	7.5393	0.32	257.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5084	0.35	100.75	7.5311	0.35	259.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4979	0.36	98.69	7.5075	0.33	261.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4756	0.33	96.67	7.4841	0.33	263.31	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

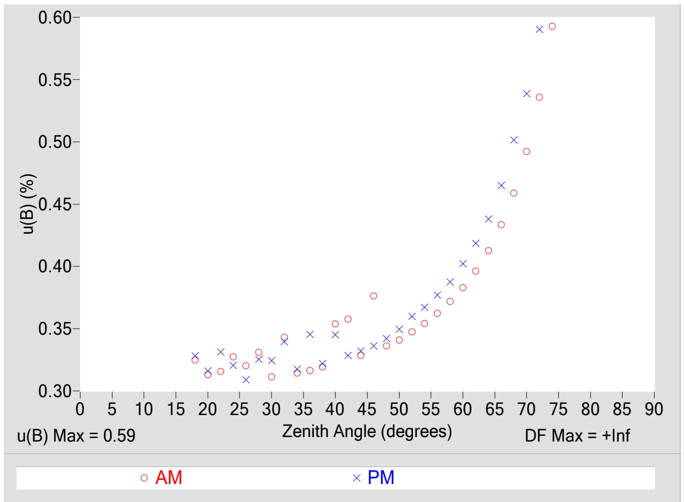


Figure 4. Residuals from Spline Interpolation

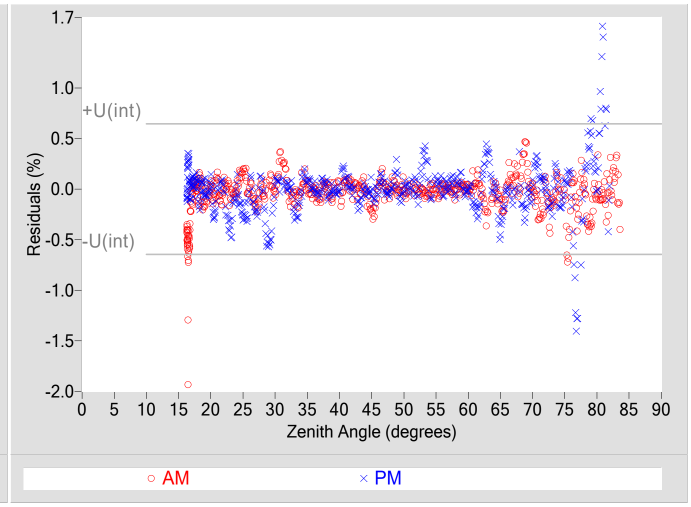


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	21034
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

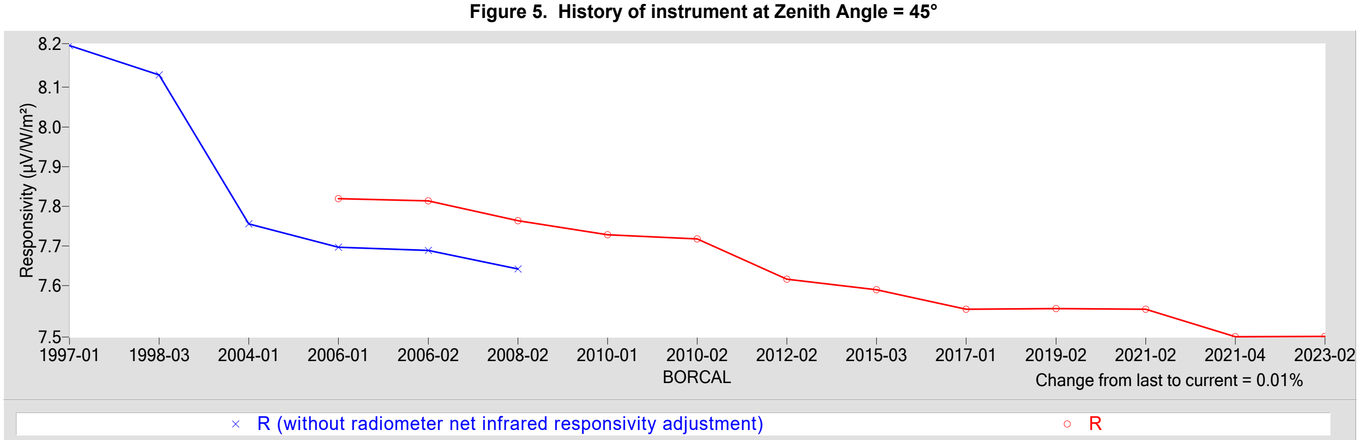
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.4713	0.56000

† Rnet determination date: 02/27/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+2.3 / -2.8
Expanded Uncertainty, U (%)	+3.1 / -3.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31147F3
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

________________________________ ____________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31147F3 Eppley PSP

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

*R = (V - Rnet * Wnet) / I* [1]

where,

V = radiometer output voltage (microvolts),
Rnet = radiometer net infrared responsivity (μV/W/m²), see Table 4,
Wnet = effective net infrared measured by pyrgeometer (W/m²),
= *Win - Wout* = *Win - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, *G = B * COS(Z) + D,*
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

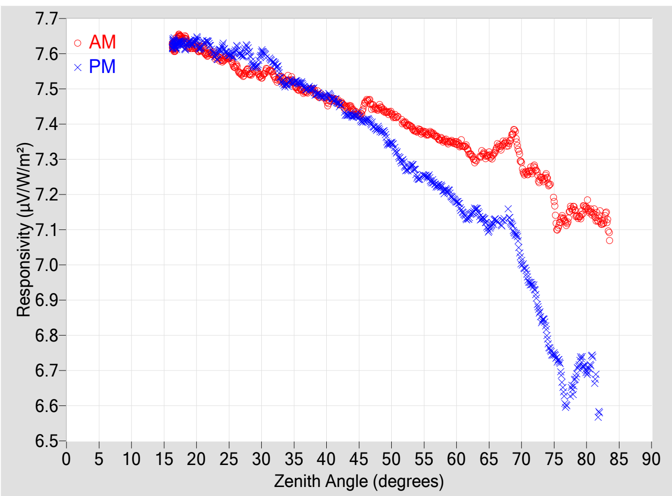


Figure 2. Responsivity vs Local Standard Time

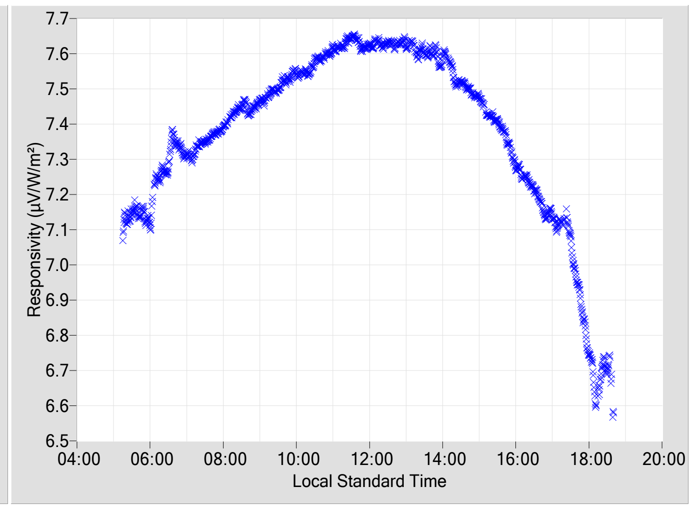


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4626	0.38	94.79	7.4101	0.34	265.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4448	0.34	93.04	7.3858	0.34	267.01
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4299	0.34	91.31	7.3454	0.35	268.71
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4037	0.35	89.59	7.2806	0.36	270.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3813	0.36	88.00	7.2481	0.37	272.01
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3743	0.36	86.39	7.2419	0.38	273.63
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3536	0.37	84.81	7.2113	0.39	275.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3461	0.39	83.27	7.1800	0.41	276.73
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3184	0.40	81.74	7.1368	0.42	278.27
18	7.6412	0.33	152.29	7.6254	0.33	207.83	64	7.3169	0.42	80.19	7.1316	0.44	279.79
20	7.6181	0.31	140.55	7.6376	0.32	219.52	66	7.3249	0.44	78.69	7.1280	0.47	281.30
22	7.6017	0.32	132.70	7.6262	0.33	227.25	68	7.3453	0.46	77.16	7.1373	0.51	282.92
24	7.5822	0.33	126.63	7.6184	0.32	233.54	70	7.2886	0.50	75.67	7.0079	0.55	284.38
26	7.5635	0.32	121.68	7.6128	0.31	238.35	72	7.2735	0.54	74.09	6.9264	0.60	285.92
28	7.5485	0.33	117.53	7.6085	0.33	242.49	74	7.2421	0.60	72.55	6.7890	N/A	287.46
30	7.5348	0.31	113.95	7.6023	0.33	246.06	76	7.1264	N/A	70.95	6.7041	N/A	289.02
32	7.5344	0.34	110.82	7.5717	0.34	249.28	78	7.1596	N/A	69.34	6.6568	N/A	290.64
34	7.5264	0.32	107.89	7.5129	0.32	252.08	80	7.1655	N/A	67.72	6.6986	N/A	292.26
36	7.4980	0.32	105.33	7.5163	0.35	254.65	82	7.1313	N/A	66.00	6.5769	N/A	293.87
38	7.4949	0.32	102.95	7.4948	0.32	257.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4665	0.36	100.75	7.4768	0.35	259.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4601	0.36	98.69	7.4552	0.33	261.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4406	0.33	96.67	7.4232	0.33	263.31	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

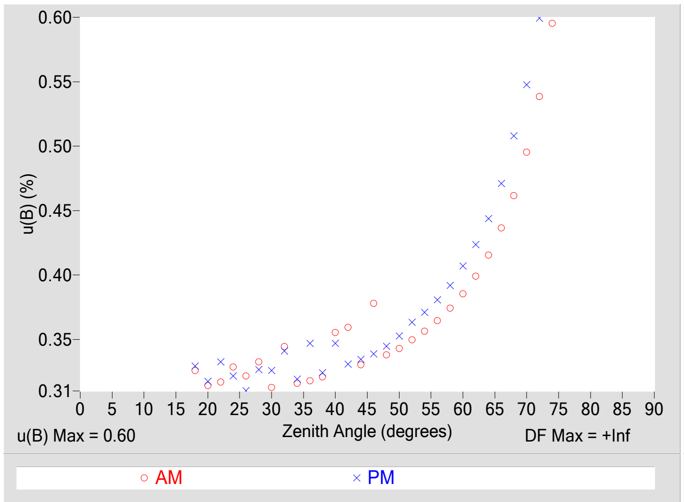


Figure 4. Residuals from Spline Interpolation

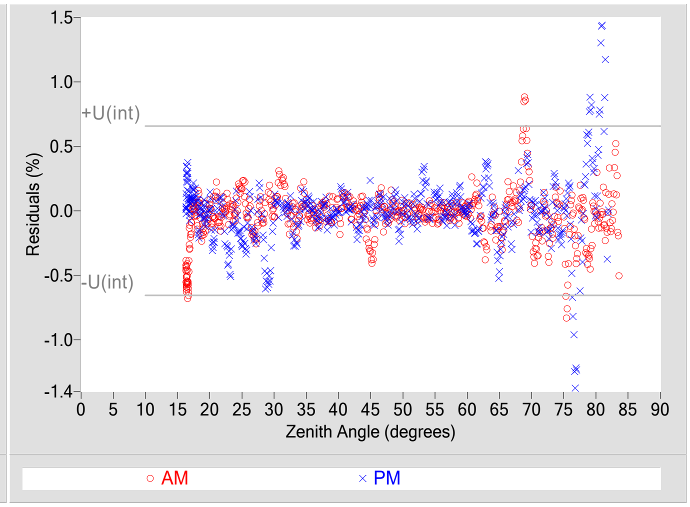


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	20814
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

