Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2024-02

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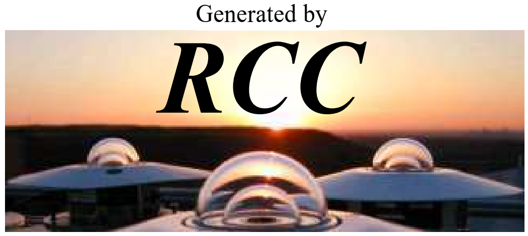

Radiometer Calibration and Characterization

Customer

NREL-SRRL-BMS

Organization: NREL
Address: BMS, SRRL, Golden, CO 80401 USA
Phone: 303-384-6326

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
05/16/2024

Report Date
May 21, 2024

NREL

NOTICE

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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.

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

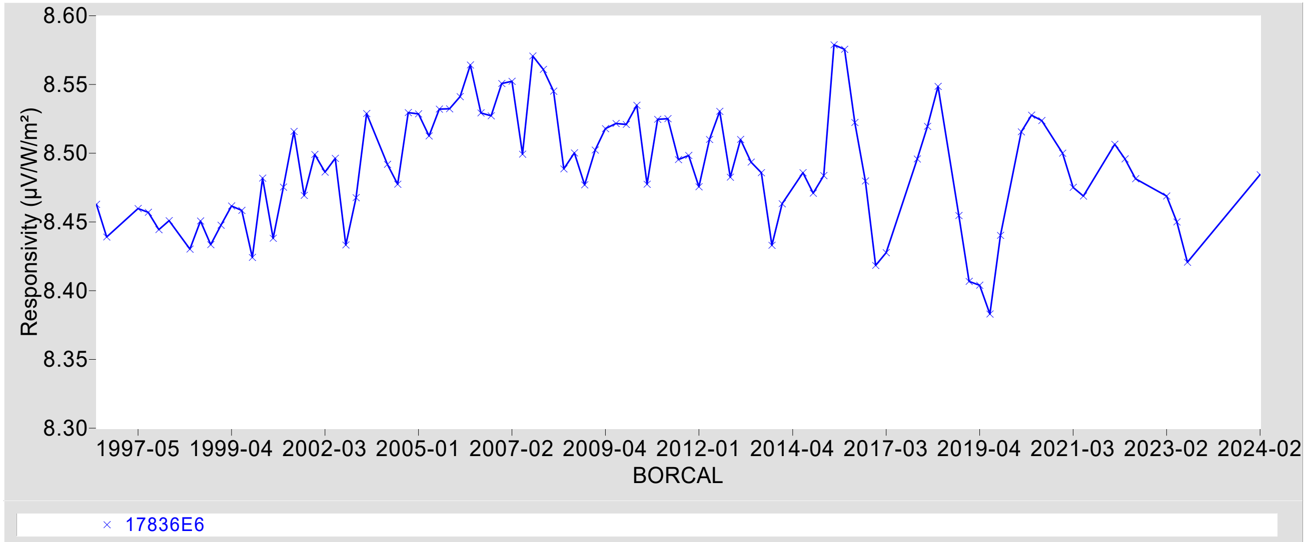


Figure 2. Eppley PSP Control Instrument History

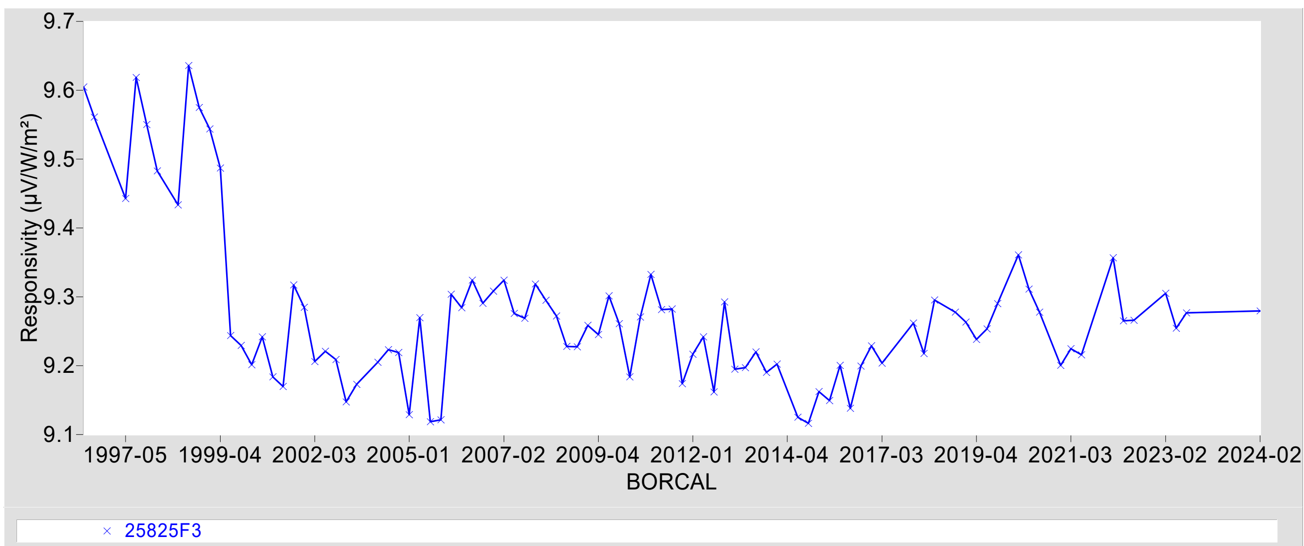
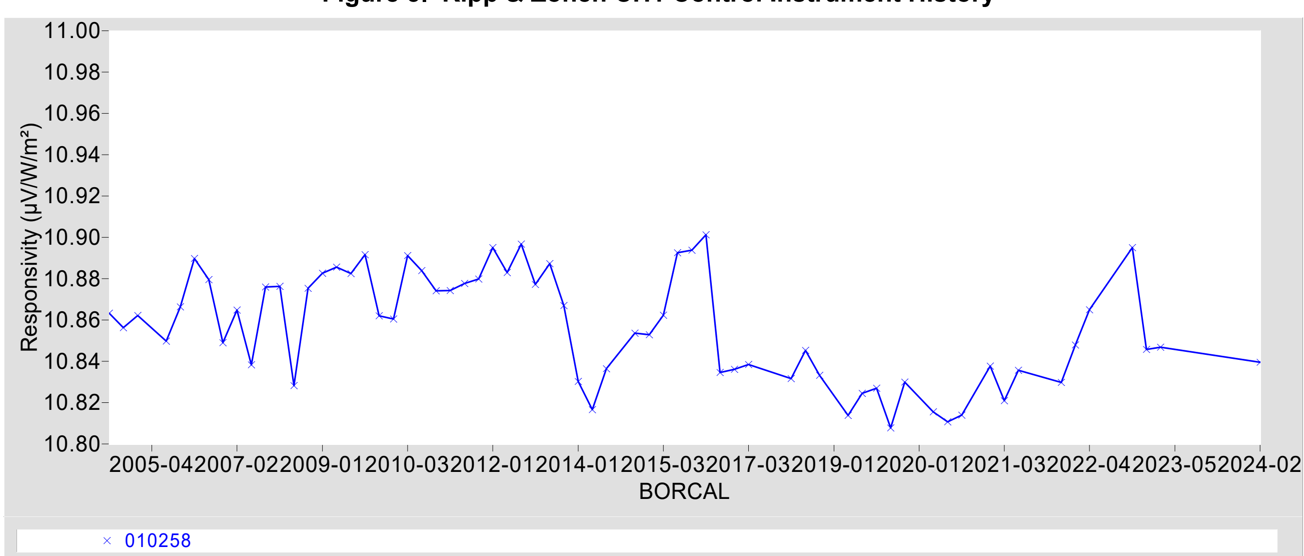


Figure 3. Kipp & Zonen CH1 Control Instrument History



Control Instrument History

Figure 4. Kipp & Zonen CHP1 Control Instrument History

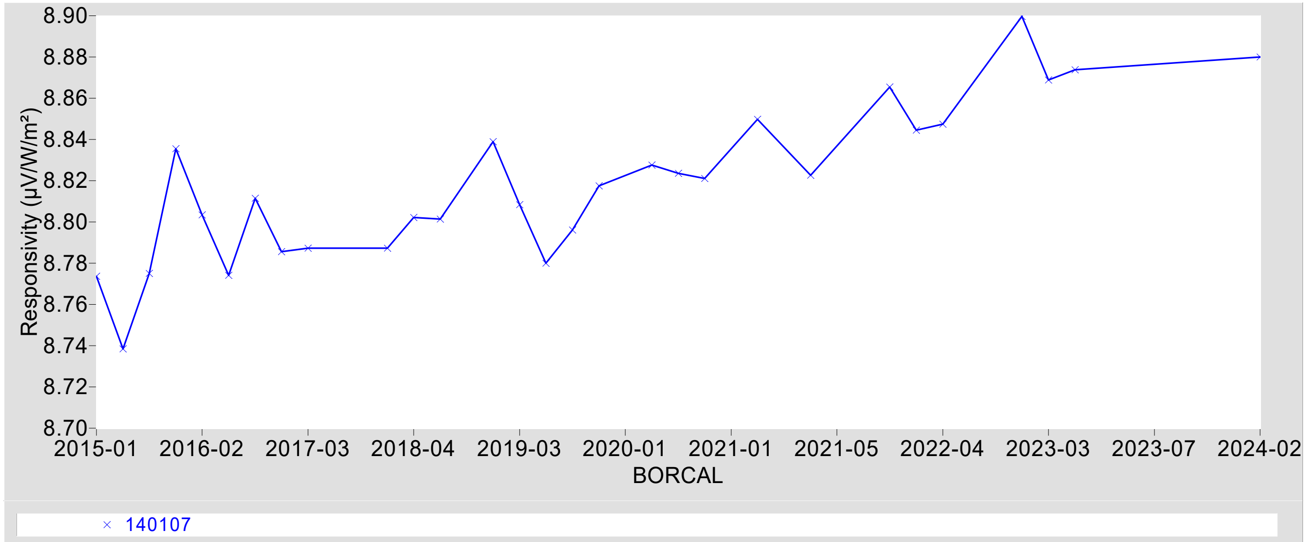


Figure 5. Kipp & Zonen CM22 Control Instrument History

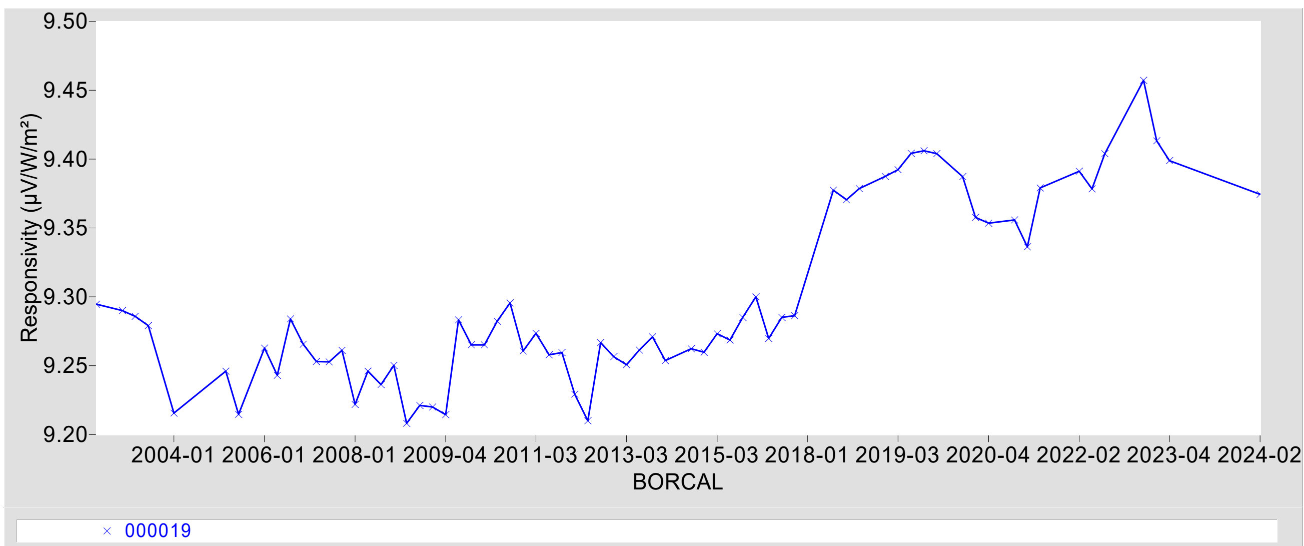
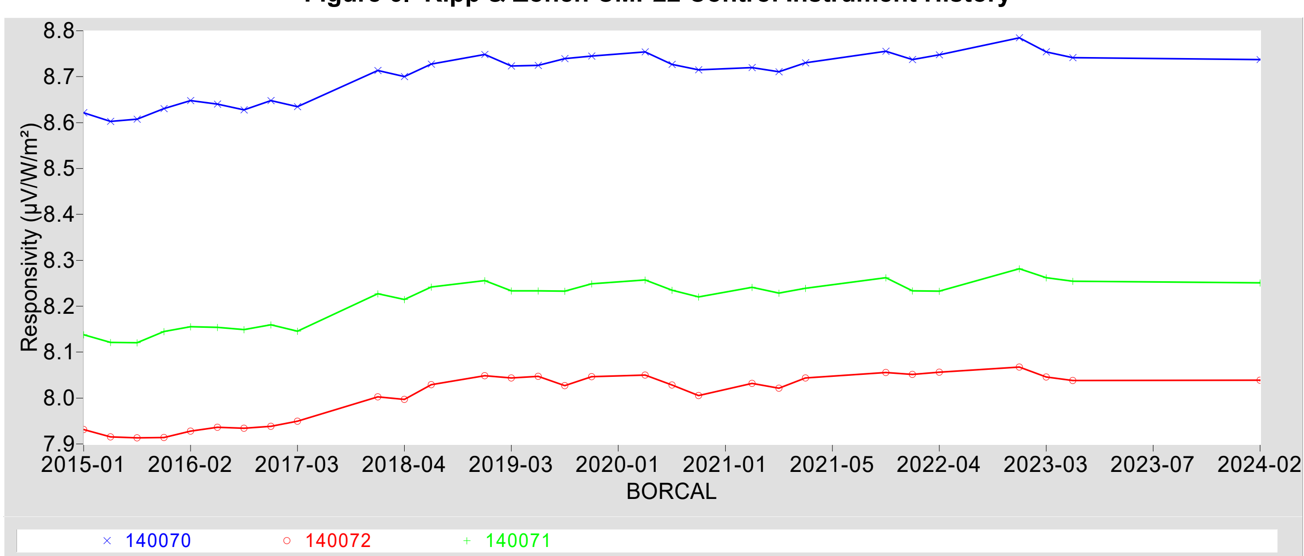


Figure 6. Kipp & Zonen CMP22 Control Instrument History



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
010046 Kipp & Zonen CM22	9.3043	107.48	+1.9 / -1.7	0.087000	A1-2
010284-DW-CM3 Kipp & Zonen CM3	17.133	58.367	+2.0 / -2.7	0.40000	A1-5
014261 Kipp & Zonen CM3	21.938	45.582	+1.3 / -1.2	0.40000	A1-8
015189 Kipp & Zonen CM6B	10.903	91.715	+1.8 / -1.4	0.30000	A1-11
0212-2 Yankee TSP-700	3006.7	0.33259	+2.2 / -2.3	0	A1-14
080009 Kipp & Zonen CHP1	7.9438	125.88	+0.89 / -0.84	0	A1-17
080016 Kipp & Zonen CMP22	9.5655	104.54	+1.3 / -1.8	0.087000	A1-20
100174 Kipp & Zonen CMP22	9.8167	101.87	+1.1 / -1.1	0.087000	A1-23
1171 Apogee SP-510	52.351	19.102	+2.9 / -6.2	2.5000	A1-26
120373 Kipp & Zonen CMP22	9.1992	108.70	+1.1 / -1.4	0.087000	A1-29
140043 Kipp & Zonen CMP22	9.1099	109.77	+1.1 / -1.2	0.087000	A1-32
140108 Kipp & Zonen CHP1	8.1294	123.01	+0.78 / -0.86	0	A1-35
140712 Kipp & Zonen CMP11	9.0525	110.47	+1.8 / -1.7	0.20500	A1-38
140713 Kipp & Zonen CMP11	8.6044	116.22	+1.7 / -1.8	0.20500	A1-41
151027 Kipp & Zonen SP-LITE2	69.562	14.376	+2.7 / -2.7	0	A1-44
15357 Hukseflux SR20-T2	16.977	58.904	+1.4 / -2.2	0.18000	A1-47
15360 Hukseflux SR20-T2	16.541	60.456	+1.2 / -2.1	0.18000	A1-50
15364 Hukseflux SR20-T2	16.975	58.912	+1.4 / -2.0	0.18000	A1-53
194362 Kipp & Zonen SP-LITE2	65.473	15.274	+2.6 / -2.5	0	A1-56
210757 Kipp & Zonen CMP22	9.0914	109.99	+1.3 / -1.4	0.087000	A1-59
21096 Eppley 8-48	11.663	85.738	+3.6 / -2.5	0	A1-62
2530 Hukseflux SR25	11.186	89.401	+1.8 / -1.7	0.043000	A1-65
2543 Hukseflux SR25	9.6022	104.14	+1.7 / -1.7	0.043000	A1-68
28402F3 Eppley PSP	6.8123	146.79	+2.8 / -2.9	0.64000	A1-71
31137E6 Eppley NIP	8.5040	117.59	+0.79 / -1.5	0	A1-74
34722 Eppley 8-48	9.8322	101.71	+3.7 / -2.4	0	A1-77
37831F3 Eppley GPP	8.4721	118.03	+2.1 / -2.8	0.15000	A1-80
37839F3 Eppley SPP	8.5775	116.58	+2.5 / -3.8	0.30000	A1-83
37882E6 Eppley sNIP	8.4189	118.78	+0.88 / -0.98	0	A1-86
40337 Apogee SP-110	182.83	5.4697	+2.0 / -1.5	0	A1-89
65089 Hukseflux DR20-A1-T2	18.575	53.836	+0.95 / -0.74	0	A1-92
9206 Hukseflux DR02	11.035	90.623	+0.91 / -0.80	0	A1-95
970003 Kipp & Zonen SP-LITE	81.395	12.286	+1.3 / -2.2	0	A1-98
A360 Delta-T SPN1	1022.7	0.97784	+7.8 / -4.9	0	A1-101
F14077R EKO MS-802	7.0906	141.03	+2.0 / -2.2	0.18000	A1-104
PY100360 Licor LI200R	10.786	92.715	+1.2 / -1.6	0	A1-107
PY108623 Licor LI200R	9.9883	100.12	+1.9 / -2.1	0	A1-110
PY28257 Licor LI200	13.973	71.569	+1.9 / -3.1	0	A1-113
PY66489 Licor LI200	9.0774	110.16	+1.6 / -2.2	0	A1-116
PYHR101 Licor LI201SB	4.5596	219.32	+3.3 / -2.1	0	A1-119
S13071483 EKO MS-602	6.9315	144.27	+2.6 / -2.9	0.30000	A1-122
S13135063 EKO ML-01	41.438	24.132	+1.4 / -1.5	0	A1-125
S13144.085R EKO MS-410	9.2644	107.94	+1.8 / -1.5	0.20000	A1-128
S17096005 EKO MS-80	10.636	94.018	+1.4 / -1.3	0.043000	A1-131
S18015.22 EKO MS-57	6.6950	149.37	+0.88 / -0.78	0	A1-134

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 A1-137.