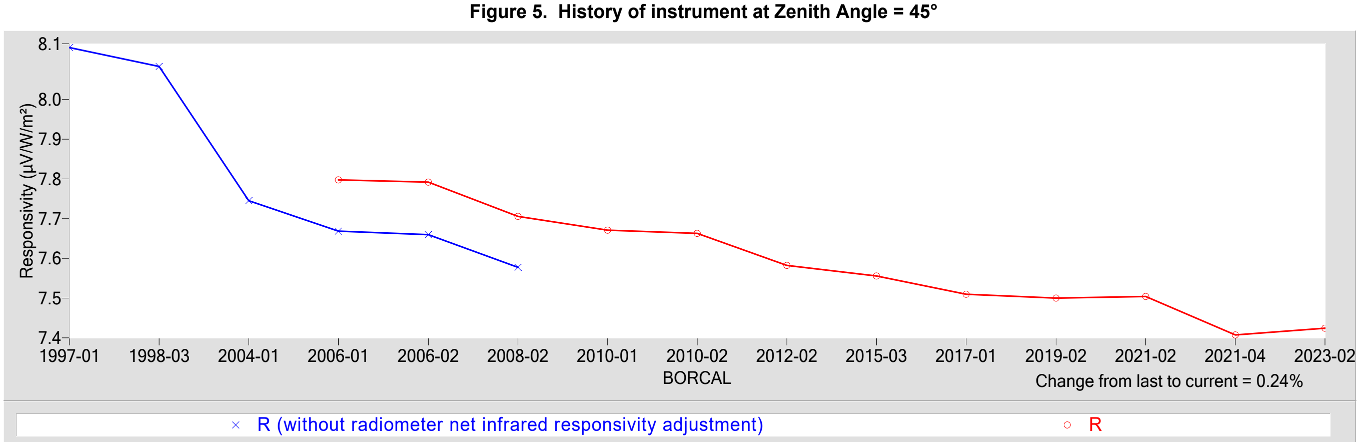
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.4244	0.59000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+2.4 / -3.3
Expanded Uncertainty, U (%)	+3.2 / -4.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31148F3
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

____ ________________
Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31148F3 Eppley PSP

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

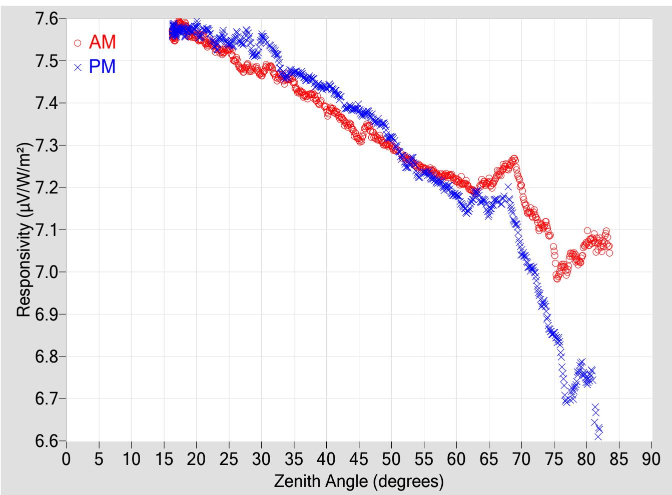


Figure 2. Responsivity vs Local Standard Time

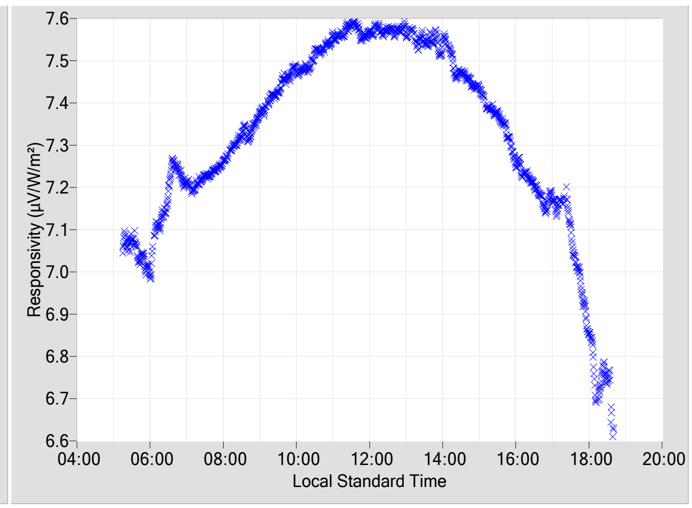


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.3415	0.38	94.79	7.3754	0.34	265.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3163	0.34	93.04	7.3542	0.34	267.01
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2986	0.34	91.31	7.3185	0.35	268.71
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2723	0.35	89.59	7.2592	0.36	270.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2510	0.35	88.00	7.2308	0.37	272.01
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2412	0.36	86.39	7.2265	0.38	273.63
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2268	0.37	84.81	7.2015	0.39	275.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2169	0.38	83.27	7.1820	0.40	276.73
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1978	0.40	81.74	7.1532	0.42	278.27
18	7.5812	0.32	152.29	7.5694	0.33	207.83	64	7.2113	0.41	80.19	7.1685	0.44	279.79
20	7.5592	0.31	140.55	7.5809	0.32	219.52	66	7.2207	0.43	78.69	7.1710	0.46	281.30
22	7.5417	0.32	132.70	7.5661	0.33	227.25	68	7.2484	0.46	77.16	7.1757	0.50	282.92
24	7.5206	0.33	126.63	7.5602	0.32	233.54	70	7.2001	0.49	75.67	7.0476	0.54	284.38
26	7.5019	0.32	121.68	7.5582	0.31	238.35	72	7.1353	0.54	74.09	6.9968	0.59	285.92
28	7.4839	0.33	117.53	7.5577	0.33	242.49	74	7.1030	0.59	72.55	6.8850	N/A	287.46
30	7.4677	0.31	113.95	7.5545	0.32	246.06	76	7.0055	N/A	70.95	6.8148	N/A	289.02
32	7.4680	0.34	110.82	7.5214	0.34	249.28	78	7.0409	N/A	69.34	6.7179	N/A	290.64
34	7.4585	0.31	107.89	7.4642	0.32	252.08	80	7.0719	N/A	67.72	6.7437	N/A	292.26
36	7.4262	0.32	105.33	7.4691	0.35	254.65	82	7.0658	N/A	66.00	6.6229	N/A	293.87
38	7.4175	0.32	102.95	7.4506	0.32	257.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3831	0.35	100.75	7.4354	0.34	259.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3677	0.36	98.69	7.4145	0.33	261.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3367	0.33	96.67	7.3858	0.33	263.31	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

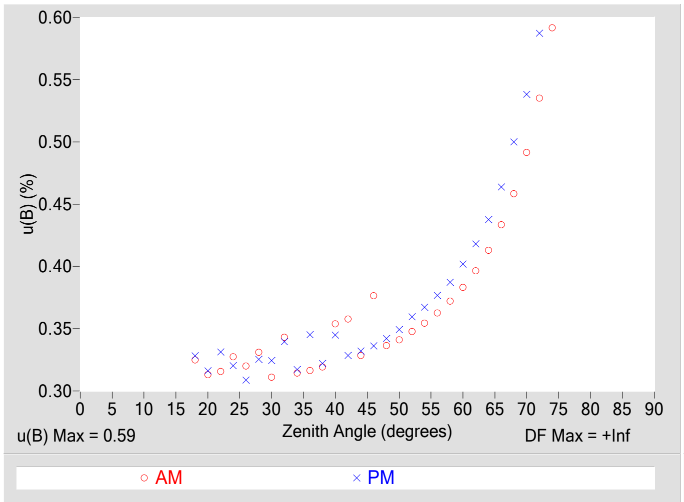


Figure 4. Residuals from Spline Interpolation

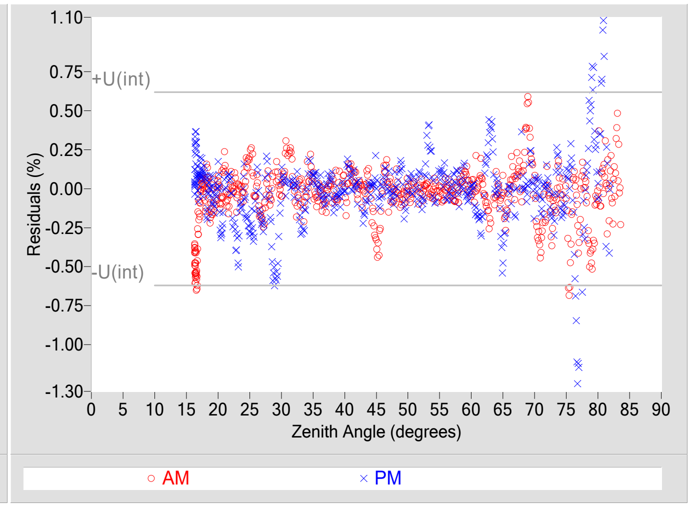


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	23755
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

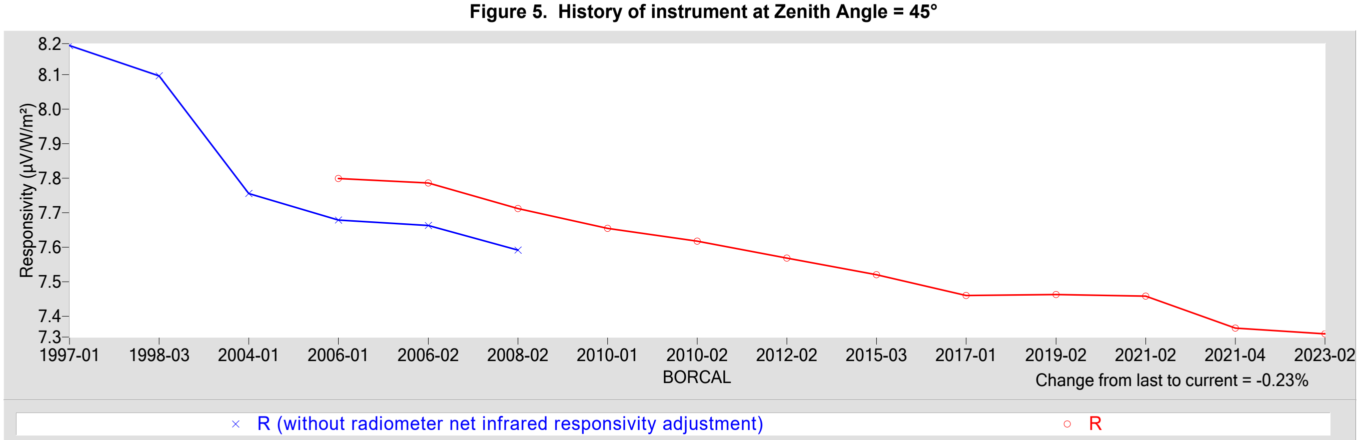
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.3491	0.55000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+2.8 / -2.3
Expanded Uncertainty, U (%)	+3.6 / -3.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31155F3
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR)   ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

________________________________ ____________

Afshin M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31155F3 Eppley PSP

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

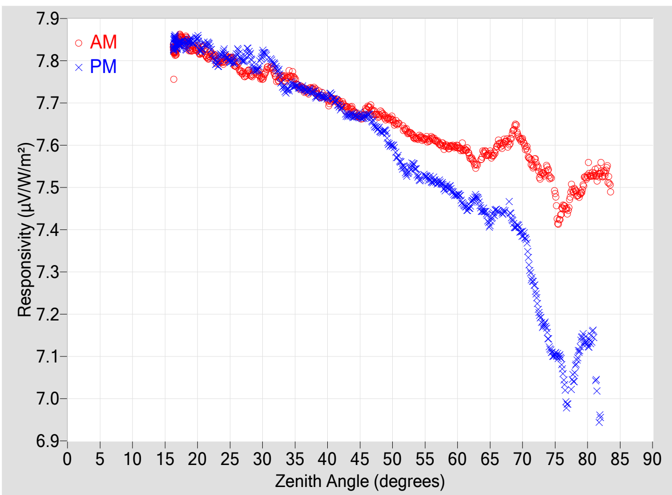


Figure 2. Responsivity vs Local Standard Time

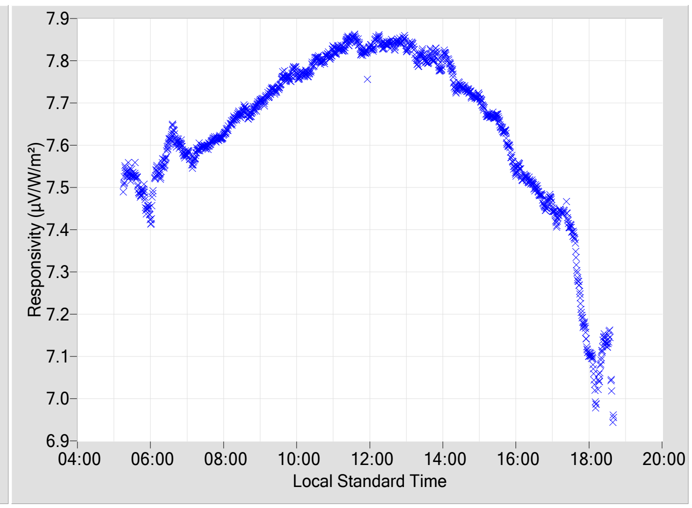


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6860	0.37	94.79	7.6698	0.33	265.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6716	0.33	93.04	7.6351	0.34	267.01
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6609	0.34	91.31	7.5985	0.35	268.71
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6369	0.35	89.59	7.5371	0.36	270.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6175	0.35	88.00	7.5232	0.36	272.01
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6157	0.36	86.39	7.5175	0.37	273.63
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5980	0.37	84.81	7.4988	0.38	275.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5959	0.38	83.27	7.4827	0.40	276.73
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5719	0.39	81.74	7.4584	0.41	278.27
18	7.8479	0.32	152.29	7.8383	0.33	207.83	64	7.5819	0.41	80.19	7.4446	0.43	279.79
20	7.8289	0.31	140.55	7.8497	0.32	219.52	66	7.5930	0.43	78.69	7.4462	0.46	281.30
22	7.8133	0.31	132.70	7.8296	0.33	227.25	68	7.6067	0.45	77.16	7.4433	0.49	282.92
24	7.7980	0.33	126.63	7.8183	0.32	233.54	70	7.6109	0.49	75.67	7.3906	0.53	284.38
26	7.7901	0.32	121.68	7.8180	0.31	238.35	72	7.5575	0.53	74.09	7.2504	0.58	285.92
28	7.7711	0.33	117.53	7.8172	0.32	242.49	74	7.5359	0.58	72.55	7.1361	N/A	287.46
30	7.7593	0.31	113.95	7.8159	0.32	246.06	76	7.4425	N/A	70.95	7.0843	N/A	289.02
32	7.7632	0.34	110.82	7.7854	0.34	249.28	78	7.4924	N/A	69.34	7.0602	N/A	290.64
34	7.7641	0.31	107.89	7.7337	0.32	252.08	80	7.5314	N/A	67.72	7.1313	N/A	292.26
36	7.7367	0.31	105.33	7.7355	0.34	254.65	82	7.5362	N/A	66.00	6.9534	N/A	293.87
38	7.7316	0.32	102.95	7.7210	0.32	257.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7080	0.35	100.75	7.7117	0.34	259.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6982	0.36	98.69	7.6886	0.33	261.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6801	0.33	96.67	7.6694	0.33	263.31	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

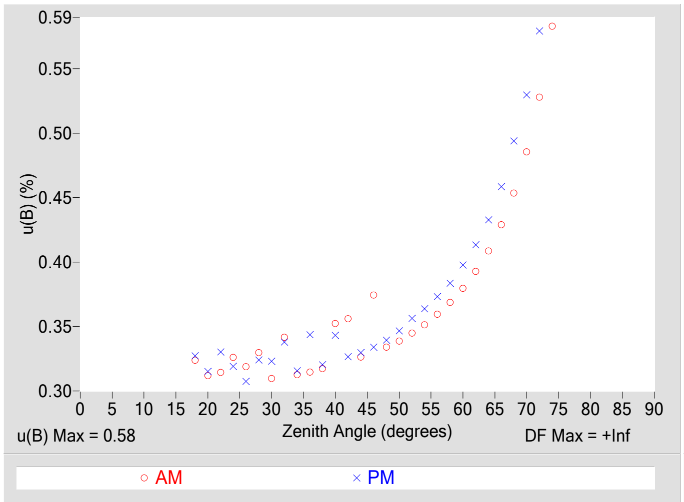


Figure 4. Residuals from Spline Interpolation

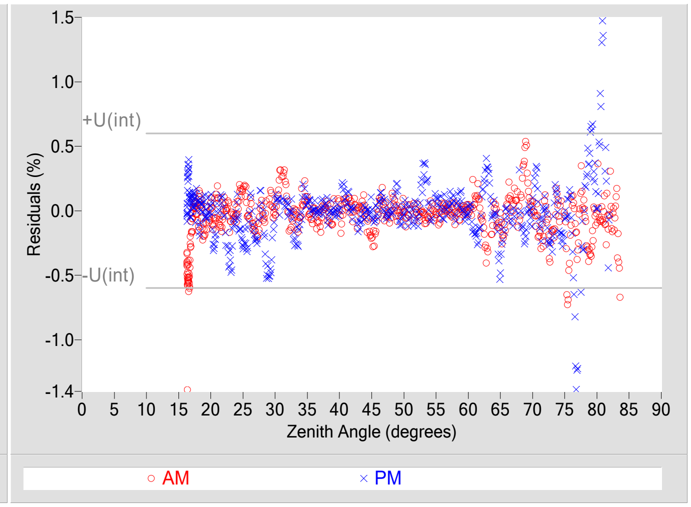


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	25287
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

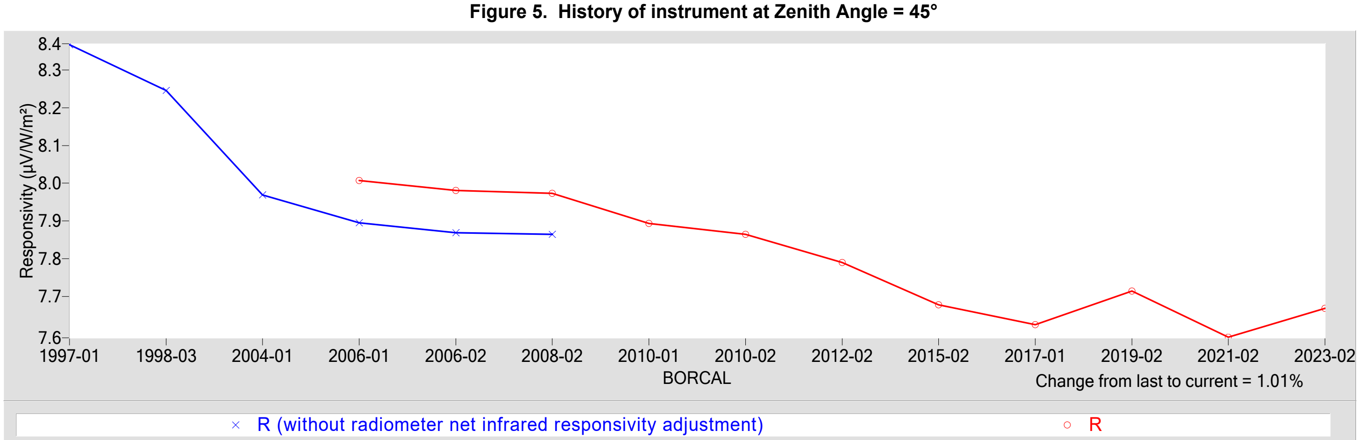
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6684	0.54000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.9 / -2.4
Expanded Uncertainty, U (%)	+2.7 / -3.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31156F3
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________ ____________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31156F3 Eppley PSP

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

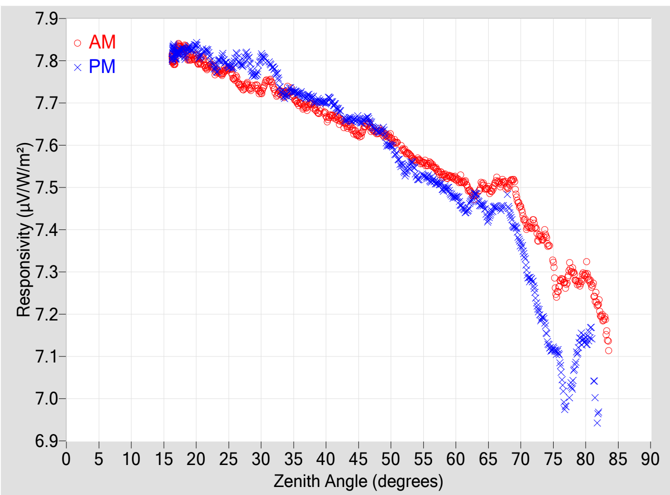


Figure 2. Responsivity vs Local Standard Time

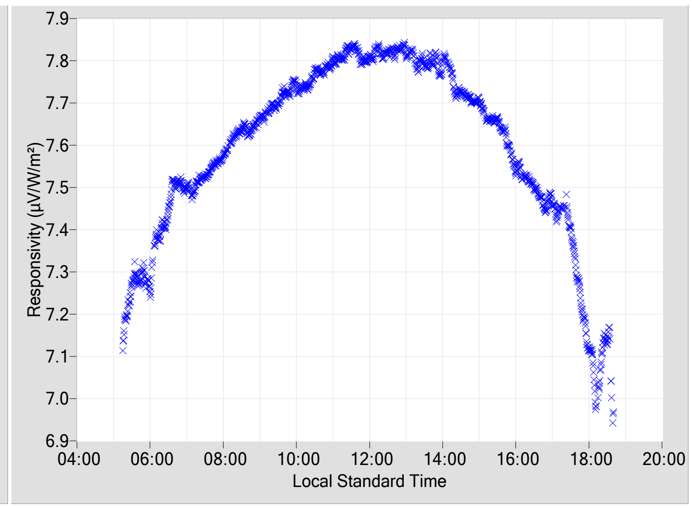


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A
18	7.8271	0.32	152.29	7.8198	0.33	207.83
20	7.8064	0.31	140.55	7.8334	0.32	219.52
22	7.7887	0.32	132.70	7.8148	0.33	227.25
24	7.7707	0.33	126.63	7.8063	0.32	233.54
26	7.7589	0.32	121.68	7.8071	0.31	238.35
28	7.7404	0.33	117.53	7.8082	0.32	242.49
30	7.7256	0.31	113.95	7.8073	0.32	246.06
32	7.7334	0.34	110.82	7.7785	0.34	249.28
34	7.7271	0.31	107.89	7.7210	0.32	252.08
36	7.6983	0.32	105.33	7.7220	0.34	254.65
38	7.6942	0.32	102.95	7.7083	0.32	257.06
40	7.6692	0.35	100.75	7.7000	0.34	259.21
42	7.6594	0.36	98.69	7.6819	0.33	261.33
44	7.6385	0.33	96.67	7.6607	0.33	263.31

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
46	7.6451	0.38	94.79	7.6610	0.34	265.19
48	7.6313	0.34	93.04	7.6337	0.34	267.01
50	7.6181	0.34	91.31	7.5988	0.35	268.71
52	7.5887	0.35	89.59	7.5400	0.36	270.41
54	7.5650	0.35	88.00	7.5246	0.37	272.01
56	7.5558	0.36	86.39	7.5198	0.38	273.63
58	7.5294	0.37	84.81	7.4975	0.39	275.17
60	7.5208	0.38	83.27	7.4778	0.40	276.73
62	7.4956	0.39	81.74	7.4537	0.42	278.27
64	7.5072	0.41	80.19	7.4582	0.44	279.79
66	7.5074	0.43	78.69	7.4544	0.46	281.30
68	7.5016	0.46	77.16	7.4567	0.50	282.92
70	7.4527	0.49	75.67	7.3644	0.53	284.38
72	7.4125	0.53	74.09	7.2621	0.58	285.92
74	7.3767	0.59	72.55	7.1490	N/A	287.46
76	7.2711	N/A	70.95	7.0919	N/A	289.02
78	7.3004	N/A	69.34	7.0444	N/A	290.64
80	7.2988	N/A	67.72	7.1368	N/A	292.26
82	7.2171	N/A	66.00	6.9585	N/A	293.87
84	N/A	N/A	N/A	N/A	N/A	N/A
86	N/A	N/A	N/A	N/A	N/A	N/A
88	N/A	N/A	N/A	N/A	N/A	N/A
90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