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:**	Kipp & Zonen
Model:	CM22	**Serial Number:**	010046
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — 05/21/2024 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

010046 Kipp & Zonen CM22

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

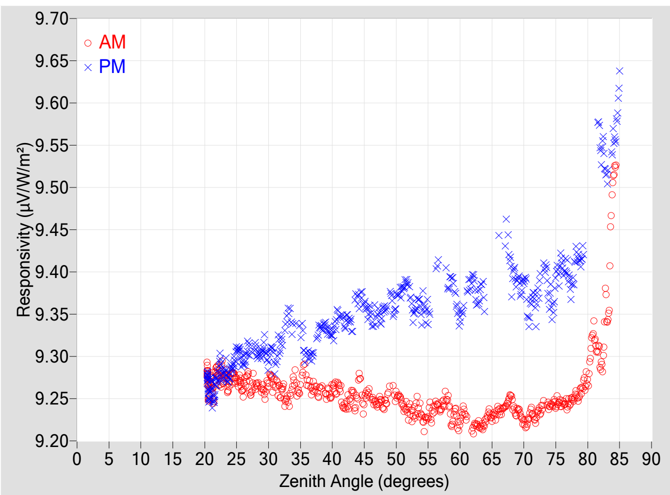


Figure 2. Responsivity vs Local Standard Time

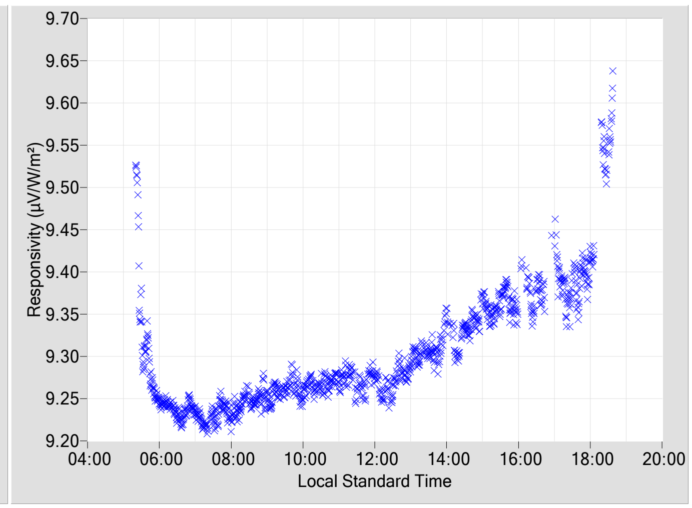


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.2535	0.33	101.79	9.3488	0.33	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2422	0.31	99.79	9.3546	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2527	0.34	97.82	9.3644	0.35	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2347	0.34	95.93	9.3786	0.34	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2305	0.34	94.15	9.3556	0.35	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2391	0.35	92.42	9.4037	0.34	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2478	0.38	90.69	9.3866	0.37	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2229	0.35	89.05	9.3473	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2135	0.39	87.38	9.3925	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2241	0.40	85.79	9.3613	0.44	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2358	0.41	84.23	9.4430	N/A	275.96
22	9.2807	0.32	155.05	9.2754	0.31	204.25	68	9.2497	0.41	82.64	9.3999	0.41	277.47
24	9.2713	0.32	144.03	9.2812	0.31	216.23	70	9.2217	0.43	81.06	9.3901	0.43	279.05
26	9.2625	0.30	136.22	9.2922	0.33	223.99	72	9.2296	0.47	79.48	9.3623	0.47	280.62
28	9.2653	0.33	130.13	9.3061	0.32	229.91	74	9.2417	0.51	77.93	9.3713	0.52	282.19
30	9.2714	0.32	125.36	9.2964	0.31	234.69	76	9.2441	0.57	76.36	9.4083	0.58	283.82
32	9.2594	0.30	121.22	9.3137	0.34	238.77	78	9.2525	N/A	74.74	9.4093	N/A	285.39
34	9.2724	0.31	117.63	9.3389	0.30	242.54	80	9.2734	N/A	73.11	N/A	N/A	N/A
36	9.2703	0.30	114.27	9.3019	0.30	245.83	82	9.2967	N/A	71.48	9.5477	N/A	288.71
38	9.2585	0.33	111.42	9.3338	0.32	248.72	84	9.5031	N/A	69.78	9.5532	N/A	290.41
40	9.2608	0.32	108.73	9.3251	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2411	0.31	106.27	9.3401	0.34	253.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2613	0.34	104.00	9.3658	0.41	256.18	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

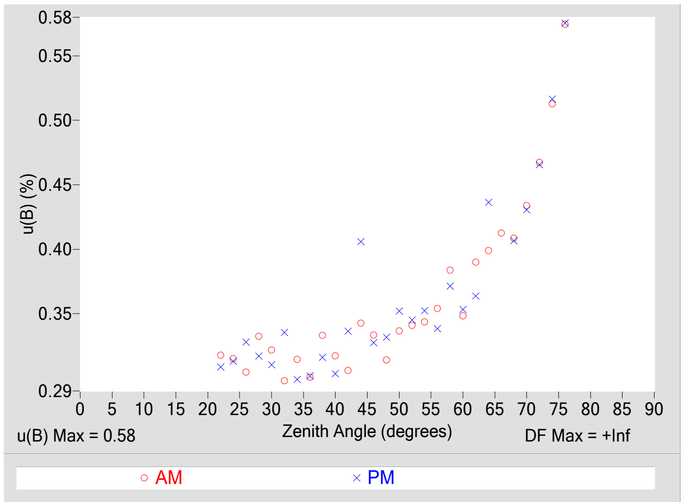


Figure 4. Residuals from Spline Interpolation

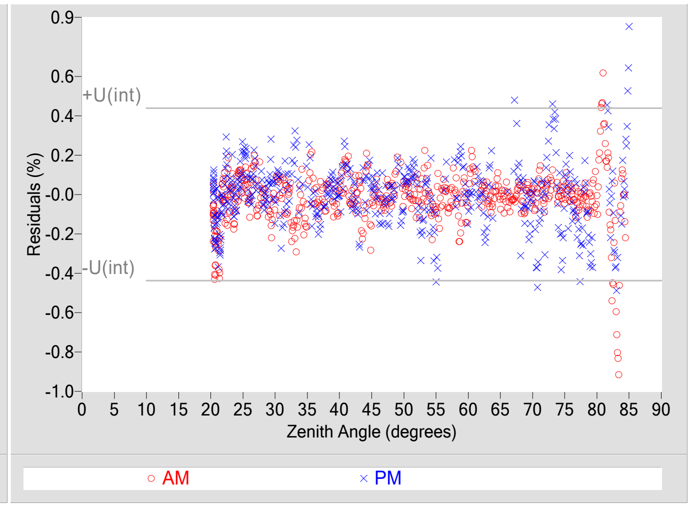


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	61300
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

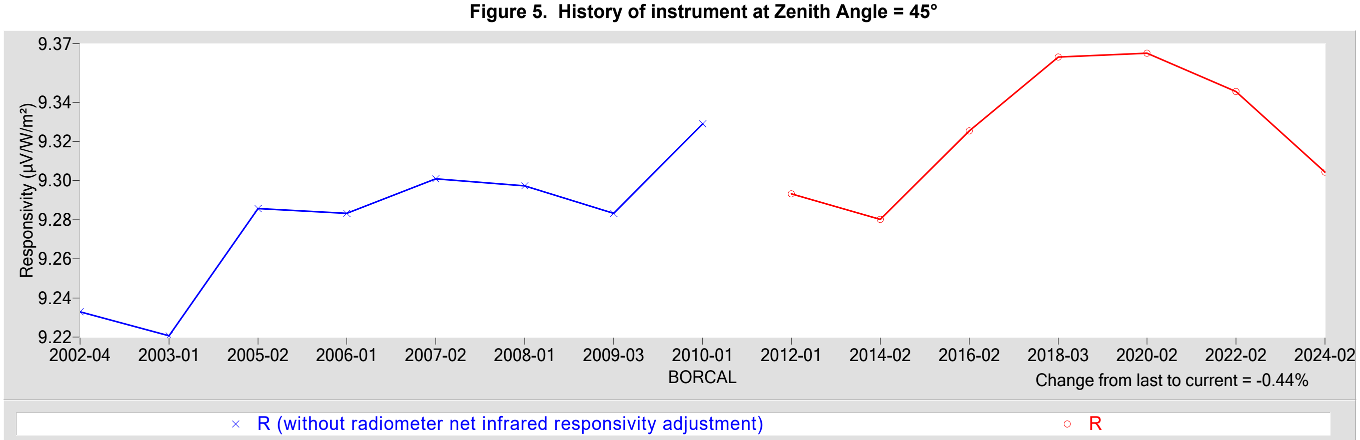
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3043	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+1.1 / -0.87
Expanded Uncertainty, U (%)	+1.9 / -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:**	Kipp & Zonen
Model:	CM3	**Serial Number:**	010284-DW-CM3
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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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Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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

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Number of pages of certificate: 4

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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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

010284-DW-CM3 Kipp & Zonen CM3

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

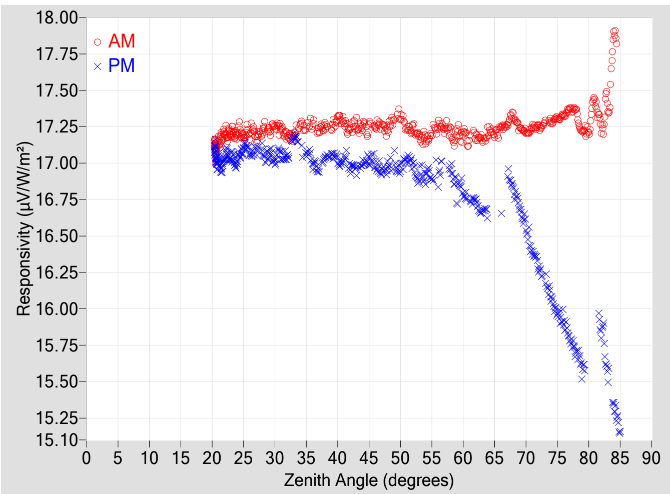


Figure 2. Responsivity vs Local Standard Time

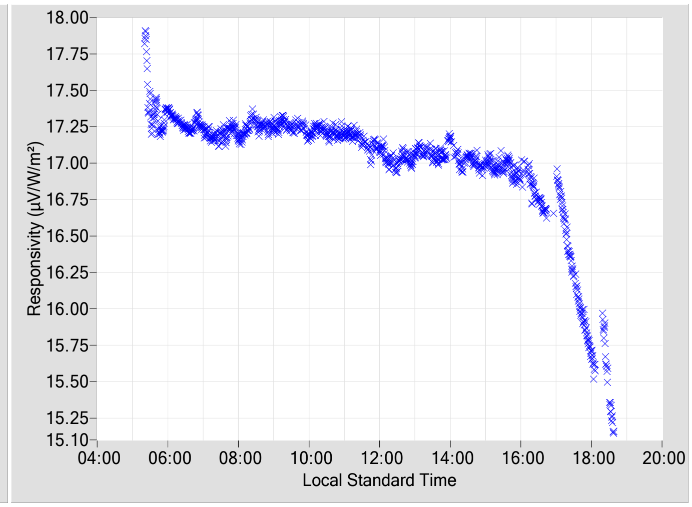


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	17.254	0.36	101.79	16.994	0.32	258.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	17.238	0.36	99.74	16.971	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	17.326	0.32	97.80	16.973	0.32	262.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	17.243	0.33	95.94	16.985	0.36	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	17.175	0.35	94.16	16.906	0.36	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	17.249	0.34	92.43	16.908	0.42	267.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	17.203	0.34	90.69	16.958	0.35	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	17.203	0.37	89.06	16.806	0.36	271.05
16	N/A	N/A	N/A	N/A	N/A	N/A	62	17.186	0.39	87.43	16.736	0.40	272.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	17.219	0.40	85.80	16.652	0.44	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	17.248	0.39	84.19	16.655	N/A	275.97
22	17.203	0.33	155.28	17.033	0.35	204.72	68	17.316	0.41	82.65	16.812	0.41	277.48
24	17.203	0.31	144.00	17.020	0.32	216.13	70	17.215	0.44	81.06	16.567	0.44	279.06
26	17.213	0.33	136.41	17.068	0.36	223.81	72	17.250	0.47	79.49	16.283	0.48	280.63
28	17.219	0.32	130.22	17.081	0.32	230.01	74	17.283	0.51	77.93	16.081	0.53	282.20
30	17.248	0.32	125.31	17.019	0.31	234.74	76	17.328	0.58	76.32	15.903	0.60	283.82
32	17.190	0.30	121.23	17.040	0.31	238.78	78	17.354	N/A	74.74	15.697	N/A	285.40
34	17.264	0.34	117.56	17.121	0.30	242.98	80	17.221	N/A	73.12	N/A	N/A	N/A
36	17.264	0.30	114.28	16.990	0.36	245.85	82	17.257	N/A	71.44	15.864	N/A	288.67
38	17.252	0.32	111.39	17.042	0.32	248.69	84	17.834	N/A	69.79	15.330	N/A	290.42
40	17.306	0.36	108.74	17.017	0.31	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	17.242	0.31	106.27	16.970	0.34	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.259	0.33	103.94	16.994	0.39	256.13	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

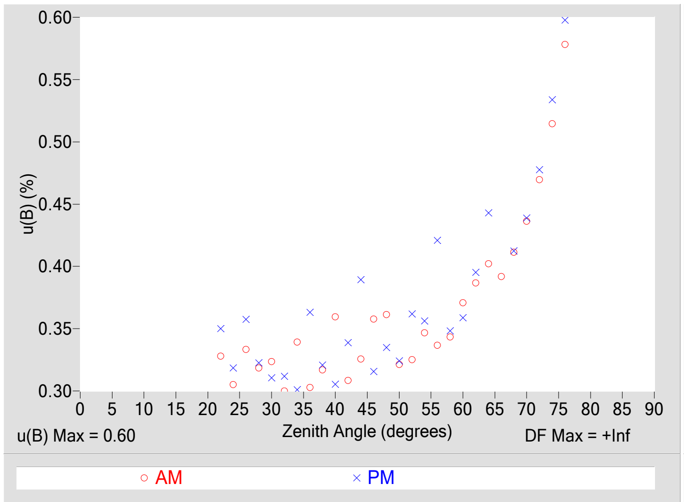


Figure 4. Residuals from Spline Interpolation

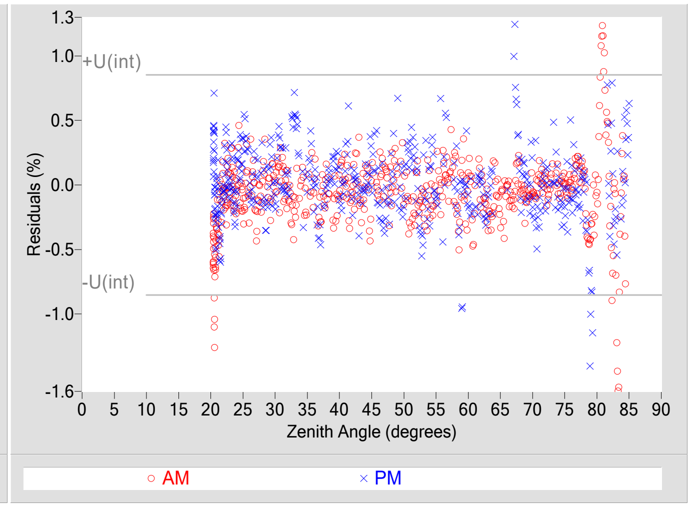


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.43
Combined Standard Uncertainty, u(c) (%)	±0.73
Effective degrees of freedom, DF(c)	8771
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

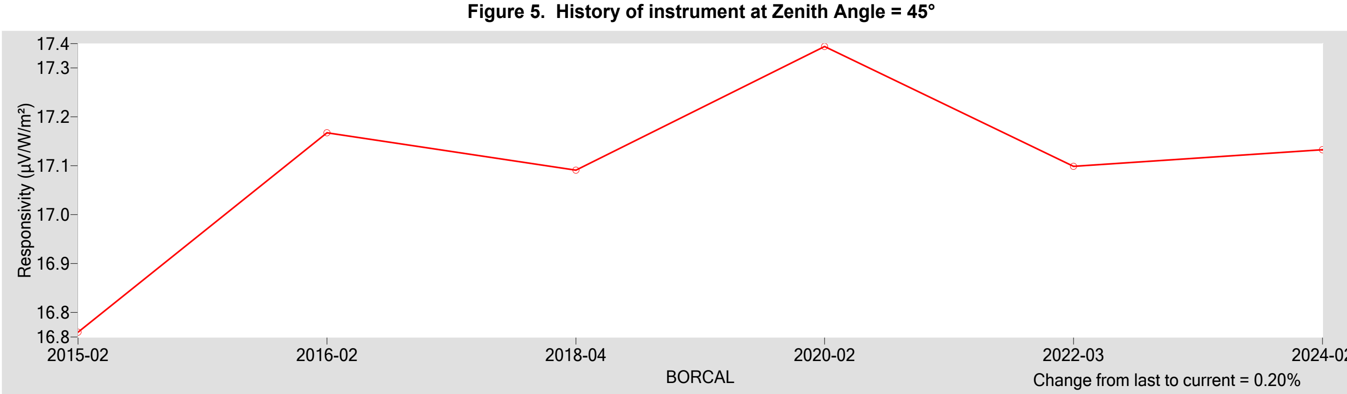
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
17.133	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.83
Offset Uncertainty, U(off) (%)	+1.1 / -1.9
Expanded Uncertainty, U (%)	+2.0 / -2.7
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:** Kipp & Zonen

Model: CM3 | **Serial Number:** 014261

Calibration Date: 5/16/2024 | **Due Date:** 5/16/2025

Customer: NREL-SRRL-BMS | **Environmental Conditions:** see page 4

Test Dates: 5/16

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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.

Calibration by: Afshin Andreas, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

014261 Kipp & Zonen CM3

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),
  = $Win - Wout$ = $Win - \sigma * Tc\text{^}4$
  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

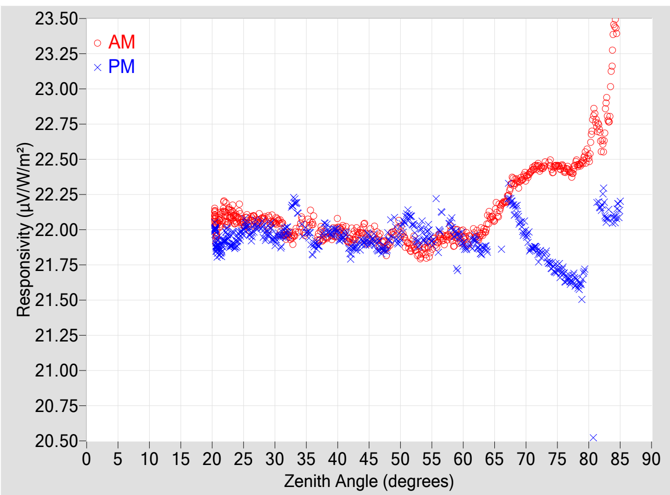


Figure 2. Responsivity vs Local Standard Time

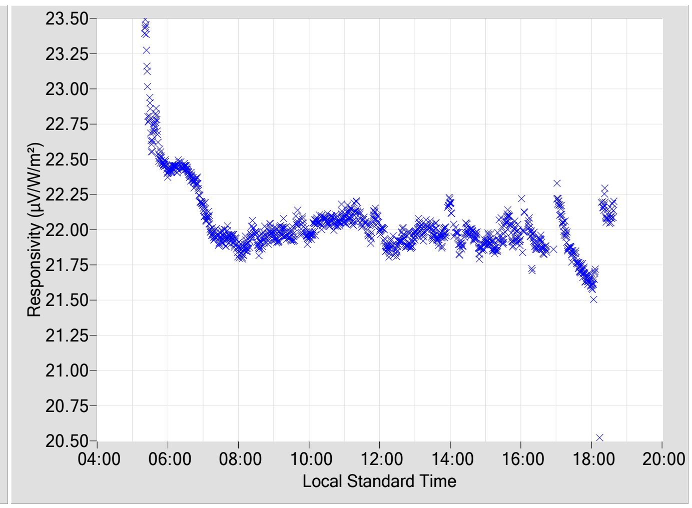


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	21.957	0.36	101.79	21.913	0.31	258.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	21.884	0.36	99.74	21.910	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	22.002	0.32	97.80	21.977	0.32	262.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	21.904	0.32	95.94	22.035	0.36	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	21.862	0.34	94.16	21.940	0.35	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	21.924	0.33	92.43	21.943	0.42	267.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	21.965	0.34	90.69	22.044	0.34	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	21.953	0.37	89.06	21.908	0.35	271.05
16	N/A	N/A	N/A	N/A	N/A	N/A	62	21.964	0.38	87.43	21.919	0.39	272.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	22.082	0.40	85.80	21.848	0.44	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	22.167	0.39	84.19	21.862	N/A	275.97
22	22.131	0.33	155.28	21.930	0.35	204.72	68	22.345	0.41	82.65	22.152	0.41	277.48
24	22.087	0.30	144.00	21.922	0.32	216.13	70	22.378	0.43	81.06	21.986	0.43	279.06
26	22.046	0.33	136.41	21.963	0.36	223.81	72	22.446	0.46	79.49	21.822	0.47	280.63
28	22.078	0.32	130.22	22.013	0.32	230.01	74	22.447	0.51	77.93	21.748	0.52	282.20
30	22.054	0.32	125.31	21.929	0.31	234.74	76	22.431	0.57	76.32	21.683	0.58	283.82
32	21.960	0.30	121.23	21.982	0.31	238.78	78	22.466	N/A	74.74	21.624	N/A	285.40
34	22.035	0.34	117.56	22.038	0.30	242.98	80	22.525	N/A	73.12	N/A	N/A	N/A
36	22.054	0.30	114.28	21.854	0.36	245.85	82	22.624	N/A	71.44	22.173	N/A	288.67
38	21.953	0.32	111.39	22.026	0.32	248.69	84	23.369	N/A	69.79	22.079	N/A	290.42
40	22.010	0.36	108.74	21.978	0.30	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	21.942	0.31	106.27	21.844	0.34	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	22.006	0.32	103.94	21.906	0.39	256.13	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