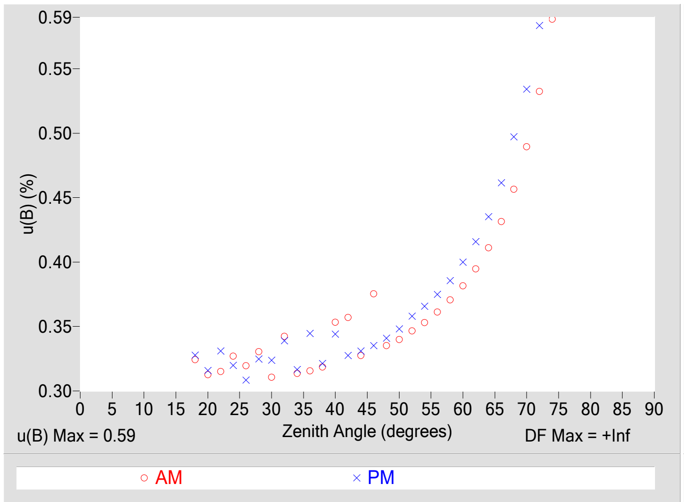


Figure 4. Residuals from Spline Interpolation

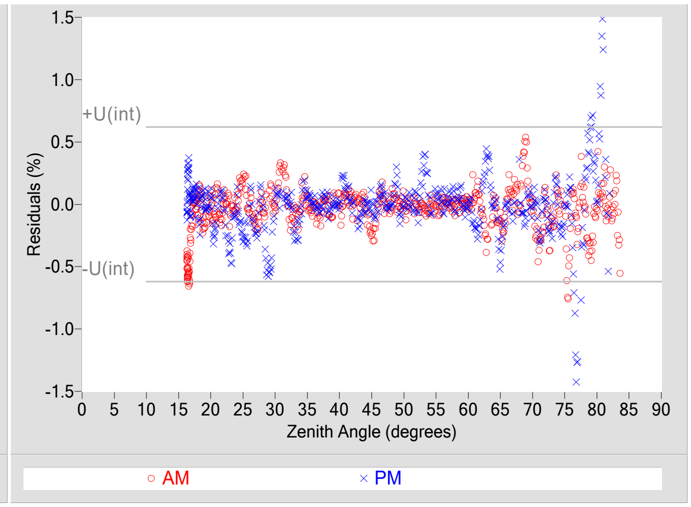


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	23480
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

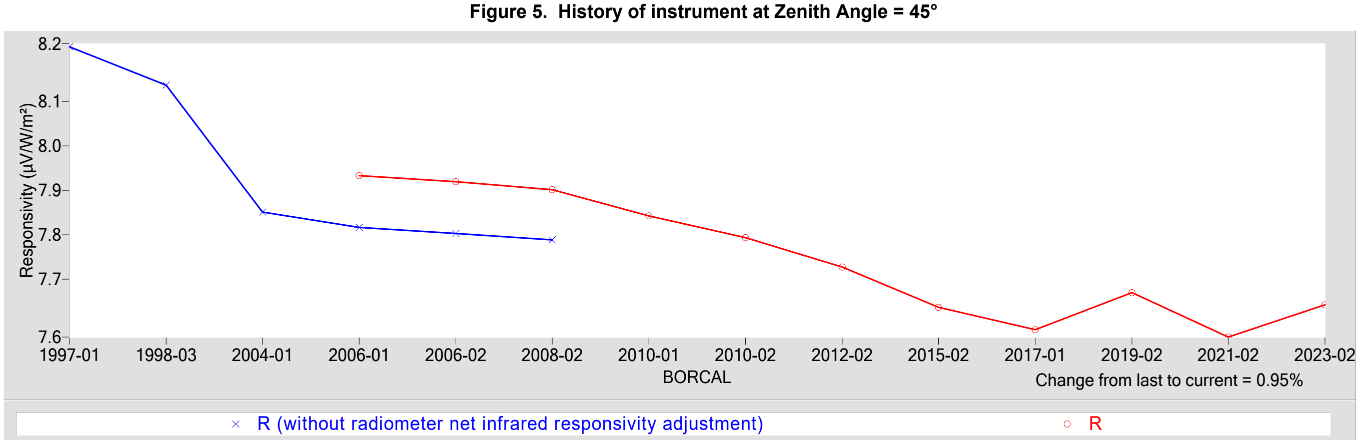
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6425	0.56000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+2.2 / -2.2
Expanded Uncertainty, U (%)	+2.9 / -2.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

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[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31157F3
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	03/31/2022	03/31/2027

† Through the World Radiometric Reference (WRR) ‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________ ____________
Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31157F3 Eppley PSP

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  - = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

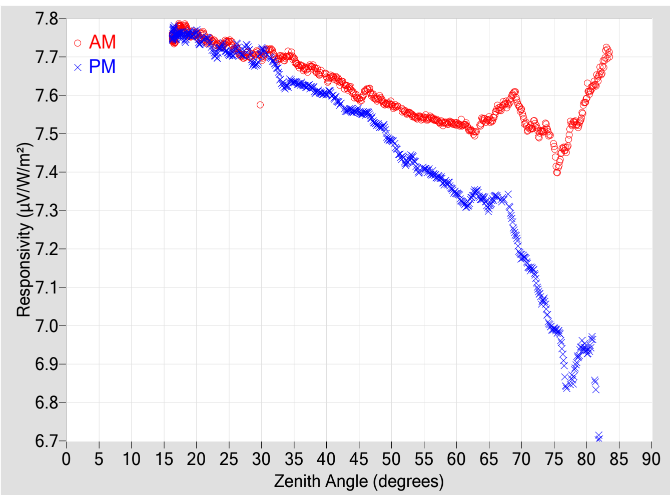


Figure 2. Responsivity vs Local Standard Time

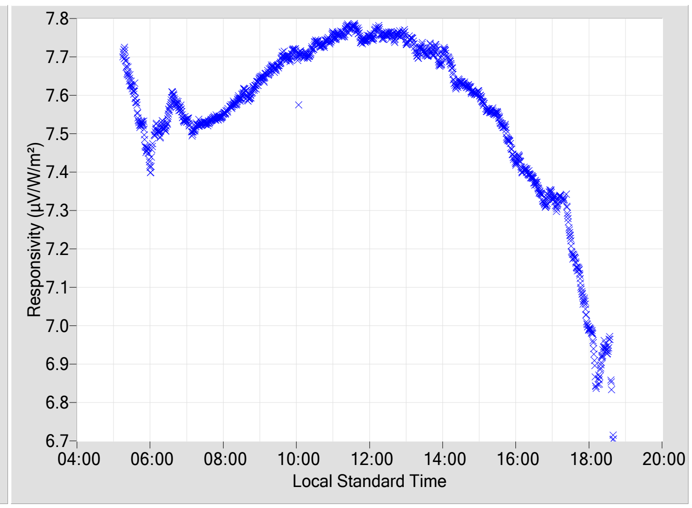


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6113	0.38	94.79	7.5531	0.34	265.19
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5909	0.34	93.04	7.5207	0.34	267.01
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5766	0.34	91.31	7.4823	0.35	268.71
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5585	0.35	89.59	7.4277	0.36	270.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5425	0.35	88.00	7.4061	0.37	272.01
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5414	0.36	86.39	7.3985	0.38	273.63
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5278	0.37	84.81	7.3732	0.39	275.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5253	0.38	83.27	7.3450	0.40	276.73
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5108	0.39	81.74	7.3216	0.42	278.27
18	7.7740	0.32	152.29	7.7539	0.33	207.83	64	7.5356	0.41	80.19	7.3312	0.44	279.79
20	7.7583	0.31	140.55	7.7600	0.32	219.52	66	7.5538	0.43	78.69	7.3382	0.46	281.30
22	7.7443	0.32	132.70	7.7382	0.33	227.25	68	7.5784	0.46	77.16	7.3134	0.50	282.92
24	7.7295	0.33	126.63	7.7271	0.32	233.54	70	7.5589	0.49	75.67	7.1806	0.54	284.38
26	7.7213	0.32	121.68	7.7252	0.31	238.35	72	7.5243	0.53	74.09	7.1322	0.59	285.92
28	7.7063	0.33	117.53	7.7199	0.33	242.49	74	7.5098	0.59	72.55	7.0229	N/A	287.46
30	7.6996	0.31	113.86	7.7163	0.32	246.06	76	7.4394	N/A	70.95	6.9671	N/A	289.02
32	7.7016	0.34	110.82	7.6822	0.34	249.28	78	7.5284	N/A	69.34	6.8704	N/A	290.64
34	7.7035	0.31	107.89	7.6264	0.32	252.08	80	7.5979	N/A	67.72	6.9369	N/A	292.26
36	7.6764	0.32	105.33	7.6294	0.34	254.65	82	7.6549	N/A	66.00	6.7079	N/A	293.87
38	7.6728	0.32	102.95	7.6146	0.32	257.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6481	0.35	100.75	7.6026	0.34	259.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6361	0.36	98.69	7.5787	0.33	261.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6083	0.33	96.67	7.5585	0.33	263.31	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

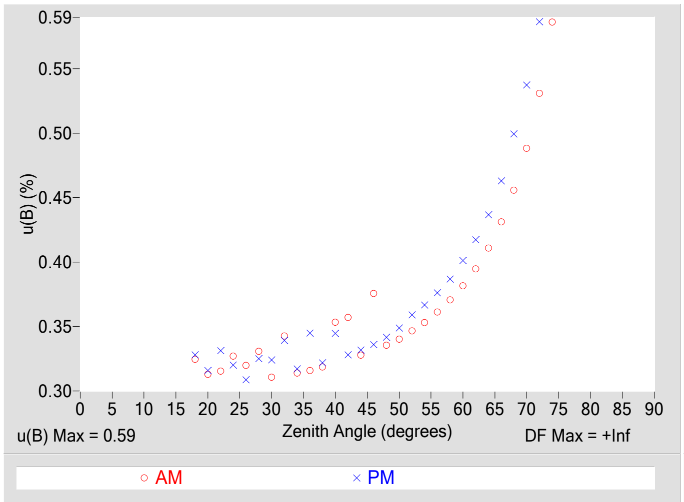


Figure 4. Residuals from Spline Interpolation

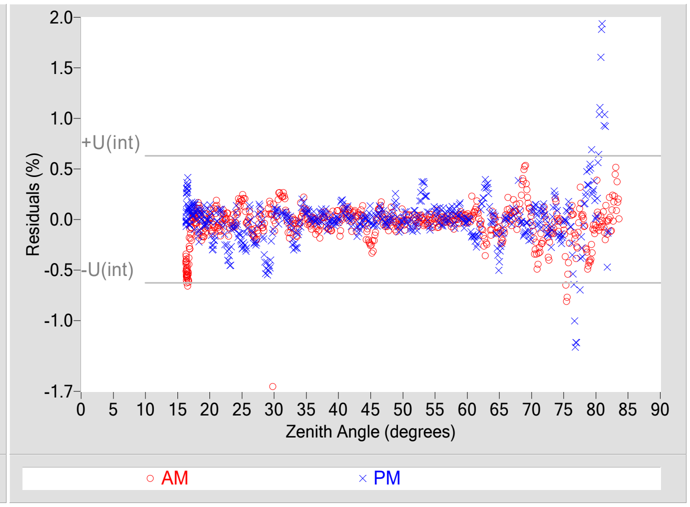


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	22246
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