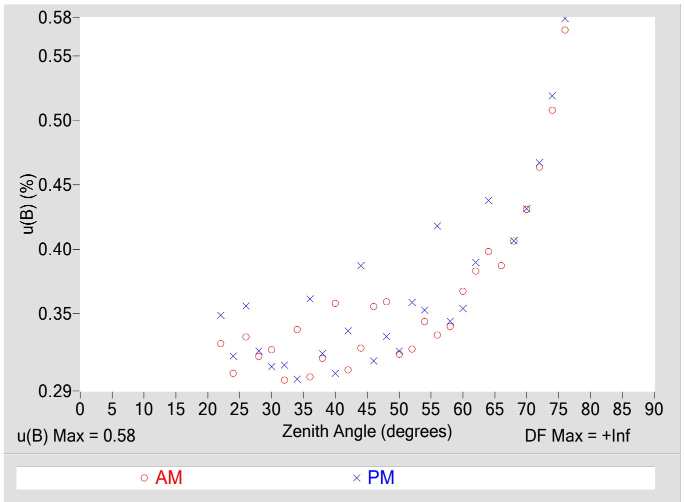


Figure 4. Residuals from Spline Interpolation

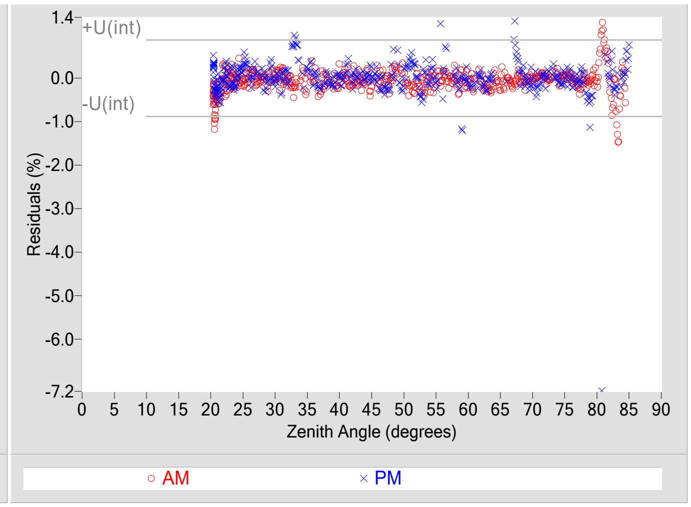


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.44
Combined Standard Uncertainty, u(c) (%)	±0.73
Effective degrees of freedom, DF(c)	7526
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

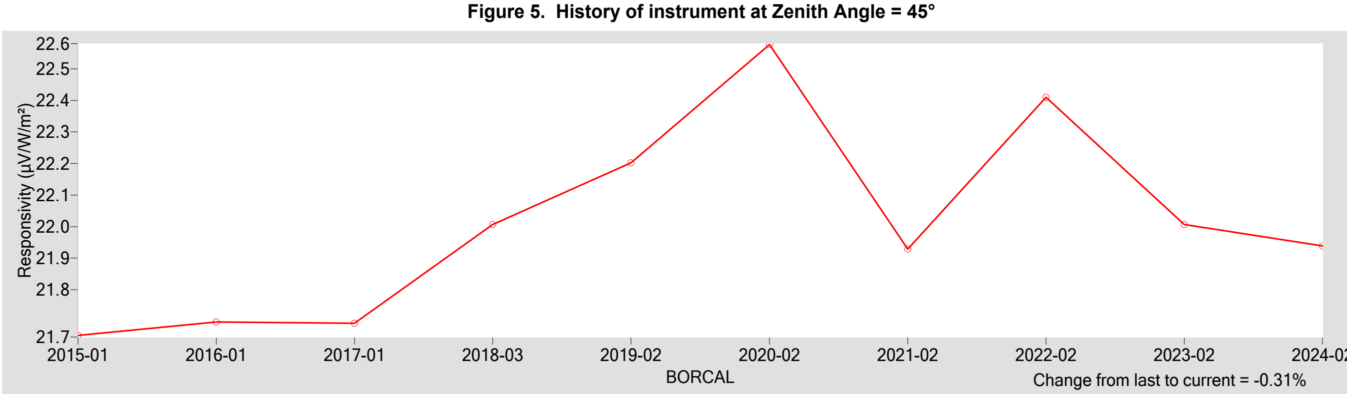
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
21.938	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.82
Offset Uncertainty, U(off) (%)	+0.53 / -0.43
Expanded Uncertainty, U (%)	+1.3 / -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

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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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[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.

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National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM6B	**Serial Number:**	015189
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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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2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager   05/21/2024
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

015189 Kipp & Zonen CM6B

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 - 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

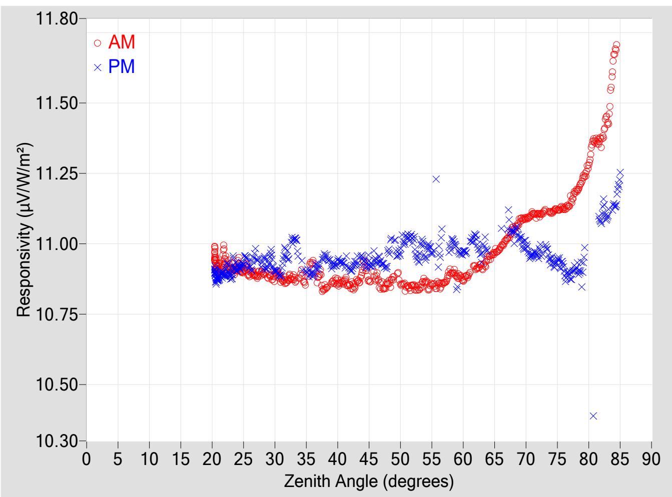


Figure 2. Responsivity vs Local Standard Time

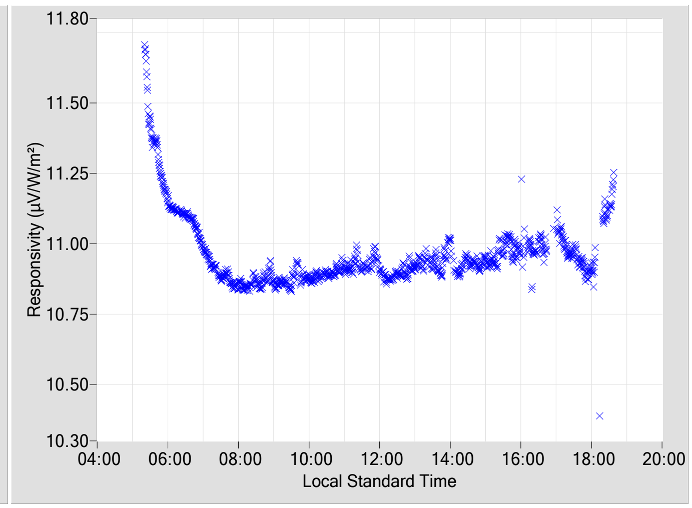


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.885	0.36	101.79	10.948	0.32	258.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.861	0.36	99.74	10.953	0.34	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.859	0.33	97.80	10.984	0.33	262.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.849	0.33	95.94	11.013	0.37	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.867	0.35	94.16	10.958	0.36	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.856	0.34	92.43	10.958	0.42	267.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.897	0.35	90.69	10.992	0.35	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.874	0.38	89.06	10.971	0.36	271.05
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.915	0.39	87.43	11.022	0.40	272.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.951	0.41	85.80	10.975	0.45	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.990	0.40	84.19	11.054	N/A	275.97
22	10.950	0.33	155.28	10.891	0.35	204.72	68	11.053	0.42	82.65	11.036	0.42	277.48
24	10.920	0.31	144.00	10.915	0.32	216.13	70	11.090	0.44	81.06	10.998	0.45	279.06
26	10.891	0.33	136.41	10.916	0.36	223.81	72	11.104	0.48	79.49	10.967	0.49	280.63
28	10.896	0.32	130.22	10.934	0.32	230.01	74	11.111	0.52	77.93	10.943	0.54	282.20
30	10.887	0.33	125.31	10.906	0.31	234.74	76	11.125	0.59	76.32	10.907	0.61	283.82
32	10.872	0.30	121.23	10.954	0.31	238.78	78	11.187	N/A	74.74	10.915	N/A	285.40
34	10.889	0.34	117.56	10.940	0.30	242.98	80	11.282	N/A	73.12	N/A	N/A	N/A
36	10.928	0.31	114.28	10.890	0.37	245.85	82	11.370	N/A	71.44	11.093	N/A	288.67
38	10.842	0.32	111.39	10.955	0.32	248.69	84	11.649	N/A	69.79	11.133	N/A	290.42
40	10.861	0.36	108.74	10.935	0.31	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.854	0.31	106.27	10.909	0.34	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.914	0.33	103.94	10.947	0.39	256.13	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

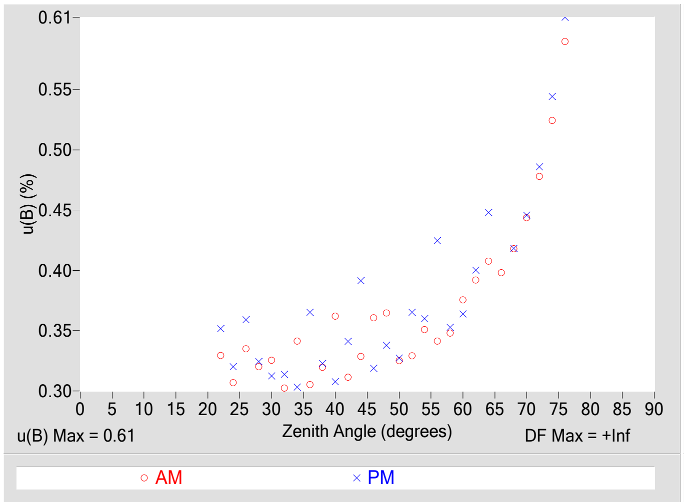


Figure 4. Residuals from Spline Interpolation

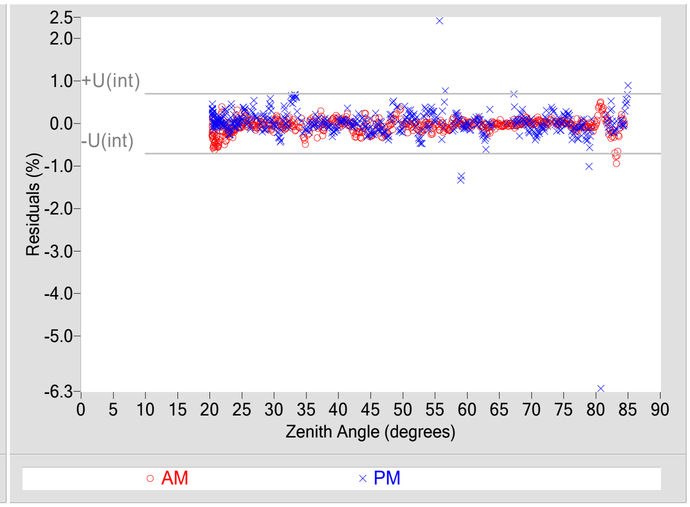


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.35
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	16037
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

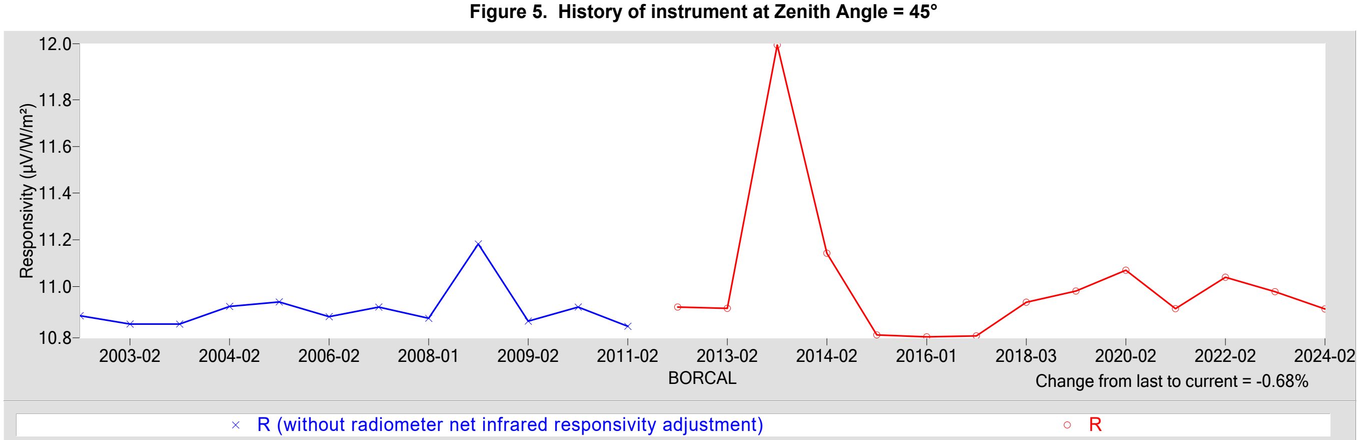
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.903	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.83
Offset Uncertainty, U(off) (%)	+1.0 / -0.56
Expanded Uncertainty, U (%)	+1.8 / -1.4
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:**	Yankee
Model:	TSP-700	**Serial Number:**	0212-2
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

0212-2 Yankee TSP-700

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

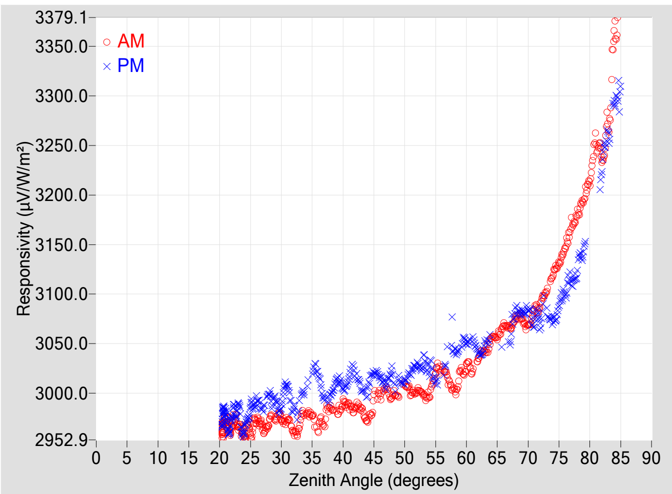


Figure 2. Responsivity vs Local Standard Time

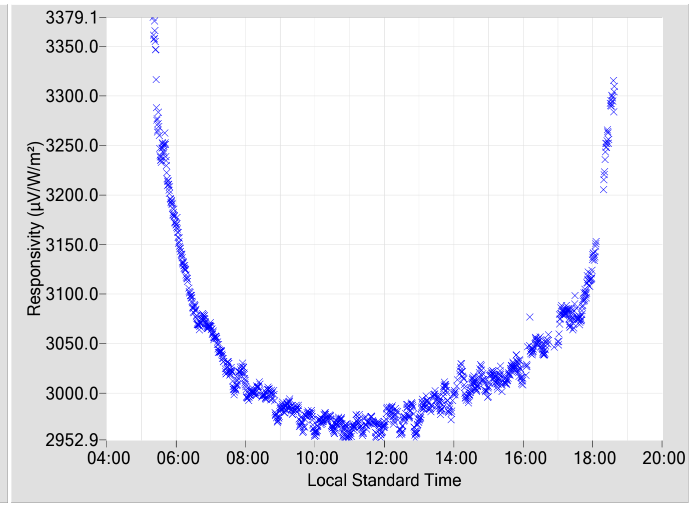


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	2998.5	0.31	101.79	3016.3	0.32	258.27
2	N/A	N/A	N/A	N/A	N/A	N/A	48	2997.8	0.31	99.74	3020.0	0.36	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	3008.4	0.31	97.80	3011.7	0.35	262.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	3001.9	0.37	95.94	3028.1	0.35	264.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	2998.4	0.32	94.16	3026.9	0.38	265.96
10	N/A	N/A	N/A	N/A	N/A	N/A	56	3024.2	0.40	92.41	3018.0	0.34	267.97
12	N/A	N/A	N/A	N/A	N/A	N/A	58	3002.9	0.35	90.69	3043.0	0.34	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	3027.1	0.34	89.06	3050.6	0.35	271.10
16	N/A	N/A	N/A	N/A	N/A	N/A	62	3035.1	0.42	87.43	3040.7	0.38	272.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	3054.4	0.39	85.80	3059.2	0.36	274.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	3067.7	0.38	84.24	N/A	N/A	N/A
22	2966.5	0.34	155.52	2978.6	0.32	204.90	68	3075.7	0.40	82.65	3082.0	0.43	277.47
24	2957.2	0.30	144.07	2963.9	0.30	216.14	70	3068.9	0.42	81.07	3084.9	0.42	279.06
26	2972.4	0.31	136.20	2990.8	0.33	223.69	72	3090.3	0.45	79.49	3072.5	0.49	280.63
28	2969.9	0.30	130.34	2998.9	0.32	229.85	74	3119.4	0.50	77.93	3074.7	0.50	282.20
30	2974.3	0.31	125.38	2988.3	0.30	234.74	76	3147.9	0.56	76.32	3099.9	0.56	283.82
32	2960.8	0.31	121.24	2984.0	0.33	238.79	78	3181.0	N/A	74.75	3126.1	N/A	285.40
34	2978.6	0.34	117.56	3004.4	0.30	242.47	80	3214.3	N/A	73.12	N/A	N/A	N/A
36	2965.8	0.30	114.31	3018.0	0.33	245.75	82	3237.9	N/A	71.44	3231.8	N/A	288.72
38	2984.5	0.31	111.46	2998.3	0.31	248.66	84	3359.7	N/A	69.75	3293.5	N/A	290.38
40	2990.1	0.33	108.74	3004.8	0.31	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	2985.4	0.32	106.27	3018.6	0.31	253.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	2972.5	0.32	104.04	3004.2	0.34	256.14	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

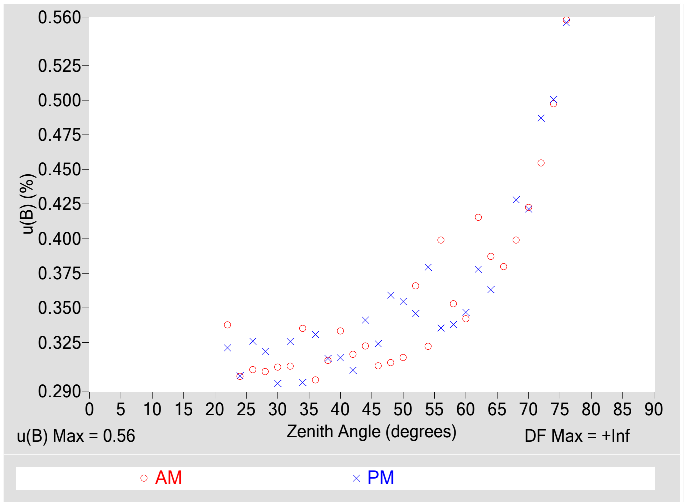


Figure 4. Residuals from Spline Interpolation

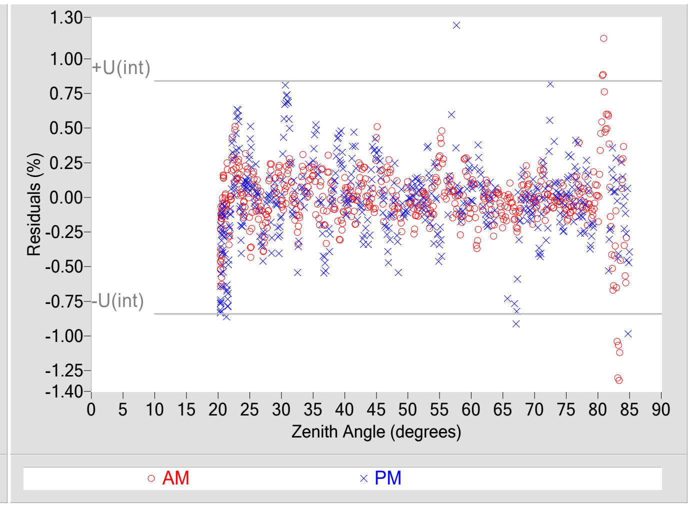


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.42
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	7533
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

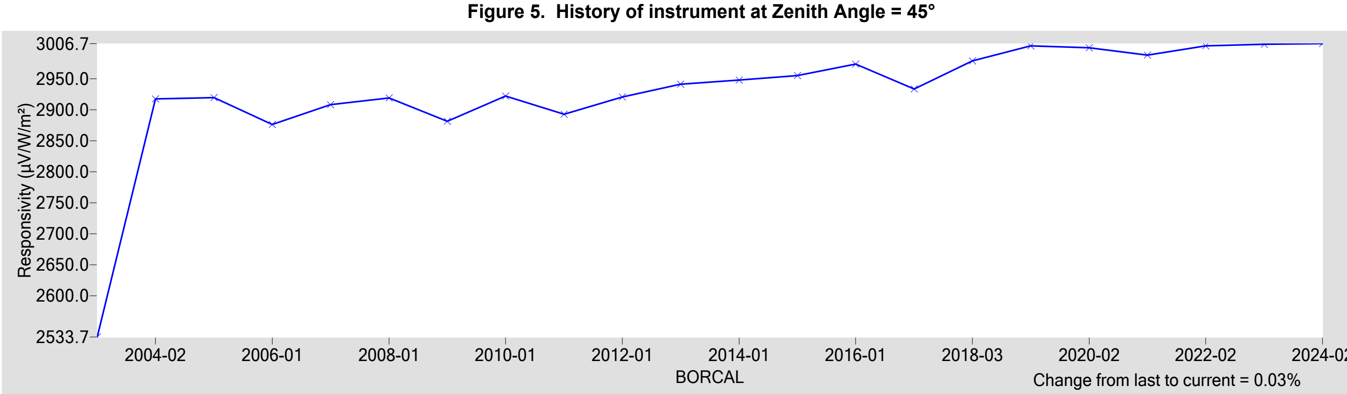
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
3006.7	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.5 / -1.5
Expanded Uncertainty, U (%)	+2.2 / -2.3
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