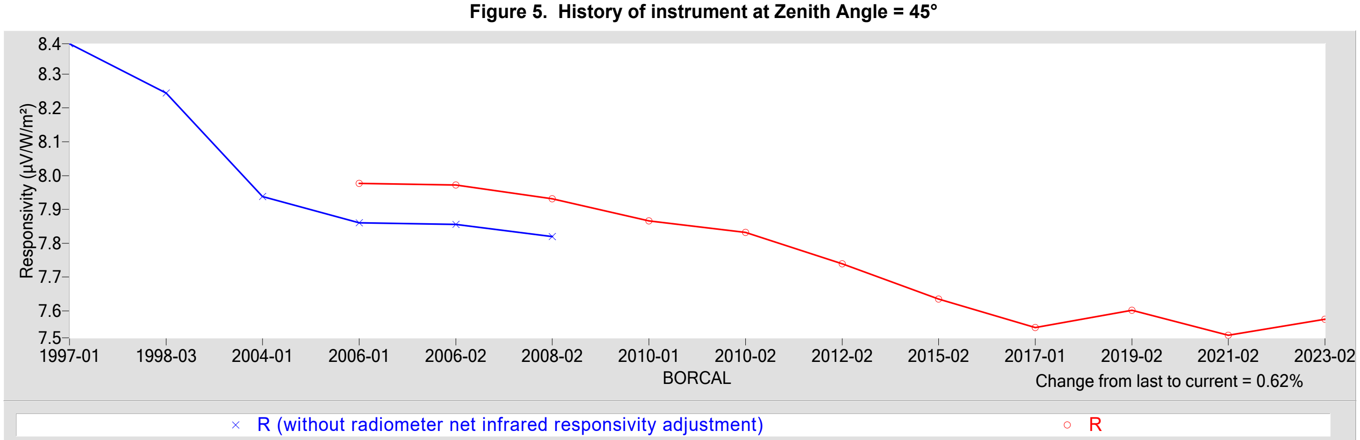
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5745	0.56000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+1.9 / -3.0
Expanded Uncertainty, U (%)	+2.7 / -3.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Short Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37947E6
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________ _______________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37947E6 Eppley sNIP

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  - Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

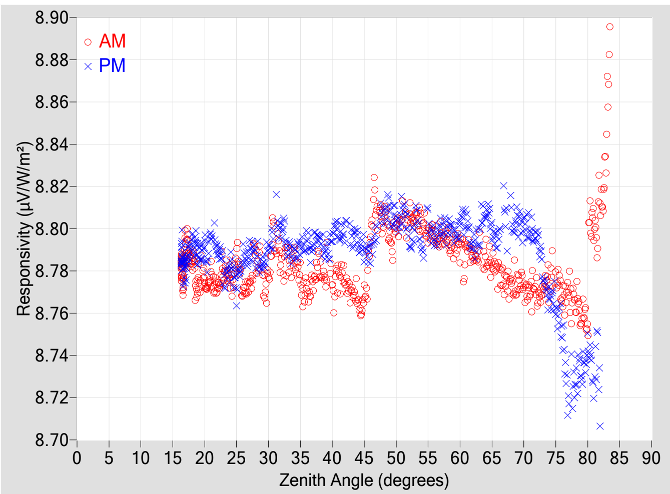


Figure 2. Responsivity vs Local Standard Time

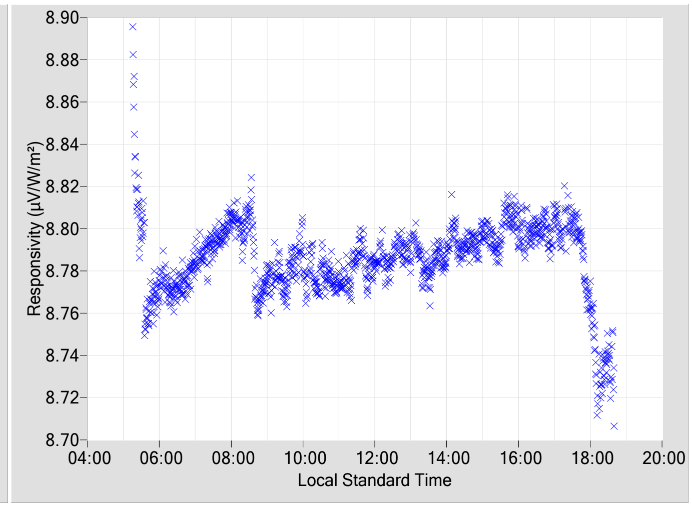


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.7965	0.30	94.82	8.7905	0.29	265.16
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8035	0.29	93.02	8.8073	0.29	266.98
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8016	0.29	91.28	8.8052	0.29	268.73
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8055	0.29	89.62	8.7964	0.29	270.38
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8024	0.29	87.97	8.7906	0.29	272.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7964	0.29	86.36	8.7961	0.29	273.61
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7970	0.29	84.83	8.8001	0.29	275.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7918	0.29	83.29	8.8025	0.30	276.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7873	0.29	81.71	8.7918	0.30	278.29
18	8.7854	0.30	152.34	8.7925	0.31	208.64	64	8.7863	0.30	80.21	8.8063	0.30	279.81
20	8.7753	0.30	140.63	8.7895	0.32	219.47	66	8.7800	0.30	78.67	8.7968	0.30	281.32
22	8.7722	0.28	132.63	8.7897	0.31	227.35	68	8.7753	0.30	77.18	8.8067	0.31	282.90
24	8.7760	0.31	126.57	8.7825	0.29	233.39	70	8.7722	0.30	75.64	8.8010	0.31	284.36
26	8.7701	0.29	121.62	8.7866	0.29	238.21	72	8.7693	0.30	74.11	8.7970	0.31	285.90
28	8.7865	0.29	117.47	8.7891	0.31	242.44	74	8.7750	0.31	72.57	8.7661	N/A	287.48
30	8.7761	0.30	113.99	8.7913	0.32	246.02	76	8.7672	N/A	70.97	8.7495	N/A	289.04
32	8.7841	0.30	110.85	8.8000	0.32	249.24	78	8.7645	N/A	69.36	8.7273	N/A	290.62
34	8.7863	0.31	107.92	8.7886	0.31	252.18	80	8.7691	N/A	67.70	8.7413	N/A	292.32
36	8.7710	0.30	105.36	8.7942	0.29	254.62	82	8.8138	N/A	65.98	8.7215	N/A	293.85
38	8.7832	0.29	102.98	8.7951	0.29	257.03	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7722	0.30	100.71	8.7965	0.30	259.29	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7762	0.29	98.66	8.8001	0.29	261.30	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7670	0.29	96.70	8.7929	0.29	263.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

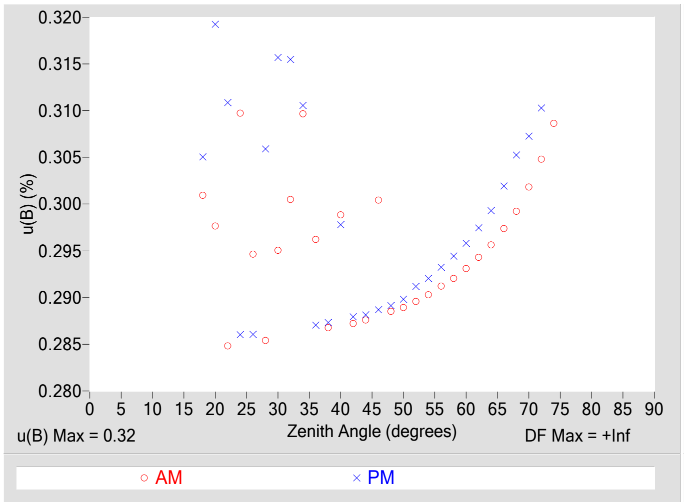


Figure 4. Residuals from Spline Interpolation

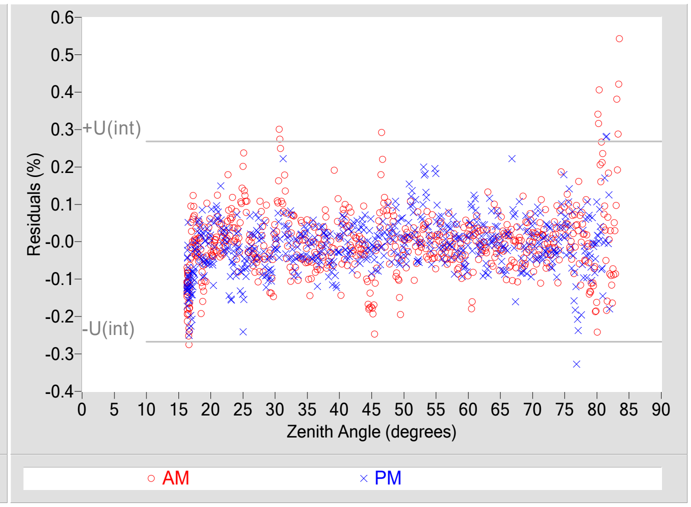


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	49497
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.68
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

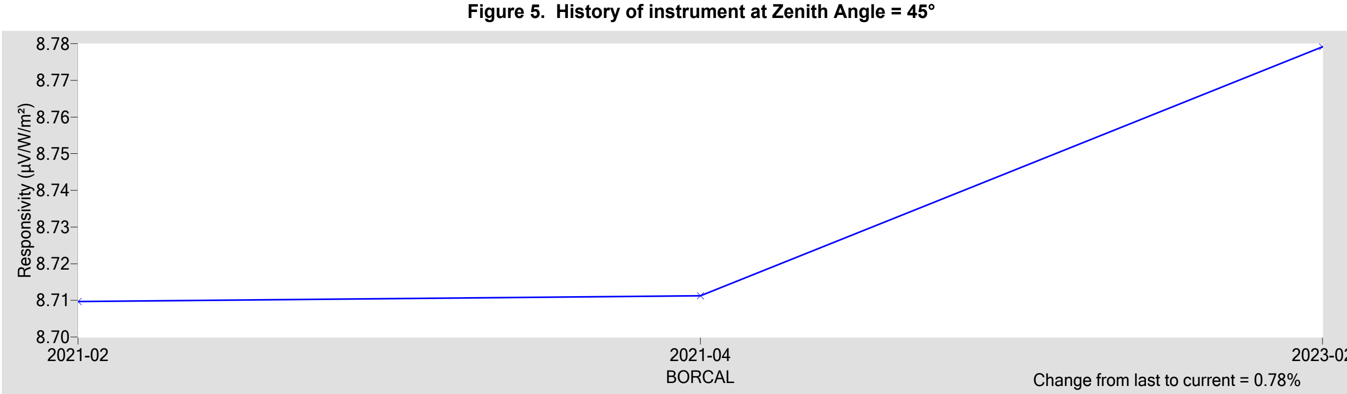
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7791	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.32 / -0.14
Expanded Uncertainty, U (%)	+0.94 / -0.76
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Hukseflux
Model:	DR20-A1-T2	**Serial Number:**	65089
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________ ______________

Afshin M. Andreas, Deputy Technical Manager Date

For questions or comments, please contact the technical manager at:

ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

65089 Hukseflux DR20-A1-T2

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V - Rnet * Wnet) / I \qquad [1]$$

where,

V = radiometer output voltage (microvolts),
$Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
$Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
= $Win - Wout$ = $Win - \sigma * Tc^4$
where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)
where, $G = B * COS(Z) + D$,
Z = zenith angle (degrees),
D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