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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

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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:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	080009
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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
080009 Kipp & Zonen CHP1

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

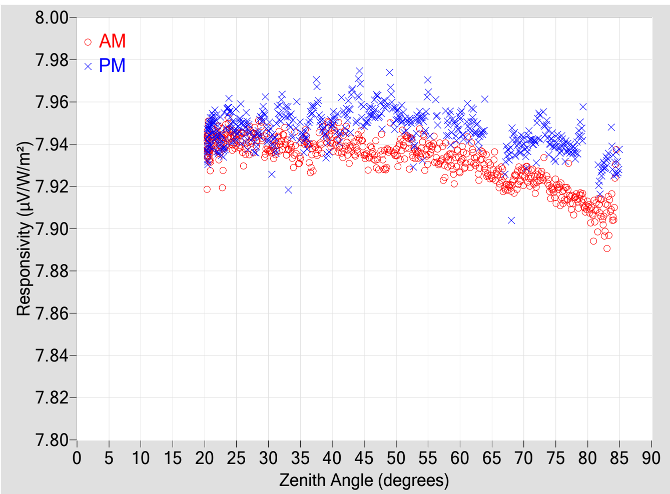


Figure 2. Responsivity vs Local Standard Time

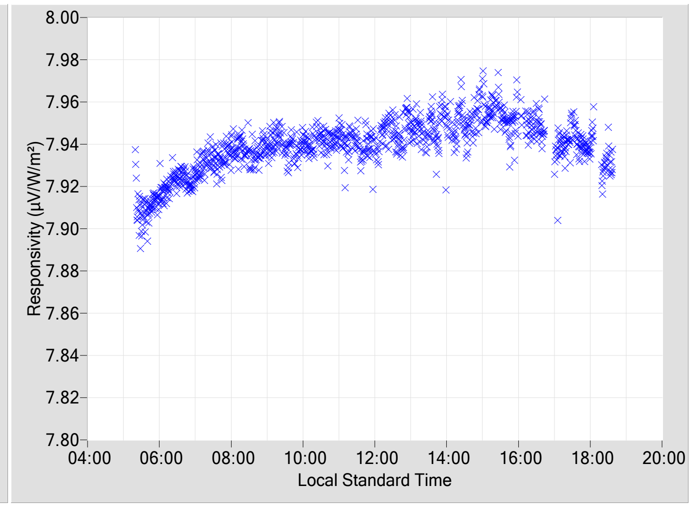


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.9360	0.29	101.84	7.9558	0.29	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9344	0.30	99.78	7.9566	0.30	260.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9345	0.31	97.81	7.9526	0.31	262.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9392	0.29	95.97	7.9510	0.30	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9387	0.32	94.14	7.9485	0.32	265.99
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9376	0.30	92.44	7.9571	0.33	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9341	0.33	90.72	7.9488	0.30	269.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9303	0.30	89.04	7.9525	0.30	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9350	0.31	87.42	7.9521	0.30	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9290	0.30	85.83	7.9539	0.30	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9243	0.31	84.22	N/A	N/A	N/A
22	7.9435	0.31	155.43	7.9432	0.31	204.77	68	7.9202	0.30	82.63	7.9408	0.32	277.51
24	7.9453	0.30	144.13	7.9520	0.32	216.08	70	7.9252	0.31	81.05	7.9395	0.32	279.04
26	7.9435	0.30	136.72	7.9467	0.32	223.86	72	7.9226	0.31	79.52	7.9432	0.31	280.61
28	7.9438	0.30	130.30	7.9393	0.31	229.77	74	7.9194	0.31	77.92	7.9408	0.31	282.23
30	7.9402	0.32	125.48	7.9448	0.31	234.71	76	7.9158	0.32	76.35	7.9404	0.32	283.80
32	7.9403	0.29	121.20	7.9576	0.29	238.75	78	7.9136	N/A	74.73	7.9373	N/A	285.43
34	7.9365	0.30	117.56	7.9474	0.31	242.41	80	7.9104	N/A	73.10	N/A	N/A	N/A
36	7.9419	0.30	114.33	7.9431	0.32	245.74	82	7.9095	N/A	71.42	7.9232	N/A	288.70
38	7.9408	0.32	111.37	7.9543	0.30	248.63	84	7.9107	N/A	69.73	7.9317	N/A	290.41
40	7.9420	0.31	108.79	7.9510	0.29	251.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9426	0.29	106.25	7.9522	0.30	253.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9403	0.30	103.99	7.9620	0.34	256.11	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

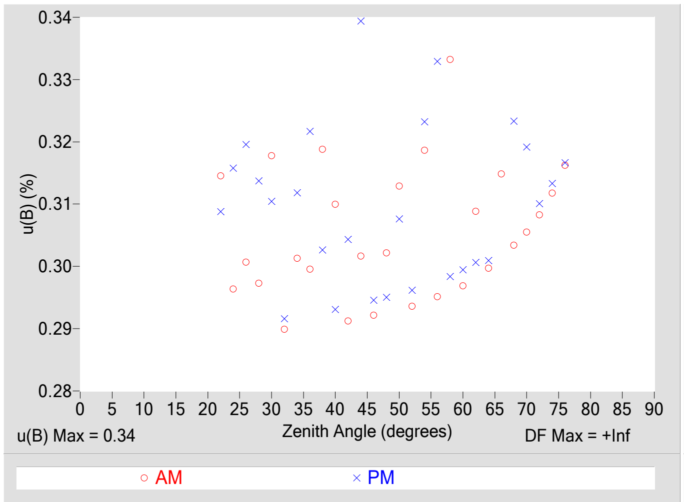


Figure 4. Residuals from Spline Interpolation

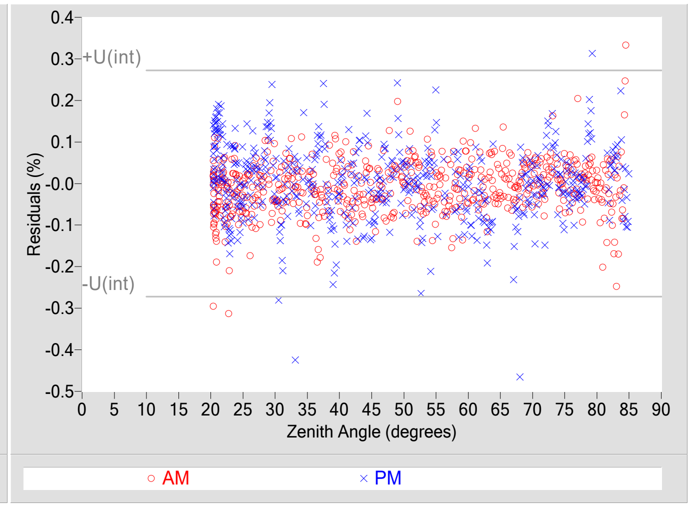


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.14
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	52593
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.72
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

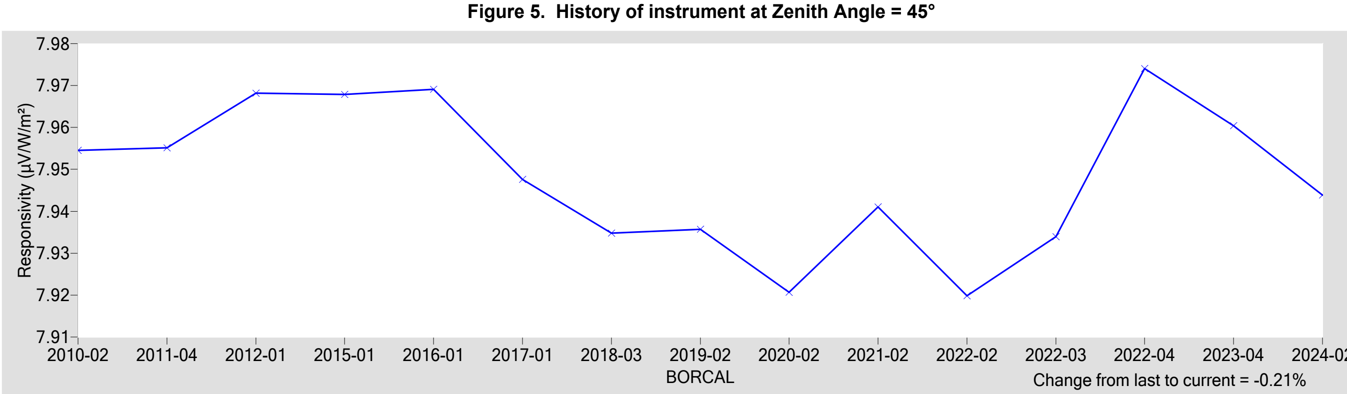
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9438	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.23 / -0.17
Expanded Uncertainty, U (%)	+0.89 / -0.84
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:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	080016
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

080016 Kipp & Zonen CMP22

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

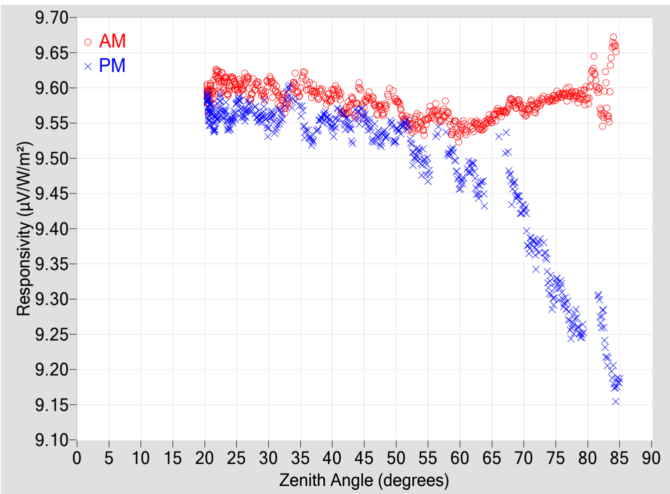


Figure 2. Responsivity vs Local Standard Time

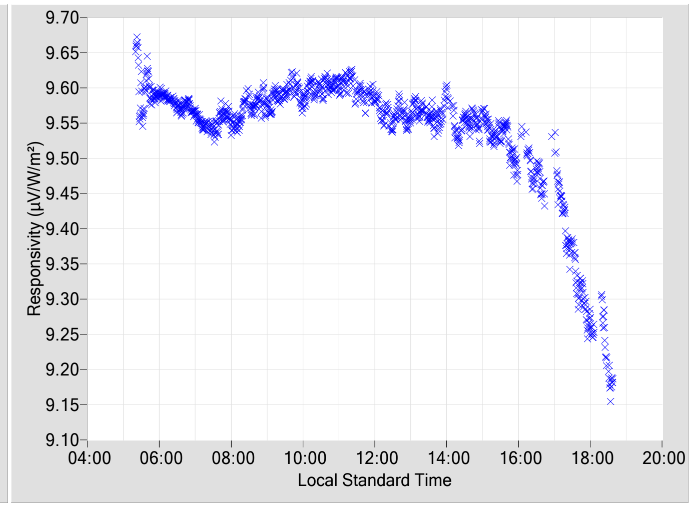


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.5870	0.33	101.79	9.5405	0.33	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.5668	0.31	99.79	9.5331	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.5823	0.34	97.82	9.5327	0.35	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.5489	0.34	95.93	9.5361	0.34	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.5479	0.34	94.15	9.4942	0.35	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.5655	0.35	92.42	9.5309	0.34	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5619	0.38	90.69	9.5132	0.37	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5373	0.35	89.05	9.4649	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.5448	0.38	87.42	9.4893	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.5498	0.40	85.79	9.4409	0.44	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.5663	0.41	84.23	9.5308	N/A	275.96
22	9.6150	0.32	155.05	9.5621	0.31	204.25	68	9.5811	0.41	82.64	9.4622	0.41	277.47
24	9.6045	0.31	144.03	9.5500	0.31	216.23	70	9.5672	0.43	81.06	9.4301	0.43	279.05
26	9.6029	0.30	136.22	9.5604	0.33	223.99	72	9.5732	0.47	79.48	9.3672	0.47	280.62
28	9.6029	0.33	130.13	9.5628	0.32	229.91	74	9.5827	0.51	77.93	9.3213	0.52	282.19
30	9.6093	0.32	125.36	9.5463	0.31	234.69	76	9.5897	0.57	76.36	9.3068	0.58	283.82
32	9.5830	0.30	121.22	9.5570	0.34	238.77	78	9.5896	N/A	74.74	9.2714	N/A	285.39
34	9.6088	0.31	117.63	9.5826	0.30	242.54	80	9.5869	N/A	73.11	N/A	N/A	N/A
36	9.6027	0.30	114.27	9.5365	0.30	245.83	82	9.5770	N/A	71.48	9.2749	N/A	288.71
38	9.5918	0.33	111.42	9.5535	0.32	248.72	84	9.6597	N/A	69.78	9.1863	N/A	290.41
40	9.5914	0.32	108.73	9.5409	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5660	0.31	106.27	9.5524	0.34	253.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.5882	0.34	104.00	9.5595	0.41	256.18	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

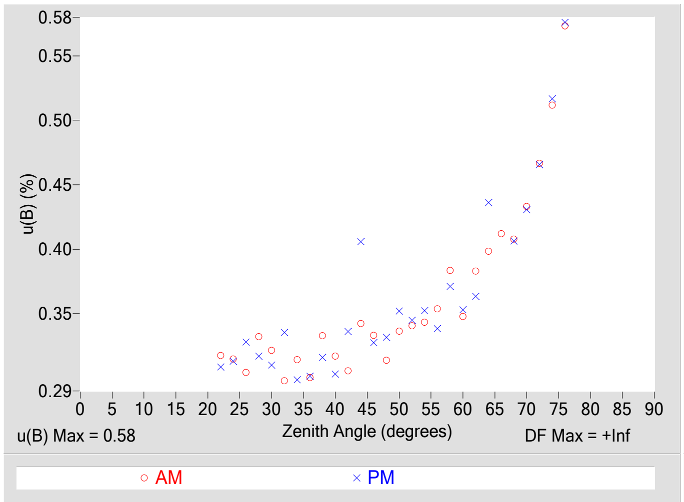


Figure 4. Residuals from Spline Interpolation

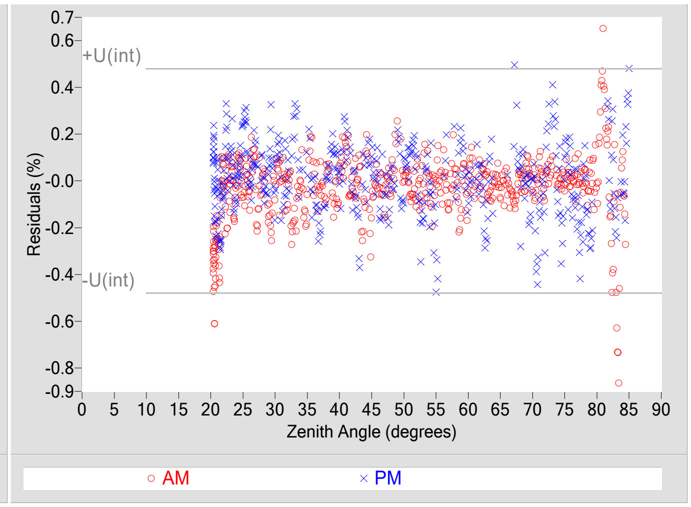


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	44888
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

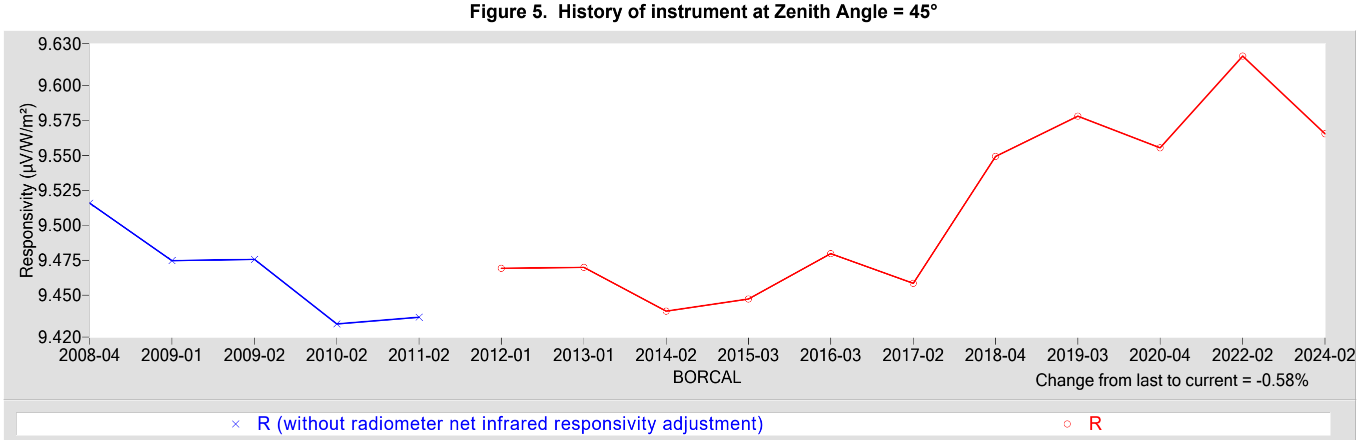
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.5655	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+0.46 / -1.1
Expanded Uncertainty, U (%)	+1.3 / -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:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	100174
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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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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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

_______________________ 05/21/2024

Ibrahim Reda, 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

100174 Kipp & Zonen CMP22

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

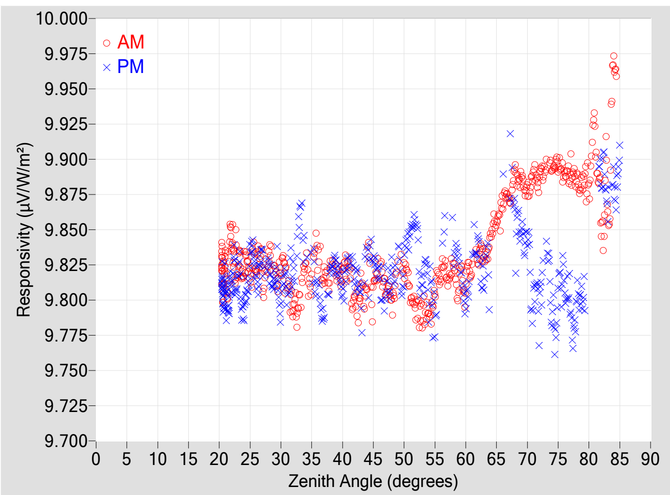


Figure 2. Responsivity vs Local Standard Time

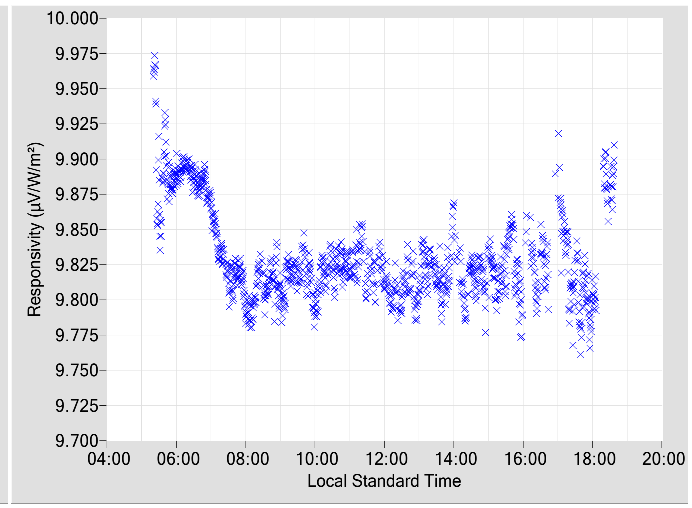


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.8244	0.33	101.79	9.8130	0.33	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7994	0.31	99.79	9.8180	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8216	0.34	97.82	9.8250	0.35	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7932	0.34	95.93	9.8514	0.34	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7914	0.34	94.15	9.8063	0.35	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8182	0.35	92.42	9.8405	0.34	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8230	0.38	90.69	9.8367	0.37	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8102	0.35	89.05	9.8002	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8295	0.38	87.42	9.8388	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.8448	0.40	85.79	9.8056	0.44	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.8696	0.41	84.23	9.8895	N/A	275.96
22	9.8412	0.32	155.05	9.8130	0.31	204.25	68	9.8894	0.41	82.64	9.8538	0.41	277.47
24	9.8223	0.31	144.03	9.7957	0.31	216.23	70	9.8784	0.43	81.06	9.8454	0.43	279.05
26	9.8257	0.30	136.22	9.8141	0.33	223.99	72	9.8876	0.47	79.48	9.7975	0.46	280.62
28	9.8292	0.33	130.13	9.8217	0.32	229.91	74	9.8940	0.51	77.93	9.7919	0.52	282.19
30	9.8238	0.32	125.36	9.7976	0.31	234.69	76	9.8882	0.57	76.36	9.8124	0.57	283.82
32	9.7963	0.30	121.22	9.8172	0.34	238.77	78	9.8856	N/A	74.74	9.7966	N/A	285.39
34	9.8255	0.31	117.63	9.8382	0.30	242.54	80	9.8838	N/A	73.11	N/A	N/A	N/A
36	9.8307	0.30	114.27	9.8101	0.30	245.83	82	9.8642	N/A	71.48	9.8884	N/A	288.71
38	9.8189	0.33	111.42	9.8194	0.32	248.72	84	9.9623	N/A	69.78	9.8802	N/A	290.41
40	9.8194	0.32	108.73	9.8046	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8009	0.31	106.27	9.8166	0.34	253.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8207	0.34	104.00	9.8260	0.41	256.18	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

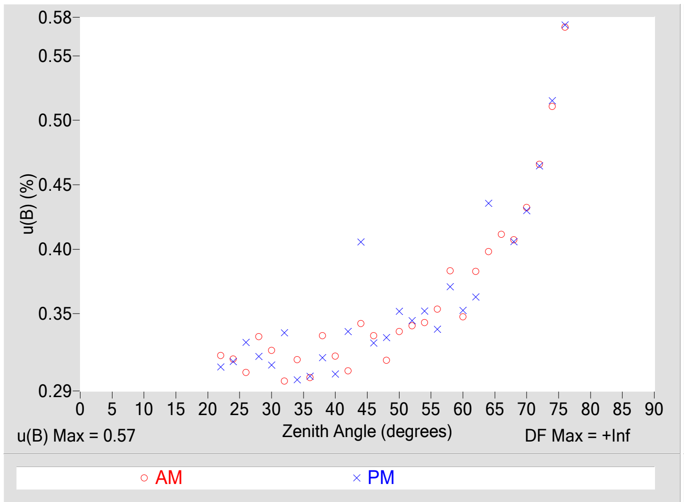


Figure 4. Residuals from Spline Interpolation

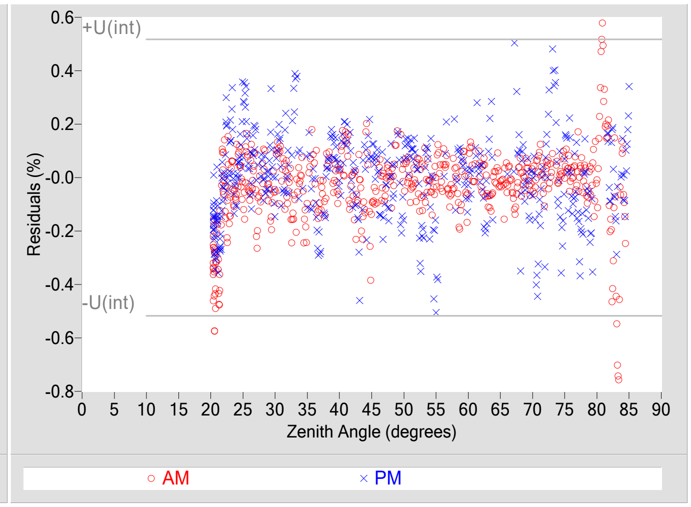


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.63
Effective degrees of freedom, DF(c)	34583
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

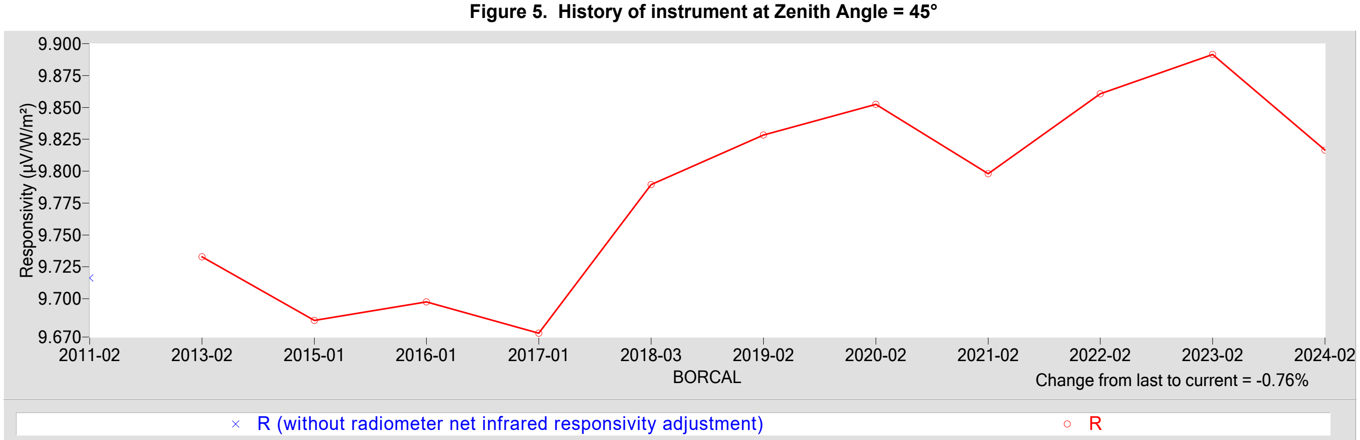
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.8167	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+0.35 / -0.26
Expanded Uncertainty, U (%)	+1.1 / -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

Calibration CERT #1239.02

Test Instrument:	Thermopile Pyranometer	**Manufacturer:**	Apogee
Model:	SP-510	**Serial Number:**	1171
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager   05/21/2024
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

1171 Apogee SP-510

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

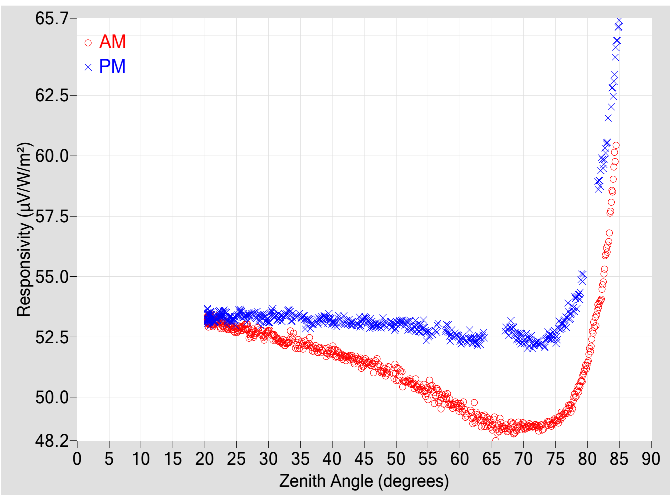


Figure 2. Responsivity vs Local Standard Time

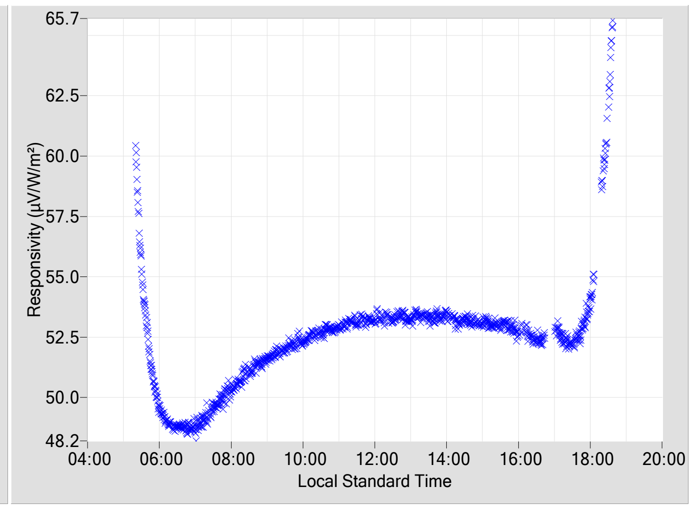


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	51.375	0.37	101.82	53.052	0.34	258.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	51.074	0.37	99.76	53.085	0.35	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	51.092	0.39	97.80	52.965	0.38	262.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	50.662	0.35	95.96	52.985	0.38	264.14
8	N/A	N/A	N/A	N/A	N/A	N/A	54	50.364	0.40	94.21	52.913	0.36	265.97
10	N/A	N/A	N/A	N/A	N/A	N/A	56	50.071	0.40	92.40	52.675	0.47	267.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	49.934	0.39	90.71	52.838	0.41	269.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	49.605	0.45	89.03	52.379	0.41	271.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	49.267	0.39	87.40	52.380	0.43	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	49.017	0.41	85.81	52.455	0.41	274.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	48.731	0.45	84.21	N/A	N/A	N/A
22	53.181	0.33	155.81	53.369	0.34	205.07	68	48.846	0.45	82.67	52.901	0.49	277.49
24	52.913	0.31	143.96	53.262	0.31	216.19	70	48.810	0.47	81.08	52.340	0.48	279.07
26	52.881	0.33	136.21	53.368	0.33	223.92	72	48.826	0.51	79.51	52.259	0.53	280.66
28	52.656	0.32	130.46	53.404	0.32	229.90	74	48.919	0.56	77.95	52.504	0.60	282.22
30	52.741	0.34	125.48	53.197	0.31	234.68	76	49.232	0.63	76.34	52.990	0.67	283.79
32	52.277	0.31	121.27	53.287	0.31	238.82	78	50.040	N/A	74.72	53.940	N/A	285.41
34	52.338	0.37	117.51	53.393	0.34	242.41	80	51.423	N/A	73.14	N/A	N/A	N/A
36	52.192	0.32	114.34	53.110	0.33	245.79	82	54.017	N/A	71.46	59.309	N/A	288.73
38	51.968	0.32	111.42	53.239	0.33	248.69	84	58.975	N/A	69.76	62.767	N/A	290.39
40	51.951	0.35	108.66	53.110	0.33	251.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	51.654	0.32	106.30	53.172	0.32	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	51.550	0.33	103.97	53.059	0.36	256.15	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

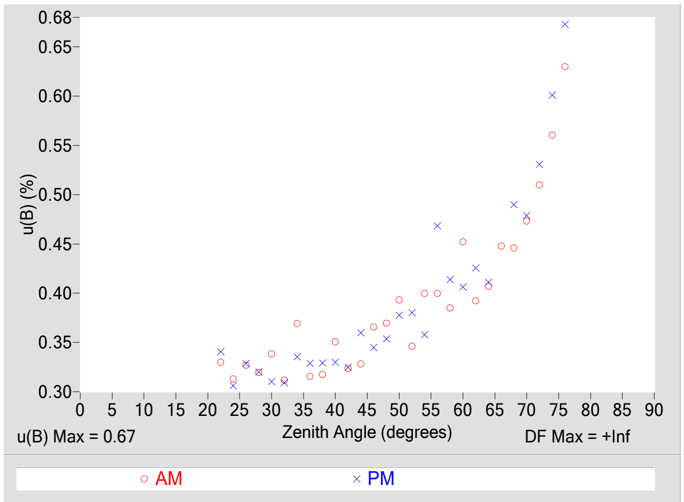


Figure 4. Residuals from Spline Interpolation

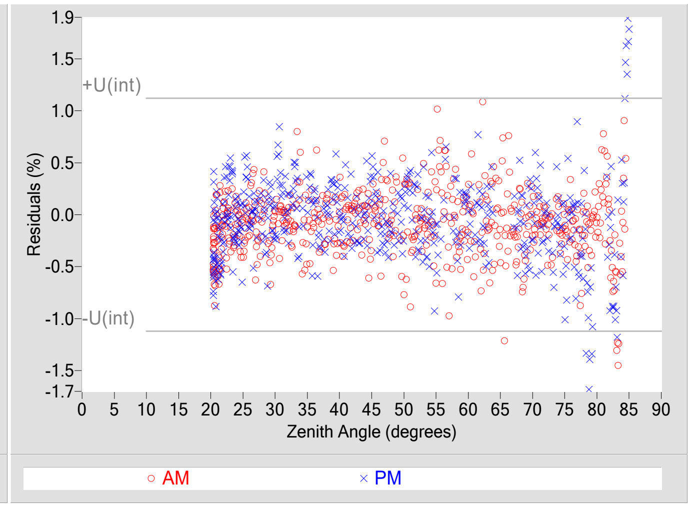


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.67
Type-A Interpolating Function, u(int) (%)	±0.56
Combined Standard Uncertainty, u(c) (%)	±0.88
Effective degrees of freedom, DF(c)	5911
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.7
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

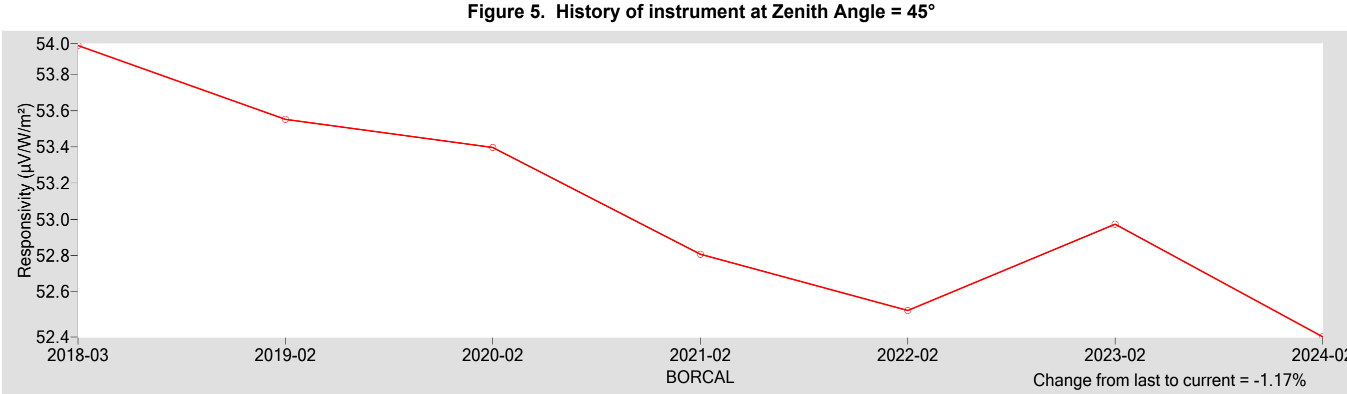
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
52.351	2.5000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.92
Offset Uncertainty, U(off) (%)	+2.0 / -5.2
Expanded Uncertainty, U (%)	+2.9 / -6.2
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 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:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	120373
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

______________________________ 05/21/2024

Ibrahim Reda, 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

120373 Kipp & Zonen CMP22

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

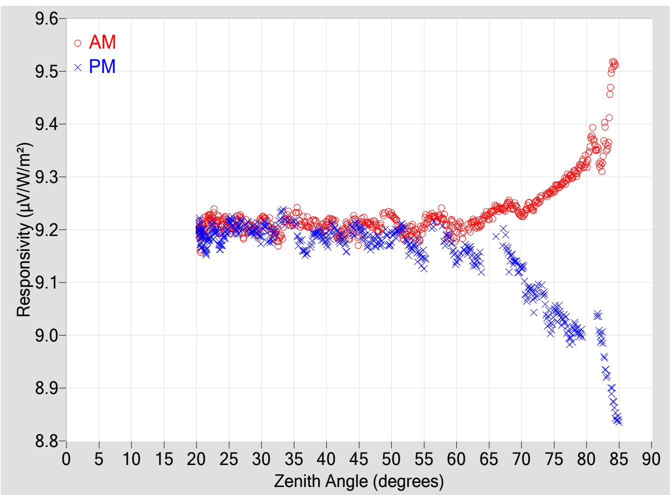


Figure 2. Responsivity vs Local Standard Time

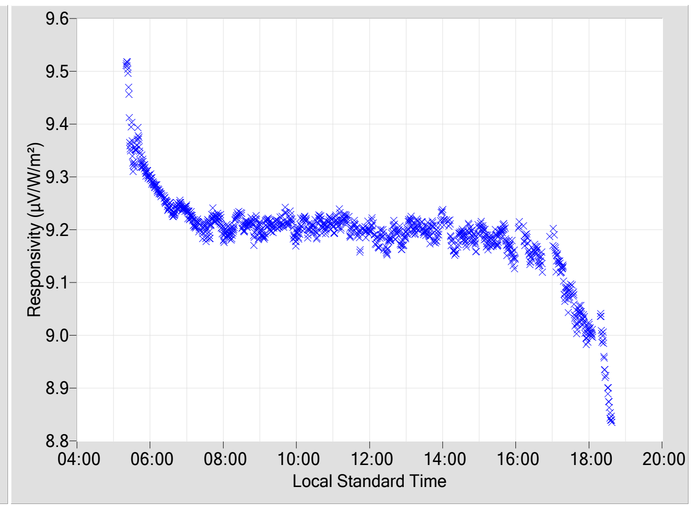


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.2142	0.33	101.79	9.1839	0.33	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1992	0.31	99.79	9.1790	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2283	0.34	97.82	9.1824	0.35	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1908	0.34	95.93	9.1946	0.35	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1888	0.34	94.15	9.1597	0.35	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2233	0.35	92.42	9.2021	0.34	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2201	0.38	90.69	9.1832	0.37	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1948	0.35	89.05	9.1438	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2048	0.38	87.42	9.1634	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2187	0.40	85.79	9.1274	0.44	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2406	0.41	84.23	9.1870	N/A	275.96
22	9.2216	0.32	155.05	9.1877	0.31	204.25	68	9.2495	0.41	82.64	9.1483	0.41	277.47
24	9.2087	0.32	144.03	9.1804	0.31	216.23	70	9.2285	0.43	81.06	9.1291	0.43	279.05
26	9.2086	0.30	136.22	9.1990	0.33	223.99	72	9.2462	0.47	79.48	9.0691	0.47	280.62
28	9.2027	0.33	130.13	9.2034	0.32	229.91	74	9.2673	0.51	77.93	9.0346	0.52	282.19
30	9.2208	0.32	125.36	9.1907	0.31	234.69	76	9.2835	0.57	76.36	9.0374	0.58	283.82
32	9.1931	0.30	121.22	9.1898	0.34	238.77	78	9.3051	N/A	74.74	9.0103	N/A	285.39
34	9.2242	0.31	117.63	9.2186	0.30	242.54	80	9.3283	N/A	73.11	N/A	N/A	N/A
36	9.2102	0.30	114.27	9.1750	0.30	245.83	82	9.3338	N/A	71.48	9.0068	N/A	288.71
38	9.2116	0.33	111.42	9.1903	0.32	248.72	84	9.5027	N/A	69.78	8.8837	N/A	290.41
40	9.2093	0.32	108.73	9.1747	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1879	0.31	106.27	9.1854	0.34	253.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2100	0.34	104.00	9.1973	0.41	256.18	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

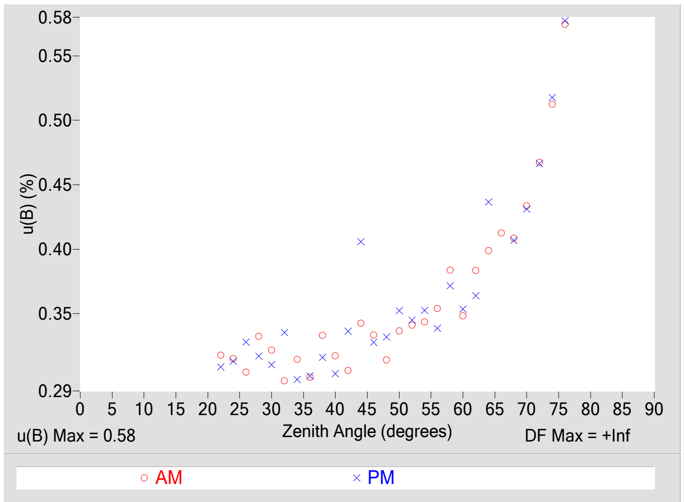


Figure 4. Residuals from Spline Interpolation

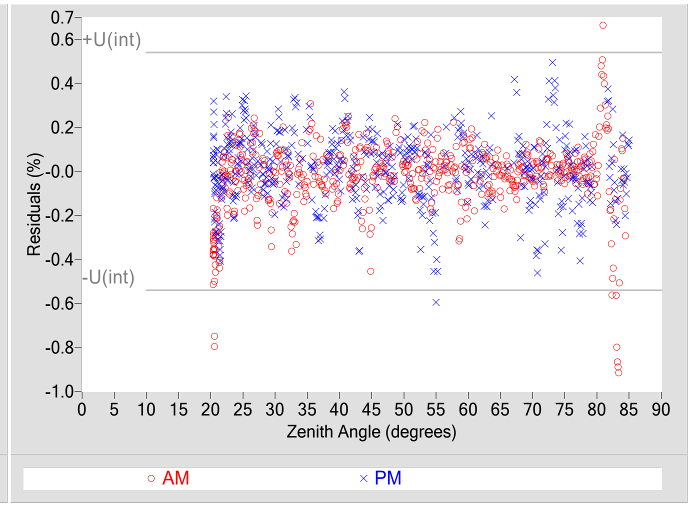


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	30381
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