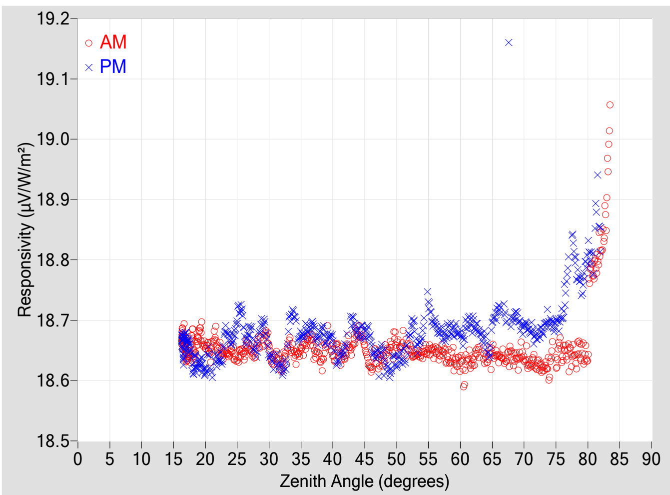


Figure 2. Responsivity vs Local Standard Time

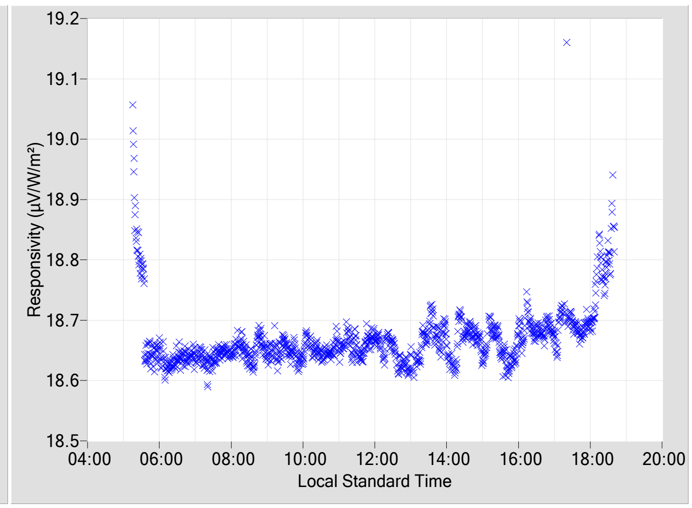


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	18.620	0.29	94.82	18.663	0.29	265.17
2	N/A	N/A	N/A	N/A	N/A	N/A	48	18.637	0.29	93.02	18.636	0.32	266.98
4	N/A	N/A	N/A	N/A	N/A	N/A	50	18.665	0.29	91.28	18.630	0.30	268.73
6	N/A	N/A	N/A	N/A	N/A	N/A	52	18.655	0.29	89.62	18.673	0.29	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	18.644	0.29	87.97	18.681	0.29	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	18.648	0.29	86.37	18.696	0.29	273.61
12	N/A	N/A	N/A	N/A	N/A	N/A	58	18.637	0.29	84.84	18.683	0.29	275.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	18.631	0.29	83.25	18.676	0.29	276.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	18.632	0.29	81.72	18.692	0.30	278.29
18	18.663	0.28	152.48	18.624	0.29	208.08	64	18.636	0.29	80.22	18.663	0.31	279.80
20	18.658	0.29	140.72	18.619	0.31	219.40	66	18.639	0.30	78.67	18.719	0.30	281.32
22	18.653	0.28	132.63	18.634	0.29	227.36	68	18.647	0.30	77.18	18.699	0.30	282.90
24	18.649	0.29	126.69	18.667	0.31	233.48	70	18.637	0.30	75.64	18.689	0.31	284.36
26	18.644	0.30	121.62	18.690	0.28	238.32	72	18.625	0.30	74.11	18.675	0.31	285.90
28	18.656	0.28	117.48	18.653	0.29	242.51	74	18.622	0.31	72.57	18.697	N/A	287.49
30	18.658	0.29	113.99	18.647	0.28	246.02	76	18.643	N/A	70.97	18.709	N/A	289.04
32	18.626	0.32	110.78	18.618	0.32	249.26	78	18.636	N/A	69.32	18.802	N/A	290.62
34	18.641	0.30	107.93	18.706	0.29	252.04	80	18.679	N/A	67.70	18.808	N/A	292.33
36	18.664	0.29	105.37	18.686	0.29	254.62	82	18.824	N/A	65.98	18.845	N/A	293.89
38	18.641	0.30	102.98	18.680	0.30	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	18.645	0.31	100.72	18.662	0.32	259.29	86	N/A	N/A	N/A	N/A	N/A	N/A
42	18.644	0.29	98.66	18.659	0.30	261.31	88	N/A	N/A	N/A	N/A	N/A	N/A
44	18.679	0.29	96.70	18.675	0.30	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

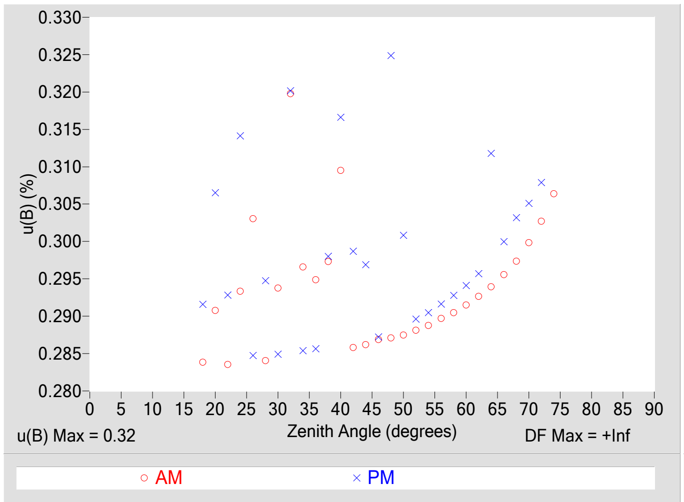


Figure 4. Residuals from Spline Interpolation

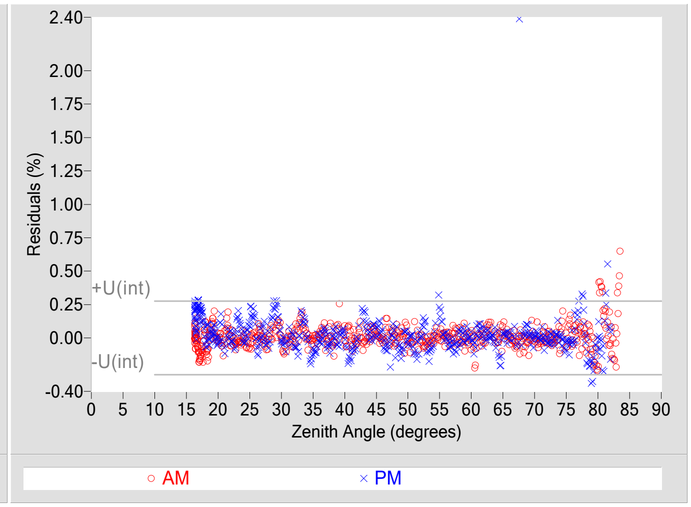


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.14
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	47494
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

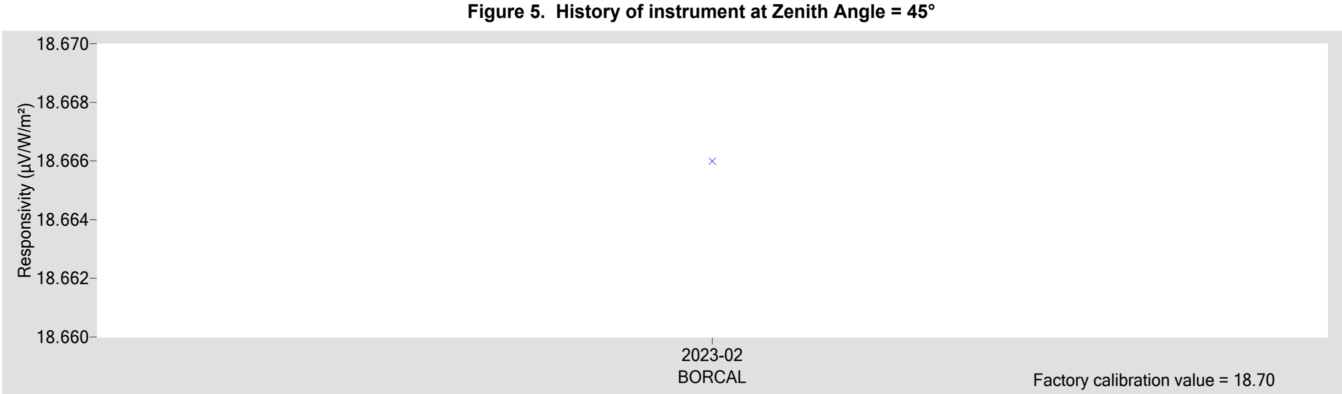
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
18.666	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.22 / -0.26
Expanded Uncertainty, U (%)	+0.85 / -0.89
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

[2] Reda, I.; Myers, D.; Stoffel, T. (2008). "Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective." Measure. (NCSLI Journal of Measurement Science). Vol. 3(4), December 2008; pp. 58-66; NREL Report No. JA-581-4137

[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Hukseflux
Model:	DR20-A1-T2	**Serial Number:**	65090
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

____ ____________________

Afshin M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

65090 Hukseflux DR20-A1-T2

The responsivity (R, µV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

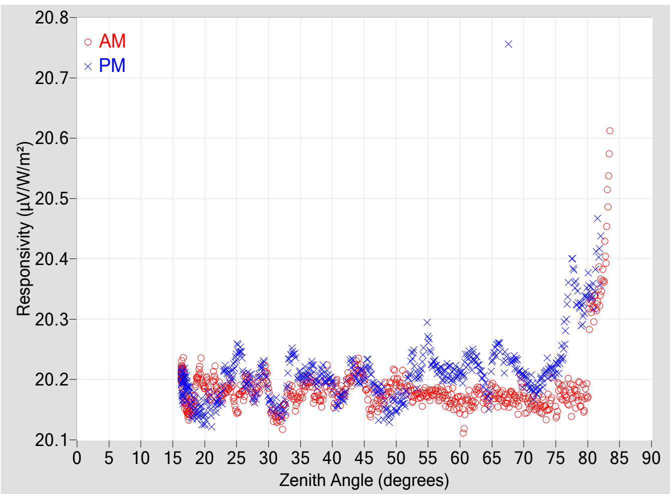


Figure 2. Responsivity vs Local Standard Time

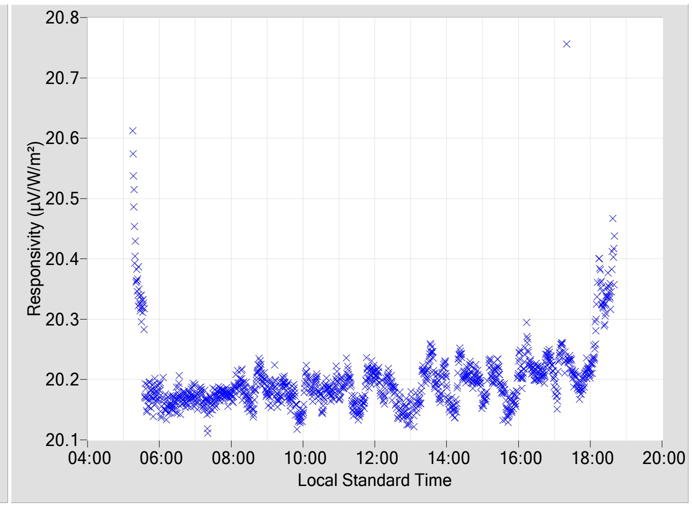


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	20.146	0.29	94.82	20.211	0.29	265.17
2	N/A	N/A	N/A	N/A	N/A	N/A	48	20.169	0.29	93.02	20.162	0.32	266.98
4	N/A	N/A	N/A	N/A	N/A	N/A	50	20.201	0.29	91.28	20.154	0.30	268.73
6	N/A	N/A	N/A	N/A	N/A	N/A	52	20.187	0.29	89.62	20.204	0.29	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	20.172	0.29	87.97	20.228	0.29	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	20.179	0.29	86.37	20.227	0.29	273.61
12	N/A	N/A	N/A	N/A	N/A	N/A	58	20.169	0.29	84.84	20.213	0.29	275.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	20.162	0.29	83.25	20.211	0.29	276.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	20.162	0.29	81.72	20.234	0.30	278.29
18	20.157	0.28	152.48	20.151	0.29	208.08	64	20.167	0.29	80.22	20.187	0.31	279.80
20	20.192	0.29	140.72	20.139	0.31	219.40	66	20.171	0.30	78.67	20.257	0.30	281.32
22	20.183	0.28	132.63	20.161	0.29	227.36	68	20.178	0.30	77.18	20.230	0.30	282.90
24	20.189	0.29	126.69	20.204	0.31	233.48	70	20.170	0.30	75.64	20.204	0.30	284.36
26	20.177	0.30	121.62	20.215	0.28	238.32	72	20.156	0.30	74.11	20.184	0.31	285.90
28	20.183	0.28	117.48	20.175	0.29	242.51	74	20.158	0.31	72.57	20.216	N/A	287.49
30	20.187	0.29	113.99	20.175	0.28	246.02	76	20.177	N/A	70.97	20.243	N/A	289.04
32	20.135	0.32	110.78	20.146	0.32	249.26	78	20.174	N/A	69.32	20.361	N/A	290.62
34	20.167	0.30	107.93	20.242	0.29	252.04	80	20.218	N/A	67.70	20.350	N/A	292.33
36	20.194	0.29	105.37	20.211	0.29	254.62	82	20.354	N/A	65.98	20.404	N/A	293.89
38	20.172	0.30	102.98	20.205	0.30	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	20.177	0.31	100.72	20.192	0.32	259.29	86	N/A	N/A	N/A	N/A	N/A	N/A
42	20.183	0.29	98.66	20.179	0.30	261.31	88	N/A	N/A	N/A	N/A	N/A	N/A
44	20.224	0.29	96.70	20.198	0.30	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