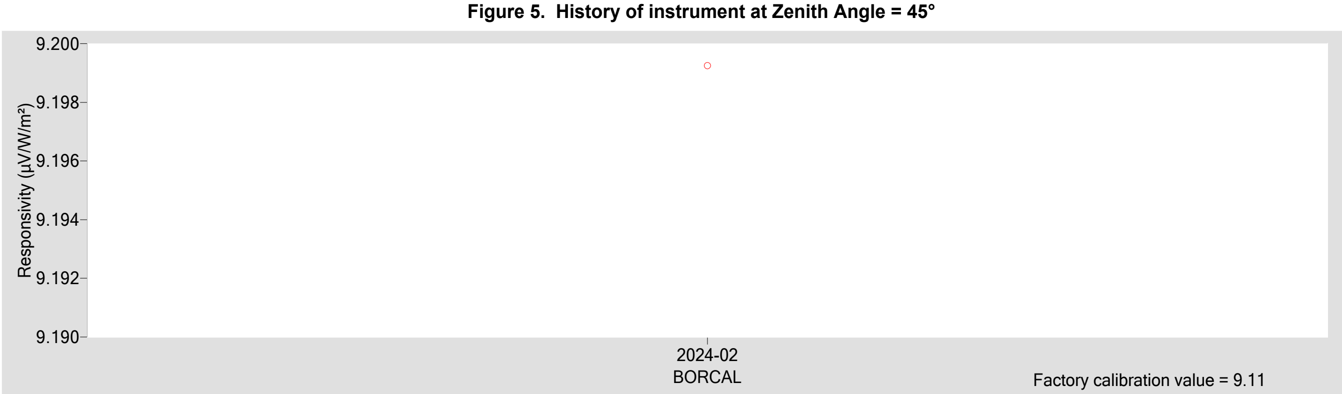
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.1992	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+0.32 / -0.60
Expanded Uncertainty, U (%)	+1.1 / -1.4
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:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	140043
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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 CGR4, S/N 140021	07/18/2023	07/18/2028

† 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, RCC, and Shawn L. Jaker

________________________ 05/21/2024

Ibrahim Reda, 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

140043 Kipp & Zonen CMP22

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

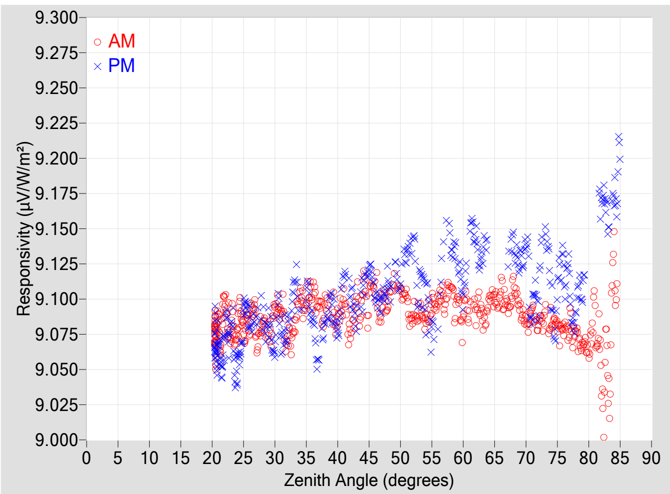


Figure 2. Responsivity vs Local Standard Time

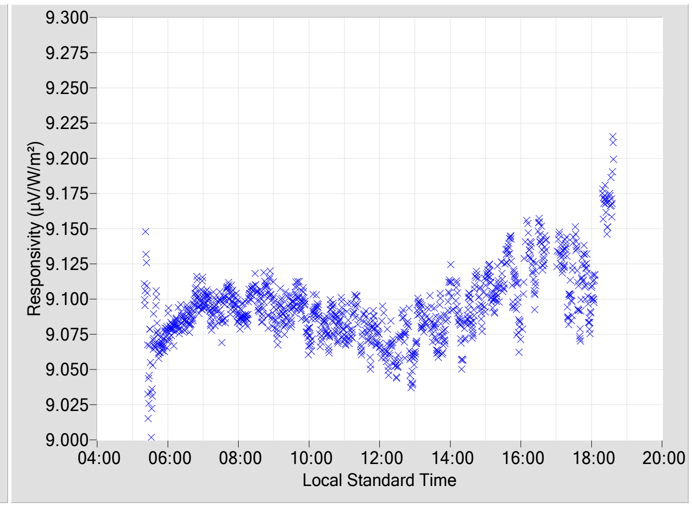


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.1081	0.33	101.80	9.1035	0.33	258.27
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0966	0.31	99.74	9.1127	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1058	0.32	97.81	9.1127	0.32	262.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0883	0.32	95.94	9.1410	0.40	264.21
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0860	0.35	94.16	9.1026	0.37	265.96
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0996	0.37	92.38	9.0911	0.40	267.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1079	0.36	90.69	9.1403	0.37	269.41
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0859	0.39	89.06	9.1042	0.38	271.10
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0921	0.36	87.39	9.1424	0.36	272.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0964	0.37	85.81	9.1423	0.37	274.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.1074	0.42	84.24	N/A	N/A	N/A
22	9.0963	0.33	155.30	9.0749	0.32	204.67	68	9.1085	0.41	82.65	9.1370	0.41	277.47
24	9.0764	0.31	144.09	9.0543	0.31	216.15	70	9.0847	0.43	81.07	9.1390	0.43	279.06
26	9.0845	0.30	136.25	9.0833	0.31	223.70	72	9.0820	0.47	79.49	9.1025	0.53	280.63
28	9.0795	0.31	130.35	9.0904	0.35	229.65	74	9.0822	0.51	77.94	9.1032	0.52	282.20
30	9.0931	0.31	125.39	9.0692	0.32	234.75	76	9.0795	0.58	76.32	9.1225	0.58	283.78
32	9.0703	0.31	121.24	9.0780	0.30	238.79	78	9.0768	N/A	74.75	9.0932	N/A	285.40
34	9.1015	0.31	117.51	9.0923	0.30	242.48	80	9.0642	N/A	73.12	N/A	N/A	N/A
36	9.1029	0.31	114.36	9.0856	0.31	245.77	82	9.0463	N/A	71.44	9.1698	N/A	288.72
38	9.0918	0.34	111.47	9.0821	0.32	248.62	84	9.1194	N/A	69.75	9.1729	N/A	290.38
40	9.0873	0.34	108.75	9.0775	0.32	251.36	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0781	0.31	106.28	9.1039	0.34	253.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1082	0.34	103.95	9.1044	0.33	256.14	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

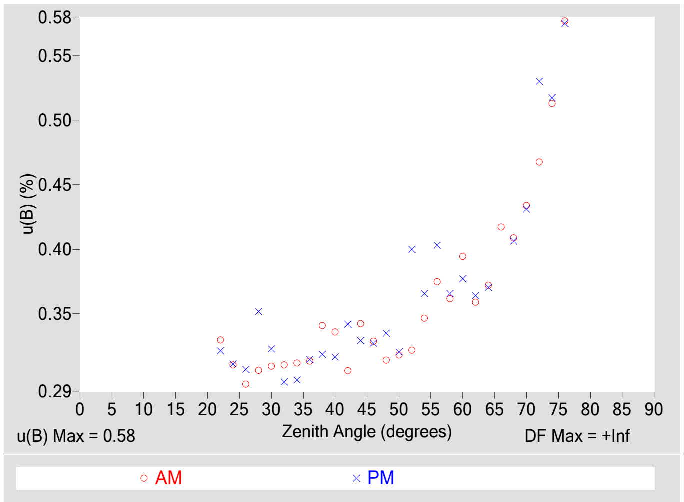


Figure 4. Residuals from Spline Interpolation

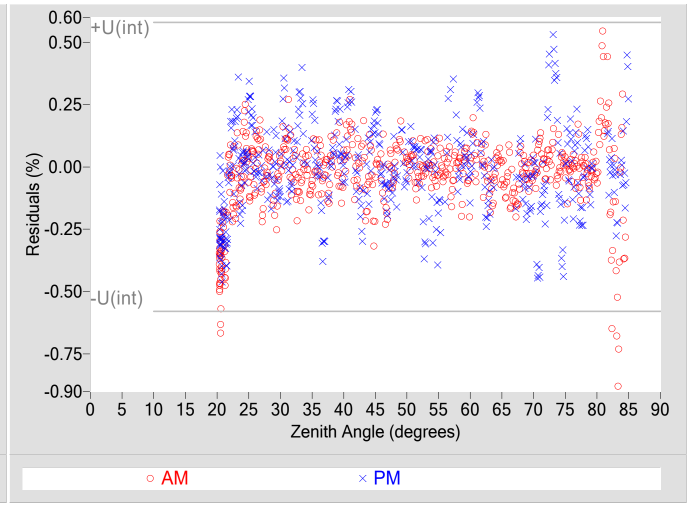


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	24600
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

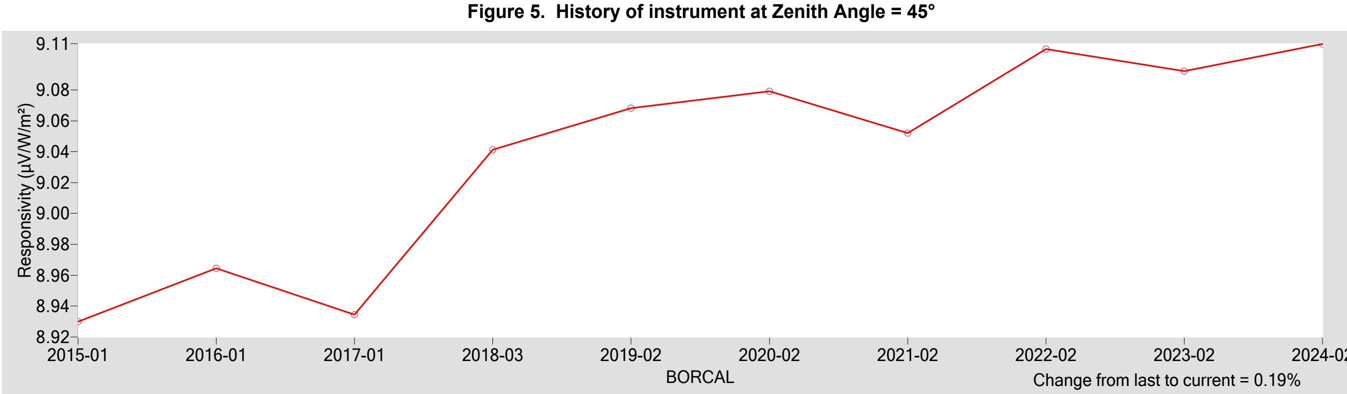
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.1099	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+0.34 / -0.45
Expanded Uncertainty, U (%)	+1.1 / -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

ACCREDITED
Calibration CERT #1239.02

Test Instrument: Pyrheliometer

Manufacturer: Kipp & Zonen

Model: CHP1

Serial Number: 140108

Calibration Date: 5/16/2024

Due Date: 5/16/2025

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/16

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

140108 Kipp & Zonen CHP1

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

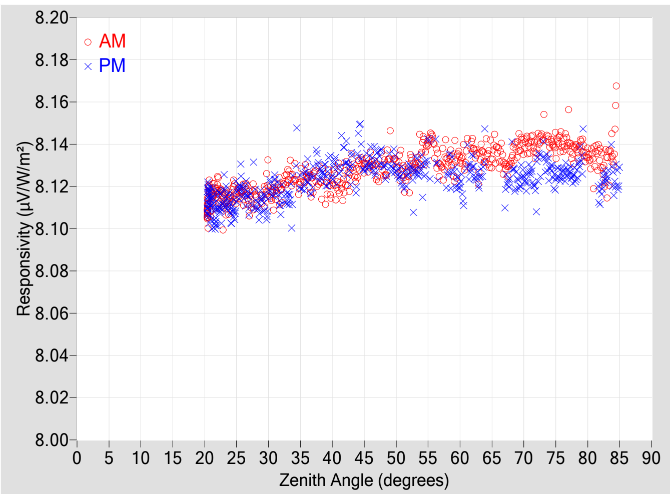


Figure 2. Responsivity vs Local Standard Time

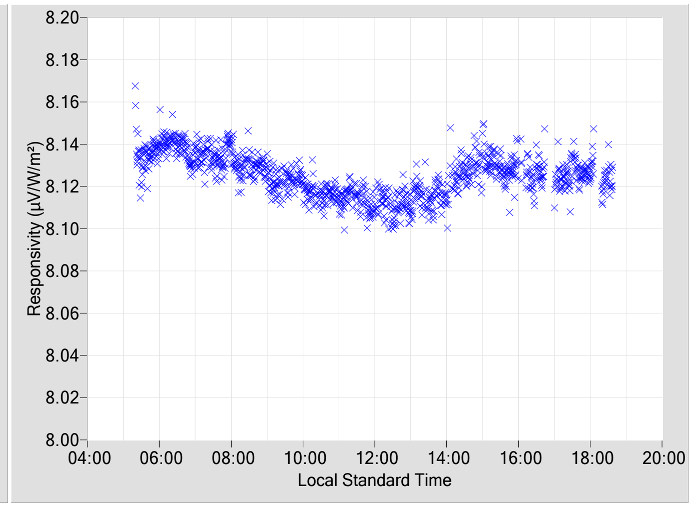


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.1314	0.29	101.84	8.1334	0.29	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1296	0.30	99.78	8.1299	0.29	260.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1303	0.31	97.81	8.1288	0.31	262.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1264	0.29	95.97	8.1286	0.30	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1373	0.32	94.14	8.1277	0.32	265.99
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1391	0.30	92.44	8.1367	0.33	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1340	0.33	90.72	8.1242	0.30	269.44
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1335	0.30	89.04	8.1216	0.30	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1392	0.31	87.42	8.1300	0.30	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1344	0.30	85.83	8.1394	0.30	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1346	0.31	84.22	N/A	N/A	N/A
22	8.1186	0.31	155.43	8.1100	0.31	204.77	68	8.1324	0.30	82.63	8.1309	0.33	277.53
24	8.1145	0.30	144.13	8.1087	0.32	216.08	70	8.1395	0.31	81.05	8.1243	0.32	279.04
26	8.1171	0.30	136.59	8.1184	0.32	223.86	72	8.1391	0.31	79.52	8.1223	0.31	280.61
28	8.1157	0.29	130.53	8.1122	0.31	229.77	74	8.1406	0.31	77.92	8.1287	0.31	282.23
30	8.1219	0.32	125.48	8.1153	0.31	234.71	76	8.1400	0.32	76.35	8.1264	0.32	283.80
32	8.1167	0.29	121.20	8.1137	0.29	238.75	78	8.1374	N/A	74.73	8.1255	N/A	285.43
34	8.1250	0.30	117.56	8.1222	0.31	242.41	80	8.1348	N/A	73.10	N/A	N/A	N/A
36	8.1258	0.30	114.33	8.1260	0.32	245.74	82	8.1335	N/A	71.42	8.1163	N/A	288.70
38	8.1237	0.32	111.37	8.1274	0.30	248.63	84	8.1372	N/A	69.73	8.1229	N/A	290.41
40	8.1207	0.31	108.79	8.1279	0.29	251.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1240	0.29	106.25	8.1353	0.30	253.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1284	0.30	103.99	8.1334	0.34	256.11	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

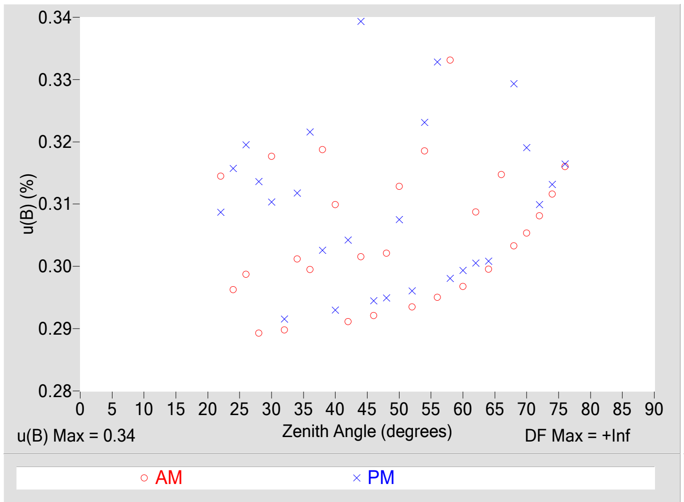


Figure 4. Residuals from Spline Interpolation

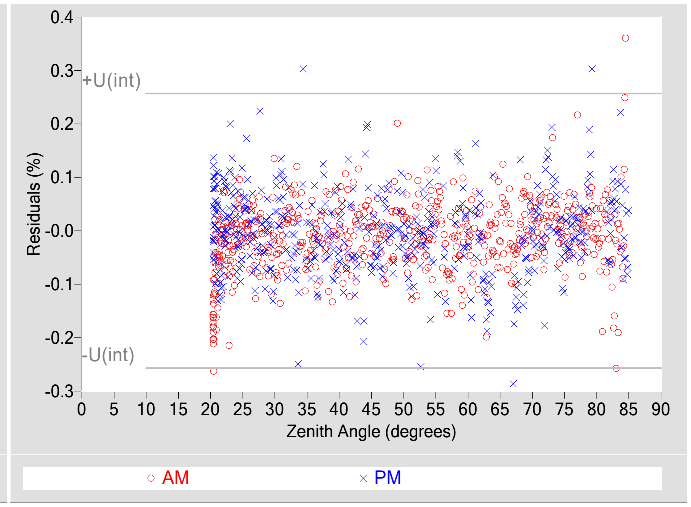


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	63735
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.71
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

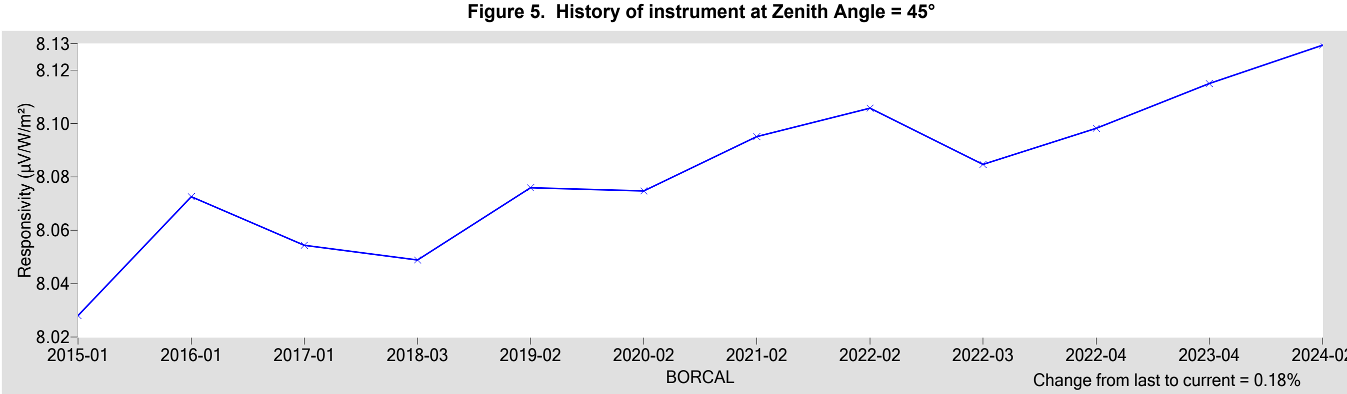
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1294	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.12 / -0.19
Expanded Uncertainty, U (%)	+0.78 / -0.86
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: Kipp & Zonen