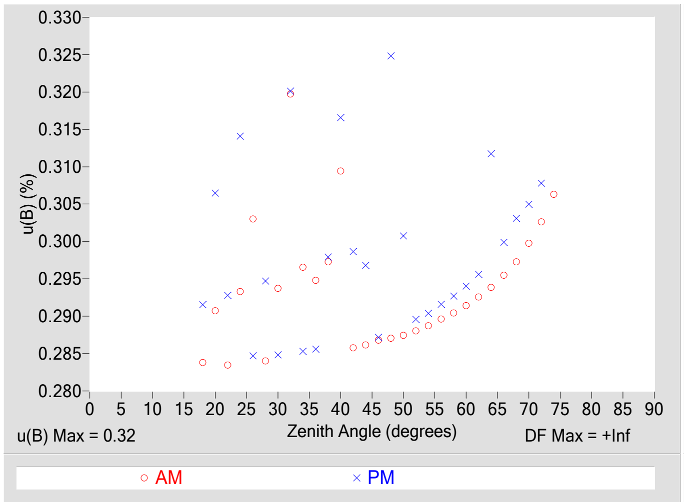


Figure 4. Residuals from Spline Interpolation

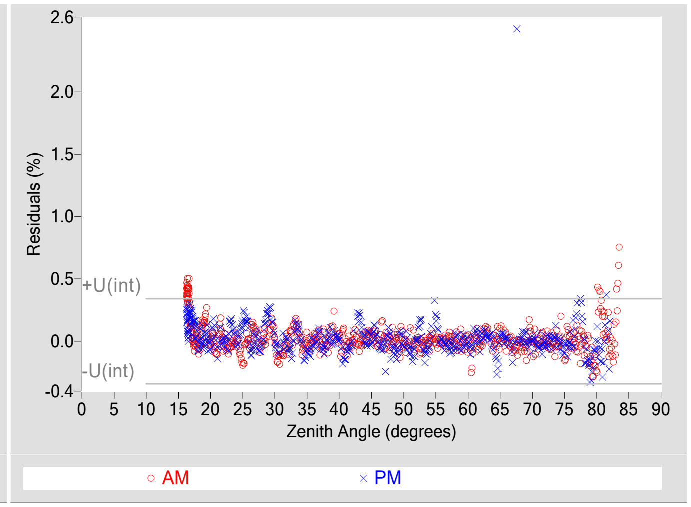


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	23917
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.72
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

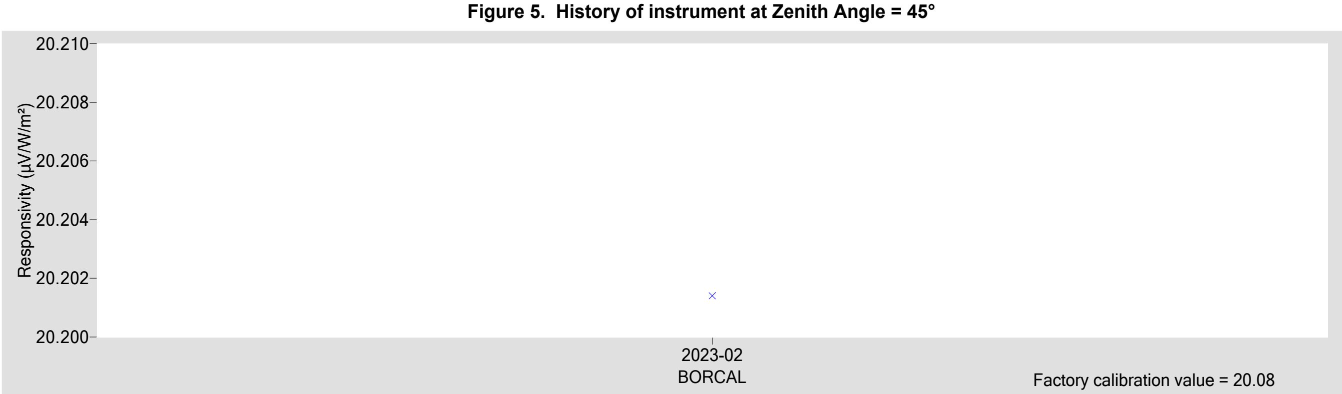
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
20.201	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.20 / -0.33
Expanded Uncertainty, U (%)	+0.84 / -0.96
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

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[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

[4] Stoffel, T.; Reda, I. (2009). "NREL Pyrheliometer Comparisons: 22 September - 3 October 2008 (NPC-2008)." 54 pp.; NREL Report No. TP-550-45016.

[5] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyrheliometer	**Manufacturer:**	Hukseflux
Model:	DR20-A1-T2	**Serial Number:**	65091
Calibration Date:	6/19/2023	**Due Date:**	6/19/2024
Customer:	Craig Webb	**Environmental Conditions:**	see page 4
Test Dates:	6/19		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2017. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

No statement of compliance with specifications is made or implied on this certificate. However, the estimated uncertainties are the uncertainties of the calibration process; users must add other uncertainties that are relevant to their measuring system, environmental and sky conditions, outdoor set-up, and site location.

The Type-B Standard Uncertainty of using the responsivity at each even zenith angle is reported, and the Expanded Uncertainty of the calibration is reported using two methods:

1. The Expanded Uncertainty of using the responsivity at zenith angle = 45°, within the zenith angle range from 30.0° to 60.0°
2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

This certificate applies only to the item identified above and shall not be reproduced other that in full, without specific written approval from the calibration facility. Certificate without signature is not valid.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	10/01/2022	10/01/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/23/2023	04/23/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/23/2023	04/23/2024
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/03/2023	02/03/2025
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/03/2023	02/03/2025

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: BORCAL-P00-Calibration and QA Procedure; available upon request.

Setup: Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.
The shading disk for the reference diffuse subtends a solid angle of 5°. Pyrheliometers are installed on solar trackers.

Calibrated by: Afshin Andreas, Jaemo Yang, and RCC

______________________________ ______________

Afshin M. Andreas, Deputy Technical Manager   Date

For questions or comments, please contact the technical manager at:
ibrahim.reda@nrel.gov; 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

65091 Hukseflux DR20-A1-T2

The responsivity (R, μV/W/m²) of the test instrument during calibration is calculated using this Measurement Equation:

$R = (V - Rnet * Wnet) / I$ [1]

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (μV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of pyrgeometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

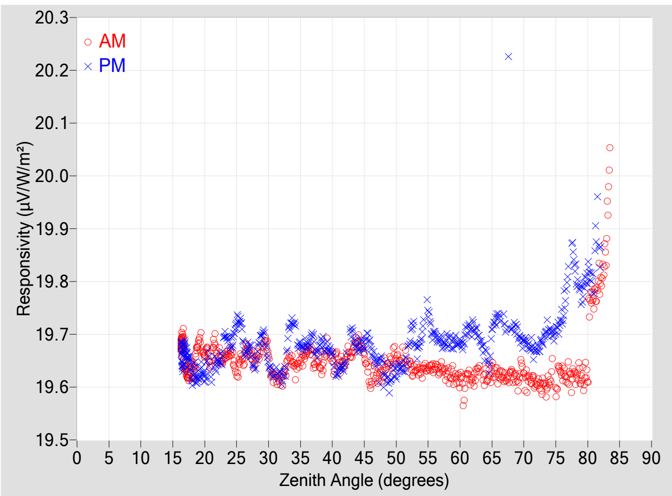


Figure 2. Responsivity vs Local Standard Time

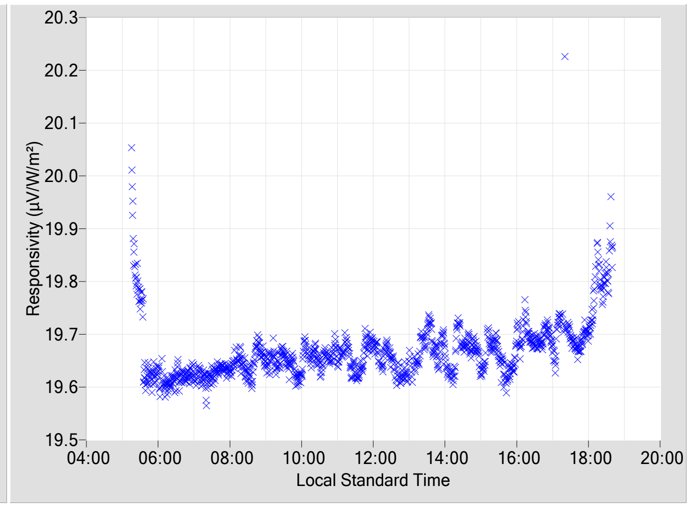


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	19.606	0.29	94.82	19.677	0.29	265.17
2	N/A	N/A	N/A	N/A	N/A	N/A	48	19.627	0.29	93.02	19.629	0.32	266.98
4	N/A	N/A	N/A	N/A	N/A	N/A	50	19.660	0.29	91.28	19.627	0.30	268.73
6	N/A	N/A	N/A	N/A	N/A	N/A	52	19.646	0.29	89.62	19.679	0.29	270.39
8	N/A	N/A	N/A	N/A	N/A	N/A	54	19.630	0.29	87.97	19.702	0.29	272.04
10	N/A	N/A	N/A	N/A	N/A	N/A	56	19.637	0.29	86.37	19.700	0.29	273.61
12	N/A	N/A	N/A	N/A	N/A	N/A	58	19.625	0.29	84.84	19.687	0.29	275.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	19.616	0.29	83.25	19.683	0.29	276.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	19.614	0.29	81.72	19.711	0.30	278.29
18	19.635	0.28	152.48	19.622	0.29	208.08	64	19.618	0.29	80.22	19.664	0.31	279.80
20	19.665	0.29	140.72	19.623	0.31	219.40	66	19.623	0.30	78.67	19.734	0.30	281.32
22	19.661	0.28	132.63	19.645	0.29	227.36	68	19.630	0.30	77.18	19.710	0.30	282.90
24	19.665	0.29	126.69	19.681	0.31	233.48	70	19.620	0.30	75.64	19.686	0.31	284.36
26	19.651	0.30	121.62	19.690	0.28	238.32	72	19.605	0.30	74.11	19.672	0.31	285.90
28	19.655	0.28	117.48	19.648	0.29	242.51	74	19.609	0.31	72.57	19.706	N/A	287.49
30	19.663	0.29	113.99	19.647	0.28	246.02	76	19.626	N/A	70.97	19.731	N/A	289.04
32	19.614	0.32	110.78	19.619	0.32	249.26	78	19.621	N/A	69.32	19.829	N/A	290.62
34	19.637	0.30	107.93	19.719	0.29	252.04	80	19.662	N/A	67.70	19.815	N/A	292.33
36	19.666	0.29	105.37	19.682	0.29	254.62	82	19.802	N/A	65.98	19.856	N/A	293.89
38	19.644	0.30	102.98	19.678	0.30	257.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	19.650	0.31	100.72	19.657	0.32	259.29	86	N/A	N/A	N/A	N/A	N/A	N/A
42	19.648	0.29	98.66	19.647	0.30	261.31	88	N/A	N/A	N/A	N/A	N/A	N/A
44	19.688	0.29	96.70	19.672	0.30	263.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

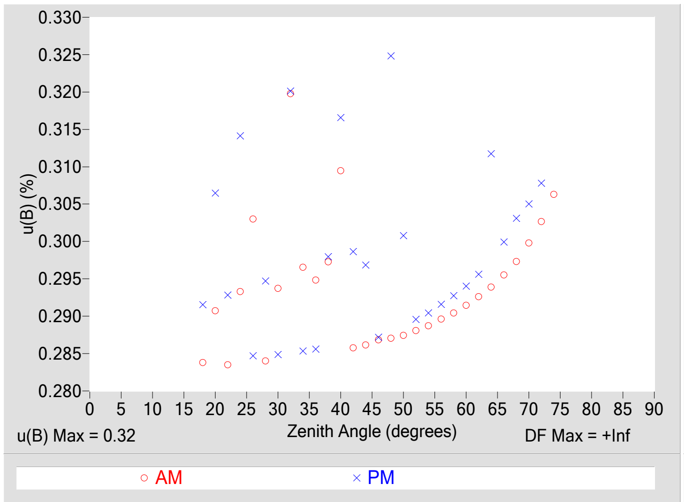


Figure 4. Residuals from Spline Interpolation

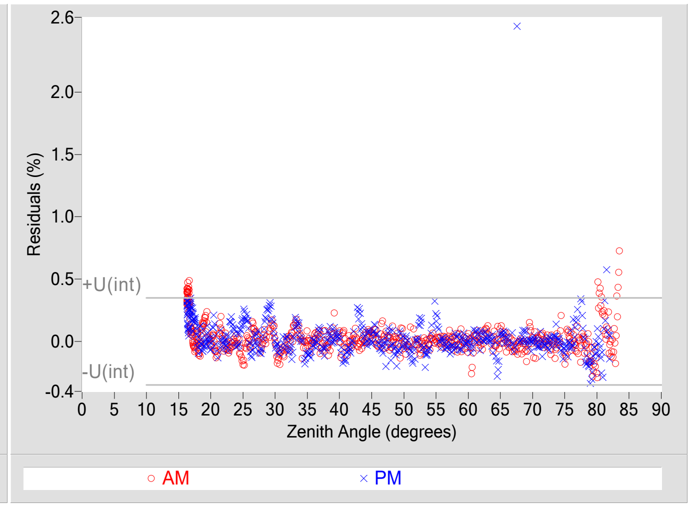


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	22155
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.72
AM Valid zenith angle range	18° to 74°
PM Valid zenith angle range	18° to 72°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°. Not accredited.

Table 4. Calibration Label Values

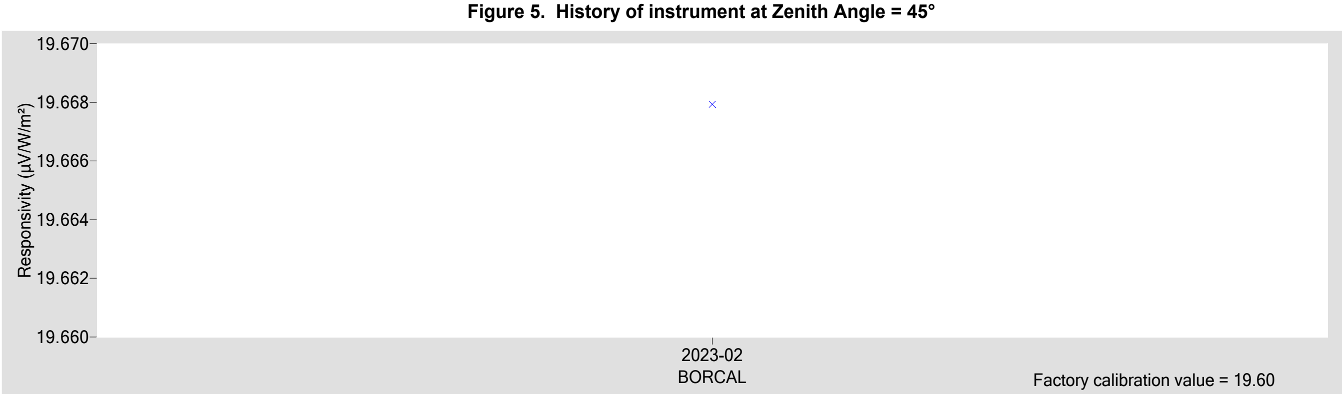
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
19.668	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.26 / -0.32
Expanded Uncertainty, U (%)	+0.90 / -0.95
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

Figure 5. History of instrument at Zenith Angle = 45°



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the Component Sum Method." Journal of Atmospheric and Oceanic Technology. , 2005; pp. 1531-1540; NREL Report No. JA-560-36646. doi:10.1175/JTECH1782.1

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[3] Reda, I.; Andreas, A. (2004). "Solar Position Algorithm for Solar Radiation Applications." Solar Energy. Vol. 76(5), 2004; pp. 577-589; NREL Report No. JA-560-35518. doi:10.1016/j.solener.2003.12.003

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[6] Reda, I. (1996). Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference. 79 pp.; NREL Report No. TP-463-20619.

[7] Reda, I.; Gröbner, J.; Stoffel, T.; Myers, D.; Forgan, B. (2008). Improvements in the Blackbody Calibration of Pyrgeometers. ARM 2008 Science Team Meeting (Poster).

Environmental and Sky Conditions for BORCAL-SW 2023-02

Calibration Facility: Solar Radiation Research Laboratory

Latitude: 39.742°N   Longitude: 105.180°W   Elevation: 1828.8 meters AMSL   Time Zone: -7.0

Reference Irradiance:

Figure 6. Reference Irradiance

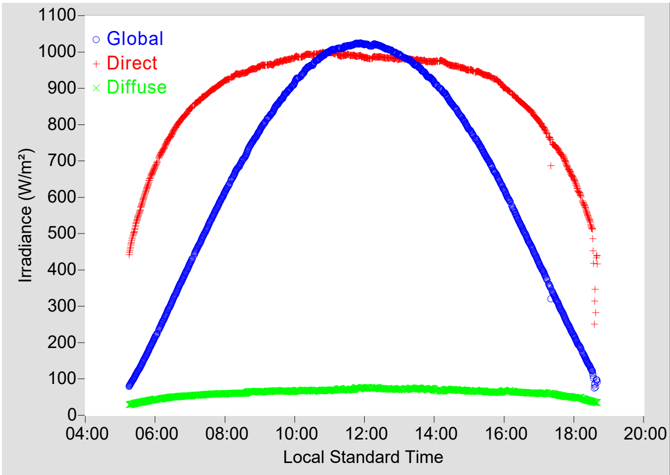
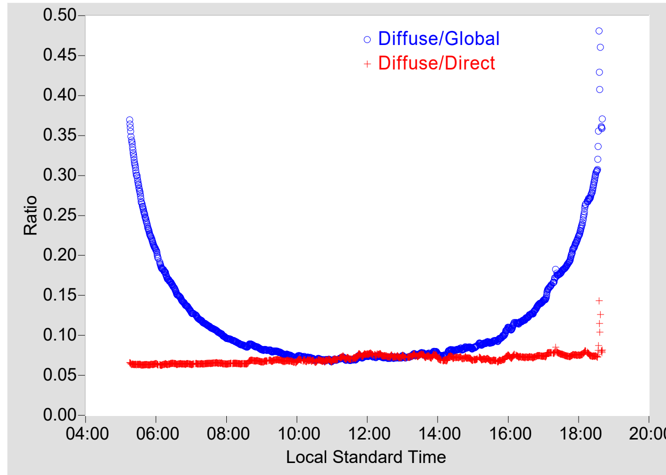


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

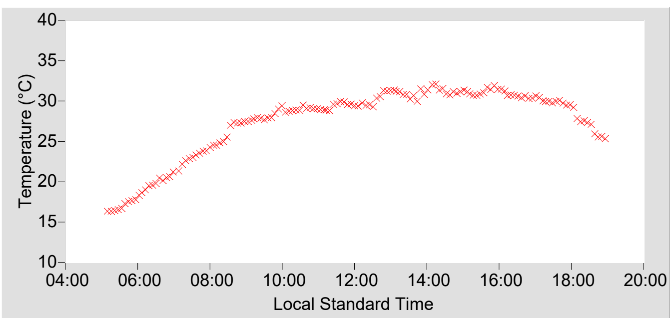


Figure 9. Humidity

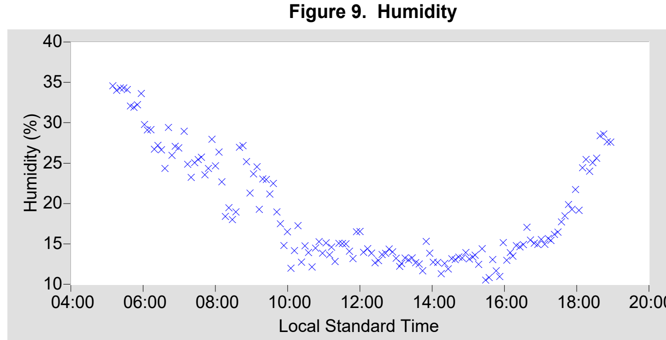


Figure 10. Pressure

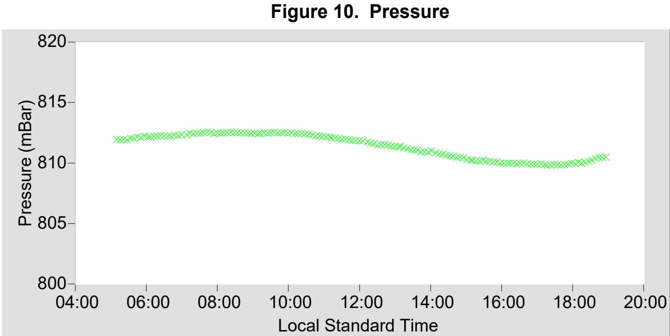


Figure 11. Effective Net Infrared

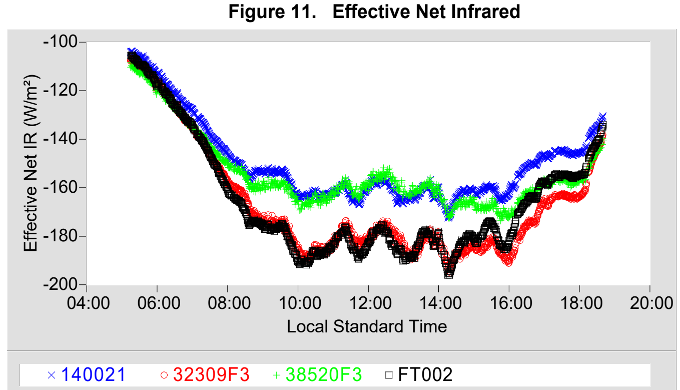


Figure 12. Estimated Broadband Aerosol Optical Depth

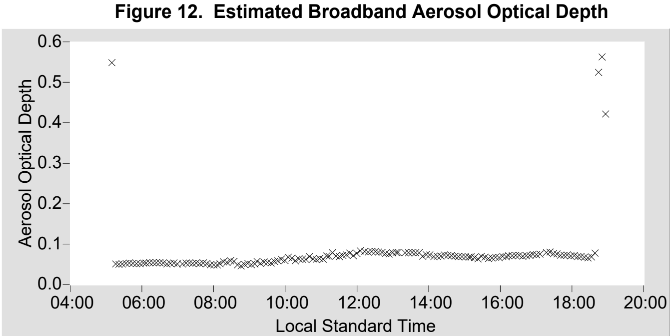


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	27.48	16.34	32.12
Humidity (%)	19.01	10.51	34.57
Pressure (mBar)	811.4	809.8	812.6
Est. Aerosol Optical Depth (BB)	0.078	0.046	0.563

For other information about the calibration facility visit: https://www.nrel.gov/grid/solar-radiation-research-laboratory.html

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Solar Radiation Research Laboratory
Comments:
Avg. Station Pressure & Temperature is for Denver, CO, which is used for the Solar Position Algorithm (SPA).