Model: CMP11

Serial Number: 140712

Calibration Date: 5/16/2024

Due Date: 5/16/2025

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/16

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

____________________________ 05/21/2024

Ibrahim Reda, 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

140712 Kipp & Zonen CMP11

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

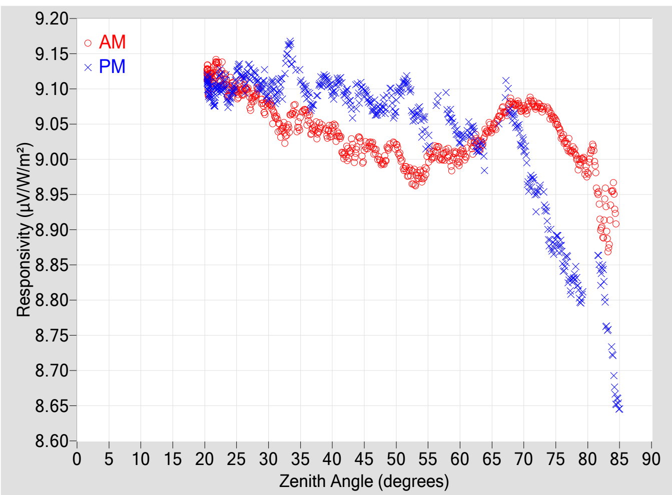


Figure 2. Responsivity vs Local Standard Time

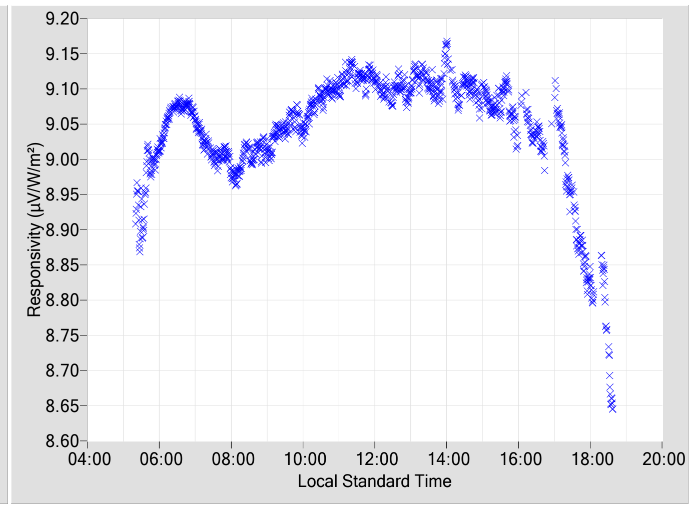


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM			PM			Zenith Angle (deg.)	AM			PM		
	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle		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	9.0213	0.33	101.84	9.0781	0.33	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9963	0.35	99.78	9.0744	0.35	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0183	0.32	97.76	9.0787	0.34	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9801	0.35	95.93	9.1023	0.37	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9772	0.35	94.15	9.0510	0.34	265.94
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0092	0.40	92.42	9.0766	0.45	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0093	0.35	90.68	9.0693	0.35	269.44
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0021	0.39	89.05	9.0289	0.36	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0182	0.37	87.42	9.0423	0.40	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0383	0.43	85.79	8.9945	0.38	274.11
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0582	0.42	84.23	9.0506	N/A	275.96
22	9.1303	0.30	155.38	9.1036	0.33	204.53	68	9.0804	0.42	82.64	9.0643	0.41	277.45
24	9.1007	0.31	144.01	9.0892	0.32	216.40	70	9.0720	0.44	81.06	9.0198	0.44	279.05
26	9.0985	0.31	136.08	9.1118	0.32	223.97	72	9.0741	0.48	79.52	8.9468	0.48	280.62
28	9.0934	0.31	130.19	9.1138	0.32	229.90	74	9.0663	0.52	77.92	8.8870	0.54	282.23
30	9.0805	0.32	125.35	9.0913	0.31	234.68	76	9.0329	0.59	76.35	8.8611	0.60	283.81
32	9.0424	0.31	121.21	9.1033	0.34	238.85	78	9.0091	N/A	74.73	8.8347	N/A	285.39
34	9.0694	0.37	117.54	9.1343	0.34	242.53	80	8.9841	N/A	73.11	N/A	N/A	N/A
36	9.0601	0.32	114.34	9.0948	0.31	245.81	82	8.9185	N/A	71.47	8.8395	N/A	288.71
38	9.0437	0.31	111.45	9.1077	0.32	248.79	84	8.9518	N/A	69.78	8.7022	N/A	290.41
40	9.0417	0.31	108.73	9.0944	0.31	251.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0081	0.31	106.26	9.0923	0.33	253.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0238	0.38	103.99	9.0887	0.37	256.12	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

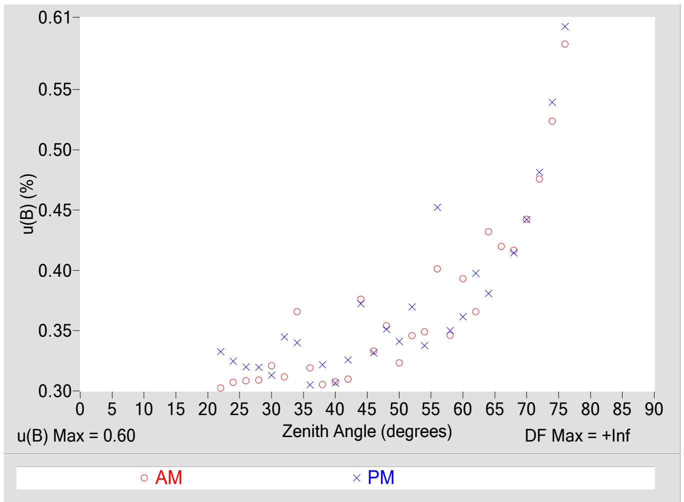


Figure 4. Residuals from Spline Interpolation

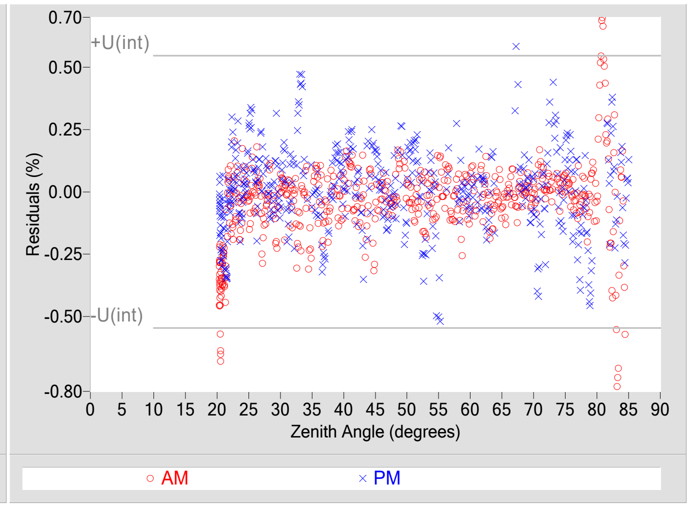


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	34370
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

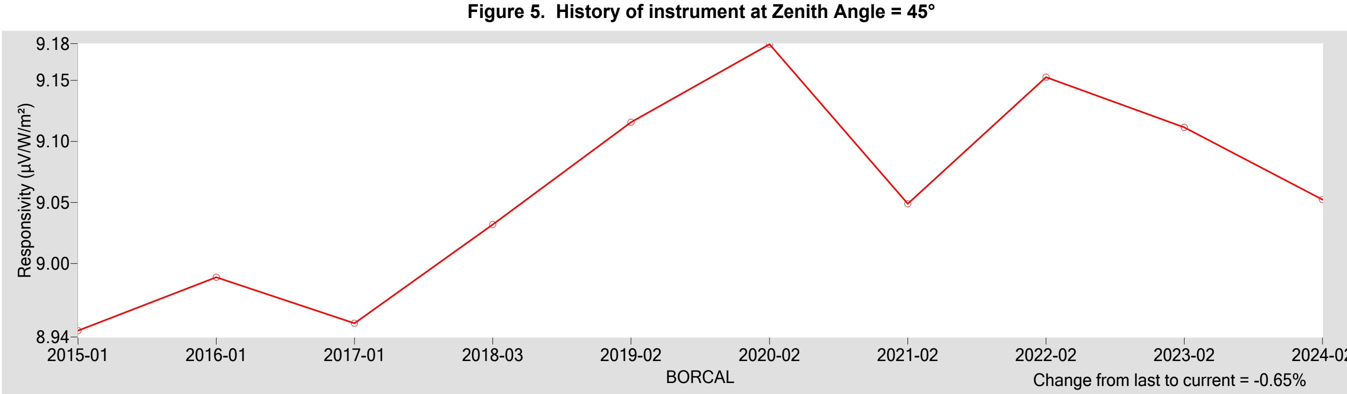
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0525	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+0.90 / -0.83
Expanded Uncertainty, U (%)	+1.8 / -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:**	Kipp & Zonen
Model:	CMP11	**Serial Number:**	140713
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager   05/21/2024 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

140713 Kipp & Zonen CMP11

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

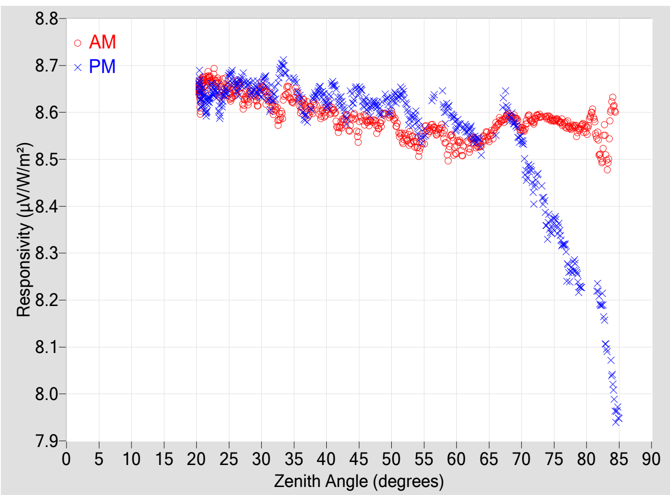


Figure 2. Responsivity vs Local Standard Time

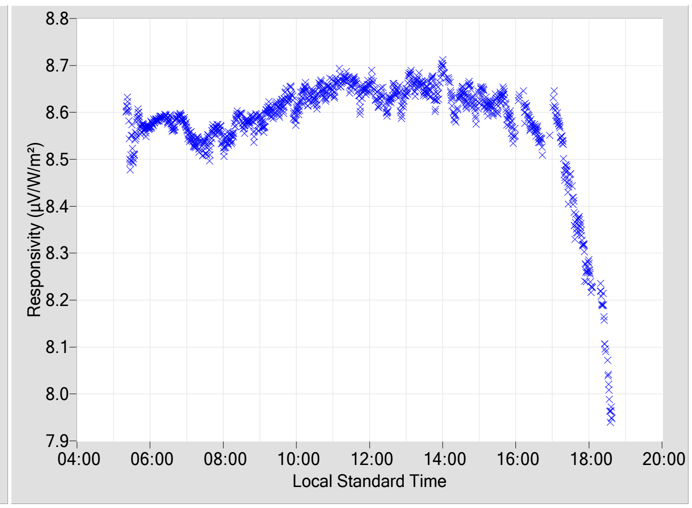


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5842	0.33	101.84	8.6189	0.33	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5669	0.35	99.78	8.6078	0.35	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5961	0.32	97.76	8.6161	0.34	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5451	0.35	95.93	8.6296	0.37	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5262	0.35	94.15	8.5774	0.34	265.94
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5646	0.40	92.42	8.6251	0.45	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5526	0.35	90.68	8.6098	0.35	269.44
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5260	0.39	89.05	8.5720	0.36	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5275	0.37	87.42	8.5624	0.40	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5420	0.43	85.79	8.5175	0.38	274.11
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5682	0.42	84.23	8.5512	N/A	275.96
22	8.6727	0.30	155.38	8.6336	0.33	204.53	68	8.5941	0.42	82.64	8.5976	0.42	277.45
24	8.6500	0.31	144.01	8.6293	0.33	216.40	70	8.5640	0.44	81.06	8.5421	0.44	279.05
26	8.6492	0.31	136.08	8.6563	0.32	223.97	72	8.5811	0.48	79.52	8.4358	0.48	280.62
28	8.6320	0.31	130.19	8.6555	0.32	229.90	74	8.5893	0.53	77.92	8.3577	0.54	282.23
30	8.6538	0.32	125.35	8.6490	0.31	234.68	76	8.5809	0.59	76.35	8.3348	0.61	283.81
32	8.6070	0.31	121.21	8.6372	0.35	238.85	78	8.5699	N/A	74.73	8.2730	N/A	285.39
34	8.6459	0.37	117.54	8.6778	0.34	242.53	80	8.5642	N/A	73.11	N/A	N/A	N/A
36	8.6111	0.32	114.34	8.6223	0.31	245.81	82	8.5217	N/A	71.47	8.1997	N/A	288.71
38	8.6112	0.31	111.45	8.6339	0.32	248.79	84	8.6146	N/A	69.78	8.0282	N/A	290.41
40	8.6060	0.31	108.73	8.6178	0.31	251.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5691	0.31	106.26	8.6249	0.33	253.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5887	0.38	103.99	8.6230	0.37	256.12	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

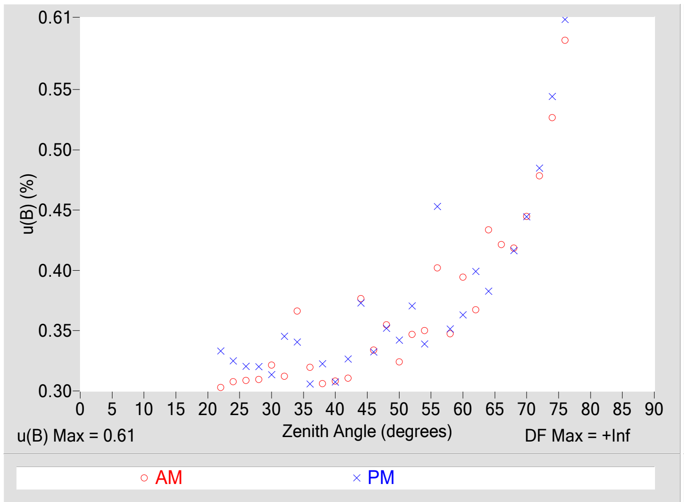


Figure 4. Residuals from Spline Interpolation

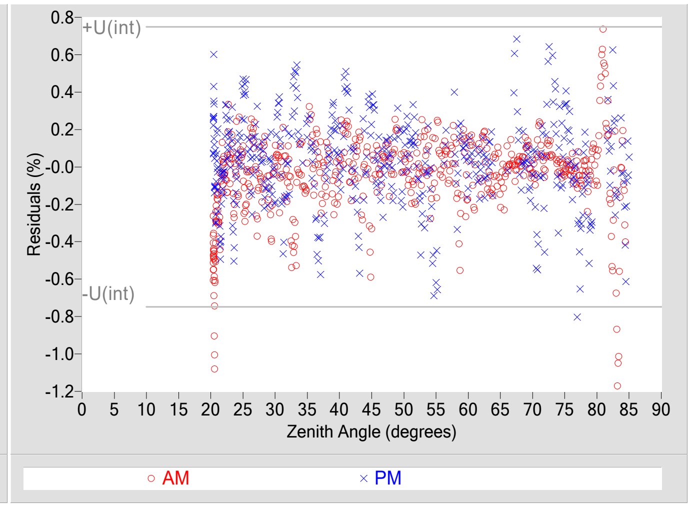


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.37
Combined Standard Uncertainty, u(c) (%)	±0.71
Effective degrees of freedom, DF(c)	13199
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

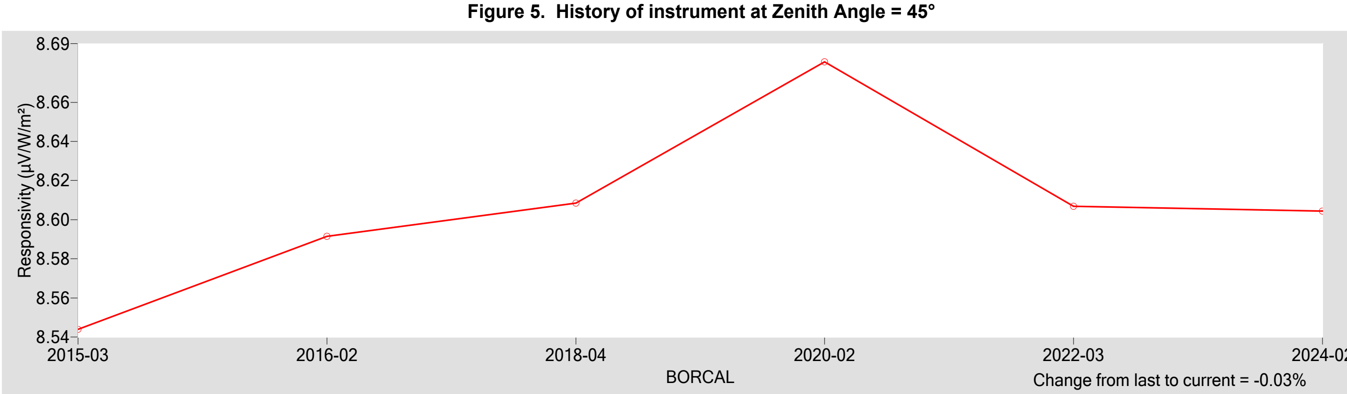
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6044	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+0.85 / -0.91
Expanded Uncertainty, U (%)	+1.7 / -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:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	151027
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

151027 Kipp & Zonen SP-LITE2

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 - 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

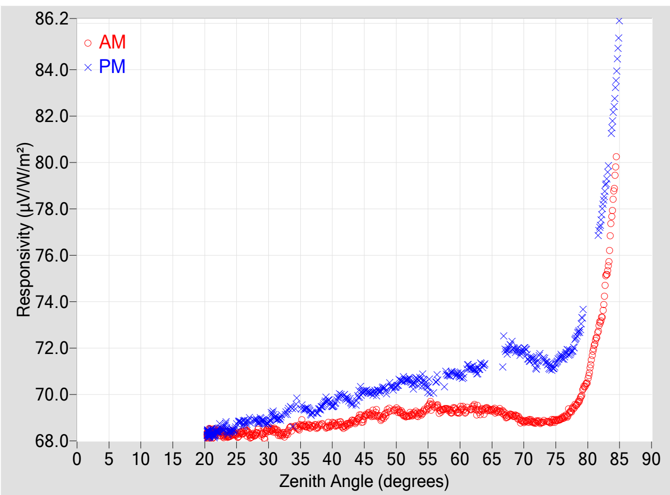


Figure 2. Responsivity vs Local Standard Time

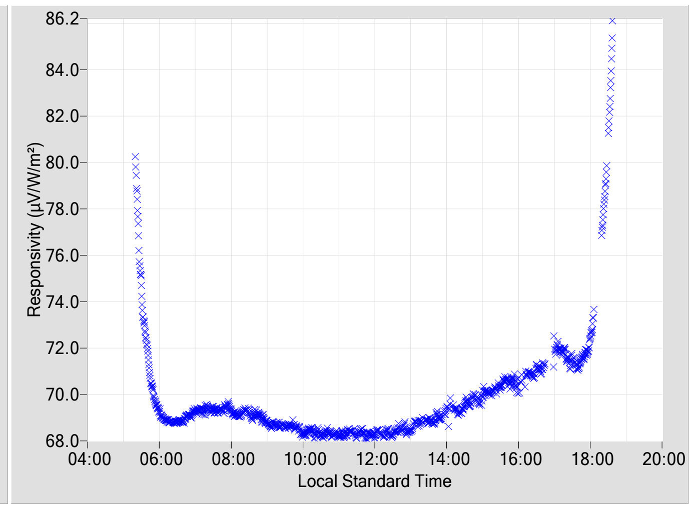


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	69.135	0.32	101.84	70.080	0.31	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	69.040	0.33	99.79	70.288	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	69.330	0.33	97.81	70.347	0.32	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	69.106	0.33	95.93	70.658	0.34	264.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	69.197	0.34	94.15	70.608	0.35	265.99
10	N/A	N/A	N/A	N/A	N/A	N/A	56	69.491	0.44	92.39	70.377	0.38	267.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	69.366	0.36	90.73	70.879	0.36	269.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	69.313	0.34	89.05	70.831	0.35	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	69.443	0.35	87.42	71.126	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	69.345	0.36	85.79	71.294	0.36	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	69.305	0.38	84.23	N/A	N/A	N/A
22	68.417	0.31	155.25	68.435	0.31	204.60	68	69.130	0.40	82.64	72.087	0.43	277.46
24	68.256	0.31	144.04	68.410	0.29	216.10	70	68.835	0.42	81.06	71.929	0.42	279.05
26	68.373	0.31	136.34	68.769	0.32	223.92	72	68.810	0.46	79.48	71.286	0.45	280.62
28	68.285	0.31	130.31	68.885	0.32	229.79	74	68.814	0.50	77.92	71.226	0.50	282.19
30	68.484	0.33	125.35	68.812	0.31	234.72	76	68.977	0.56	76.35	71.598	0.56	283.81
32	68.282	0.31	121.21	69.009	0.33	238.67	78	69.484	N/A	74.73	72.294	N/A	285.43
34	68.603	0.34	117.29	69.135	0.32	242.36	80	70.643	N/A	73.11	N/A	N/A	N/A
36	68.637	0.31	114.34	69.396	0.31	245.75	82	73.167	N/A	71.43	77.479	N/A	288.71
38	68.645	0.32	111.52	69.356	0.31	248.64	84	78.515	N/A	69.74	82.122	N/A	290.41
40	68.729	0.30	108.76	69.523	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	68.643	0.32	106.26	69.883	0.32	253.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	68.942	0.33	103.99	69.862	0.37	256.12	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

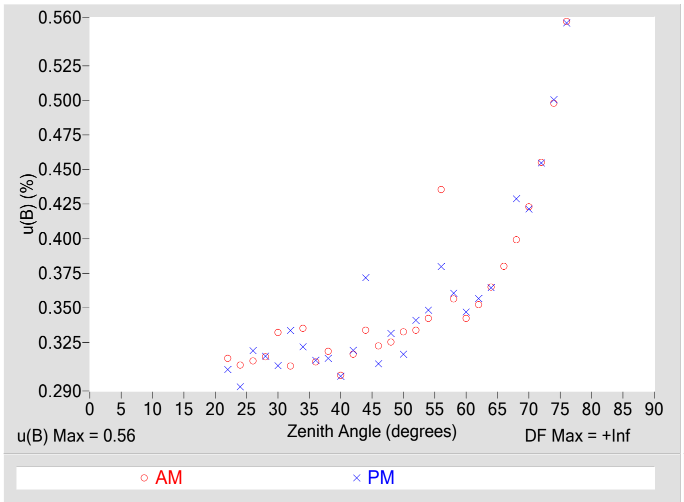


Figure 4. Residuals from Spline Interpolation

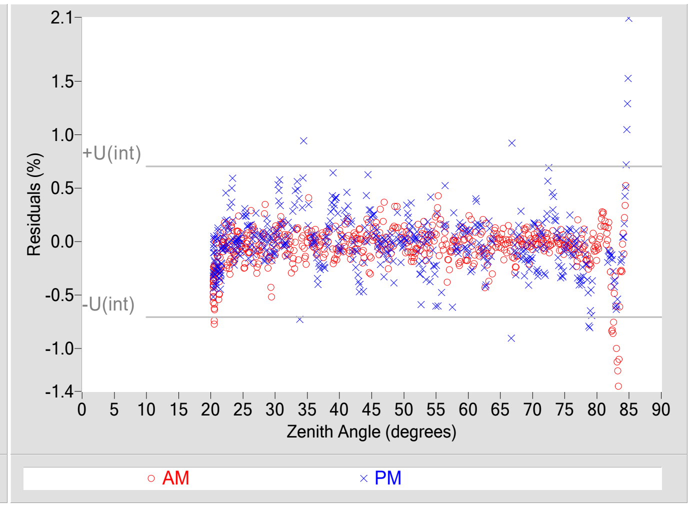


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.35
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	12186
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

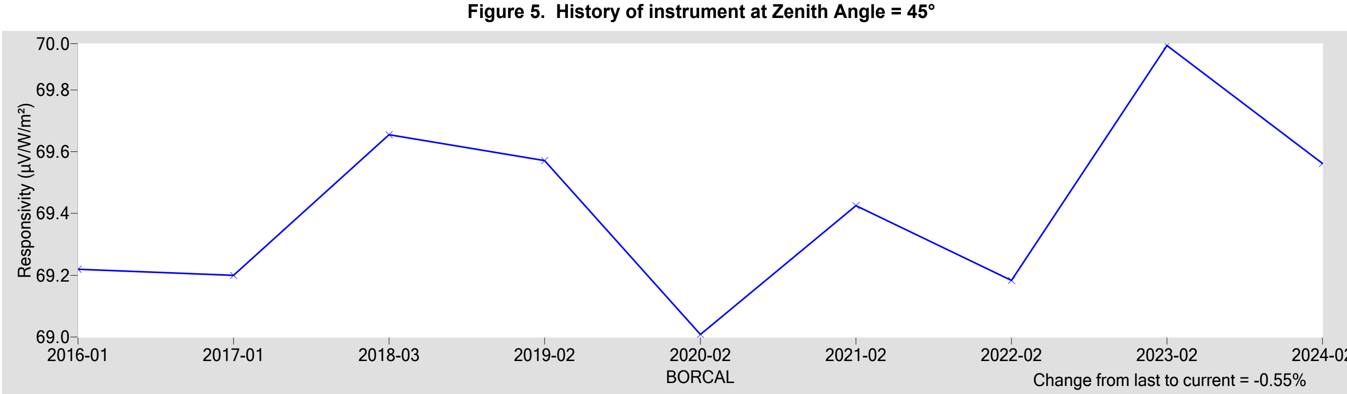
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
69.562	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+1.9 / -1.8
Expanded Uncertainty, U (%)	+2.7 / -2.7
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

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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:	Pyranometer (Ventilated)	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15357
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager   05/21/2024 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:

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

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

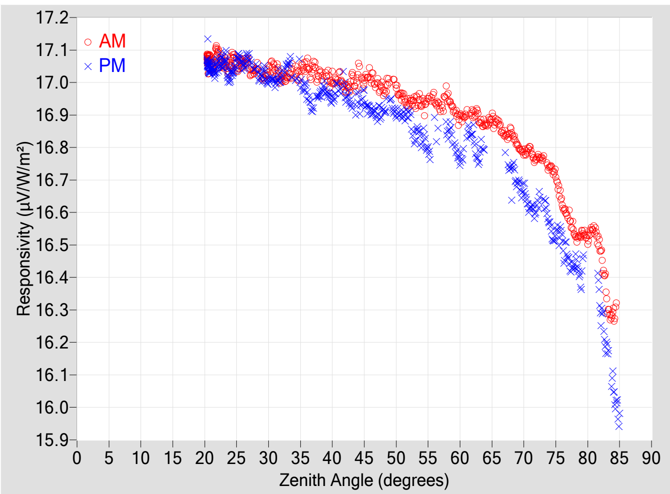


Figure 2. Responsivity vs Local Standard Time

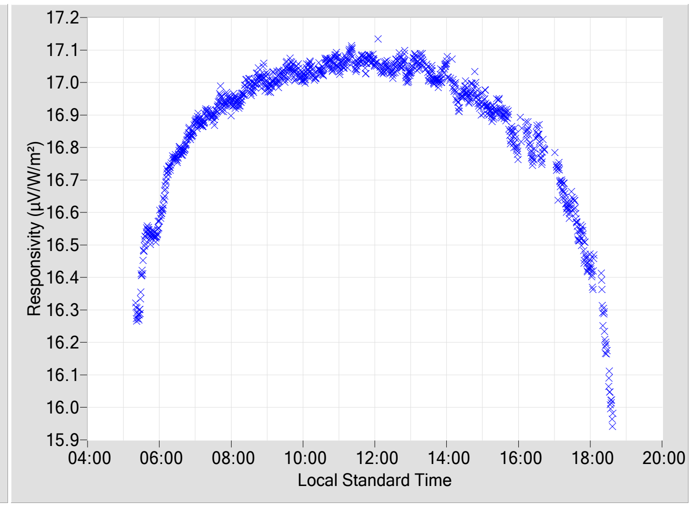


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	17.020	0.33	101.81	16.913	0.31	258.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.976	0.35	99.76	16.915	0.31	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.982	0.34	97.74	16.906	0.34	262.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.939	0.34	95.95	16.901	0.34	264.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.936	0.36	94.18	16.824	0.33	265.96
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.948	0.37	92.39	16.893	0.47	267.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.959	0.34	90.71	16.849	0.36	269.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.889	0.36	89.03	16.765	0.37	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.903	0.36	87.40	16.841	0.36	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	16.872	0.37	85.81	16.792	0.37	274.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	16.876	0.38	84.21	N/A	N/A	N/A
22	17.094	0.31	155.65	17.054	0.33	204.74	68	16.849	0.40	82.66	16.723	0.43	277.49
24	17.056	0.32	143.97	17.022	0.32	216.18	70	16.786	0.43	81.08	16.669	0.43	279.07
26	17.058	0.32	136.28	17.053	0.32	223.86	72	16.767	0.46	79.50	16.614	0.46	280.65
28	17.038	0.32	130.37	17.043	0.31	229.79	74	16.740	0.50	77.94	16.564	0.51	282.21
30	17.039	0.34	125.47	17.005	0.32	234.67	76	16.625	0.57	76.33	16.512	0.57	283.79
32	17.010	0.30	121.26	17.015	0.31	238.81	78	16.529	N/A	74.71	16.445	N/A	285.41
34	17.039	0.30	117.15	17.010	0.30	242.49	80	16.520	N/A	73.13	N/A	N/A	N/A
36	17.052	0.31	114.34	16.971	0.35	245.74	82	16.485	N/A	71.45	16.302	N/A	288.73
38	17.029	0.32	111.41	16.961	0.30	248.68	84	16.282	N/A	69.76	16.061	N/A	290.39
40	17.007	0.33	108.76	16.947	0.32	251.37	86	N/A	N/A	N/A	N/A	N/A	N/A
42	16.985	0.30	106.30	16.967	0.34	253.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.030	0.32	103.97	16.941	0.39	256.11	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

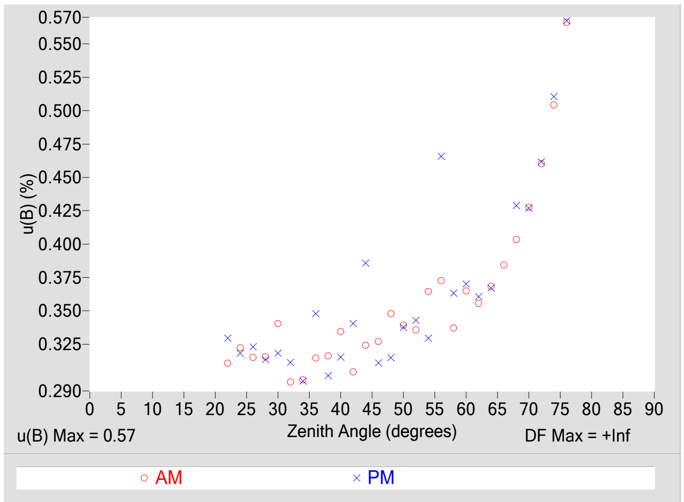


Figure 4. Residuals from Spline Interpolation

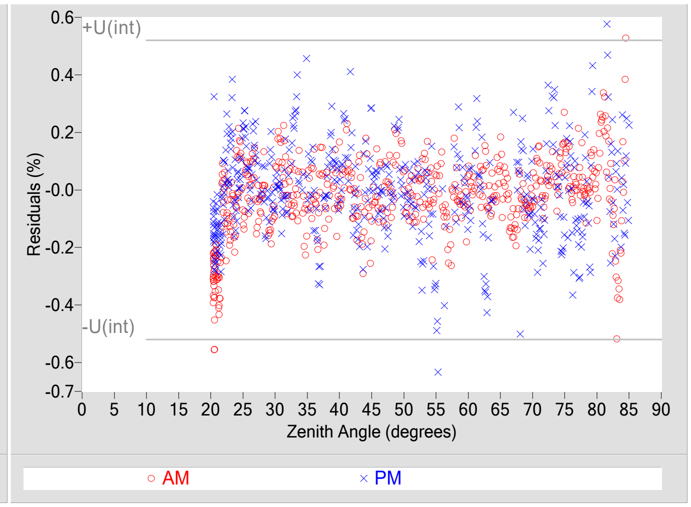


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	32953
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

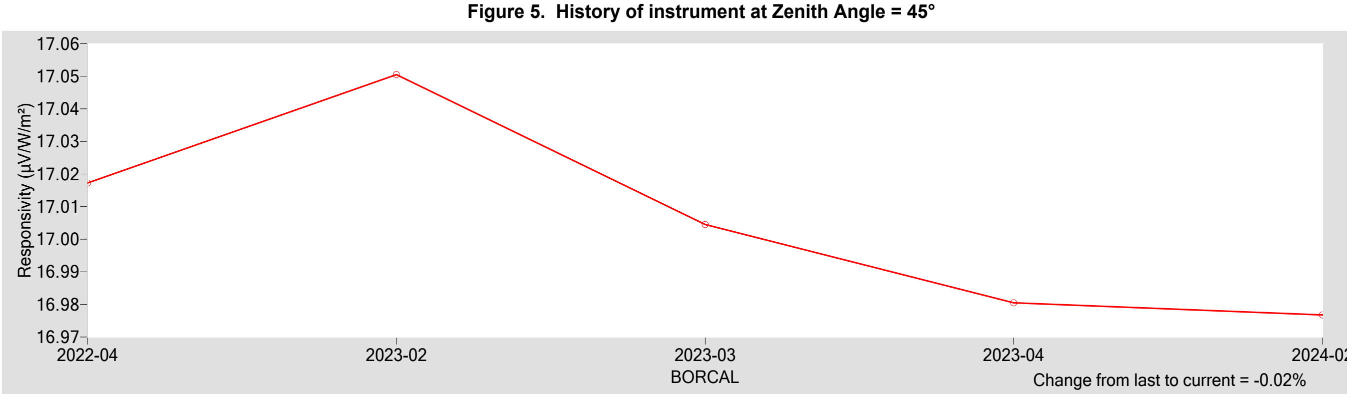
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
16.977	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+0.44 / -1.2
Expanded Uncertainty, U (%)	+1.4 / -2.2
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 (Ventilated)	**Manufacturer:**	Hukseflux
Model:	SR20-T2	**Serial Number:**	15360
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager   05/21/2024 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:

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

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

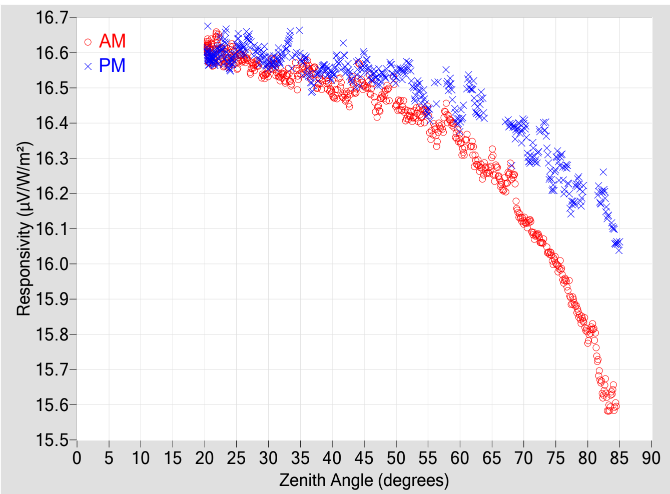


Figure 2. Responsivity vs Local Standard Time

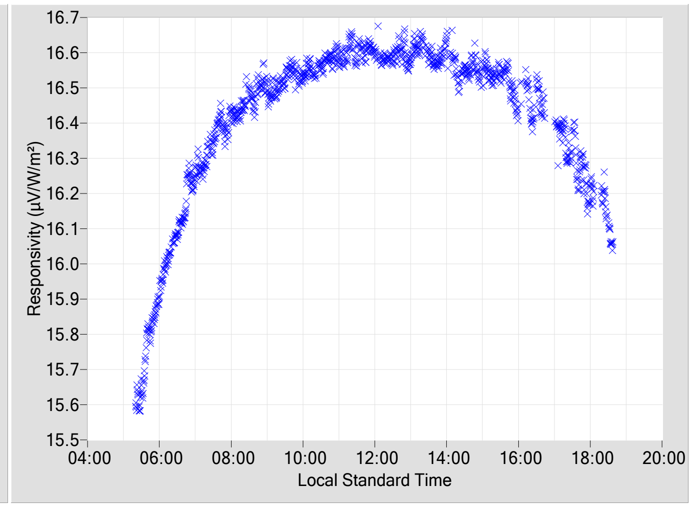


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	16.506	0.33	101.81	16.534	0.31	258.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.479	0.35	99.76	16.538	0.31	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.446	0.34	97.74	16.536	0.34	262.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.423	0.34	95.95	16.560	0.34	264.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.419	0.36	94.18	16.479	0.33	265.96
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.380	0.37	92.39	16.514	0.47	267.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.425	0.34	90.71	16.516	0.36	269.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.345	0.37	89.03	16.407	0.37	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.320	0.36	87.40	16.496	0.36	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	16.268	0.37	85.81	16.413	0.37	274.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	16.251	0.38	84.21	N/A	N/A	N/A
22	16.635	0.31	155.65	16.597	0.33	204.74	68	16.262	0.40	82.66	16.394	0.40	277.48
24	16.586	0.32	143.97	16.568	0.32	216.18	70	16.123	0.43	81.08	16.396	0.43	279.07
26	16.584	0.32	136.28	16.607	0.32	223.86	72	16.082	0.46	79.50	16.301	0.46	280.65
28	16.566	0.32	130.37	16.609	0.31	229.79	74	16.032	0.50	77.94	16.265	0.51	282.21
30	16.548	0.34	125.47	16.571	0.32	234.67	76	15.968	0.57	76.33	16.273	0.57	283.79
32	16.532	0.30	121.26	16.584	0.31	238.81	78	15.883	N/A	74.71	16.193	N/A	285.41
34	16.561	0.30	117.15	16.589	0.30	242.49	80	15.798	N/A	73.13	N/A	N/A	N/A
36	16.559	0.31	114.34	16.560	0.35	245.74	82	15.668	N/A	71.45	16.189	N/A	288.73
38	16.517	0.32	111.41	16.541	0.30	248.68	84	15.624	N/A	69.76	16.097	N/A	290.39
40	16.489	0.33	108.76	16.535	0.32	251.37	86	N/A	N/A	N/A	N/A	N/A	N/A
42	16.475	0.30	106.30	16.567	0.34	253.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	16.536	0.32	103.97	16.550	0.39	256.11	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

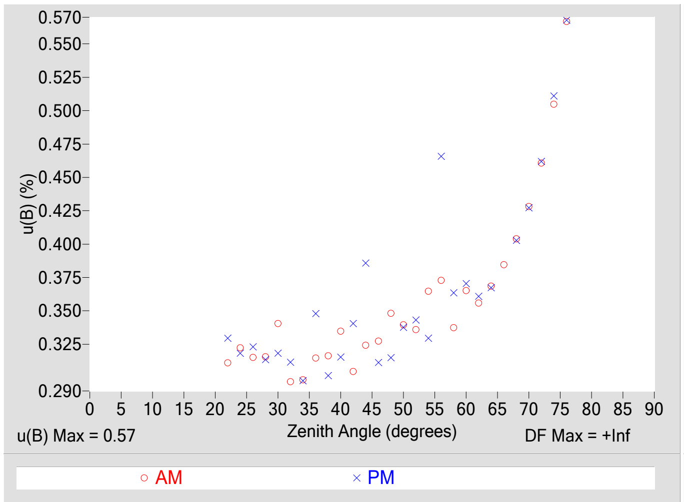


Figure 3. Type-B Standard Uncertainty vs Zenith Angle

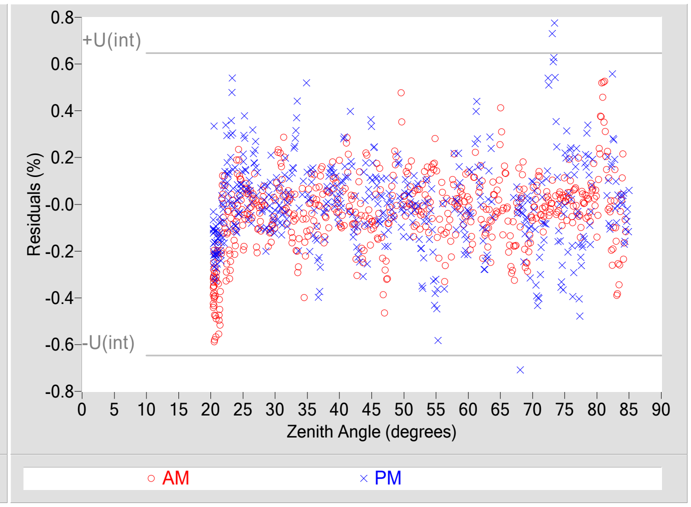


Figure 4. Residuals from Spline Interpolation

Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	16606
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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) †
16.541	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+0.29 / -1.2
Expanded Uncertainty, U (%)	+1.2 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

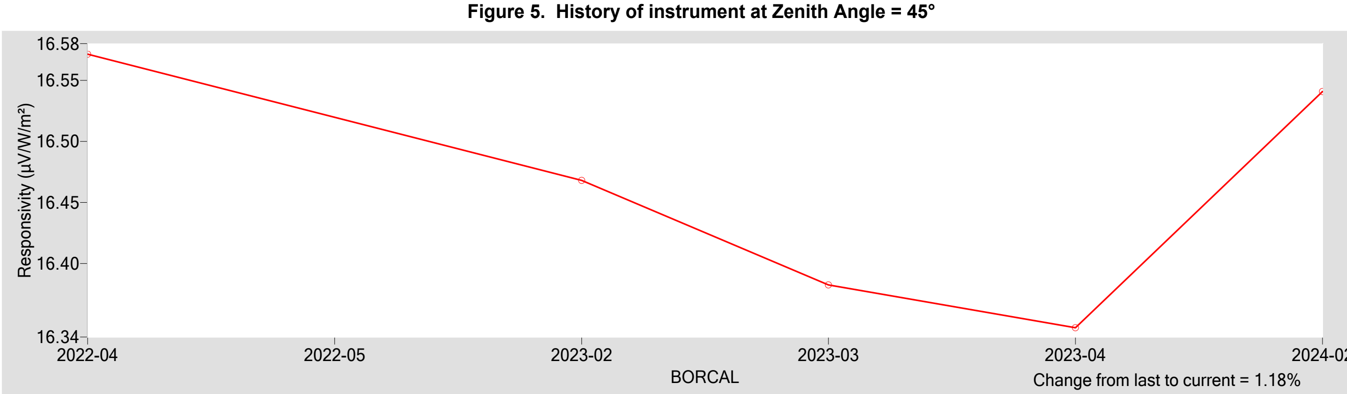


Figure 5. History of instrument at Zenith Angle = 45°

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

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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.

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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.

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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:**	15364
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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:

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

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

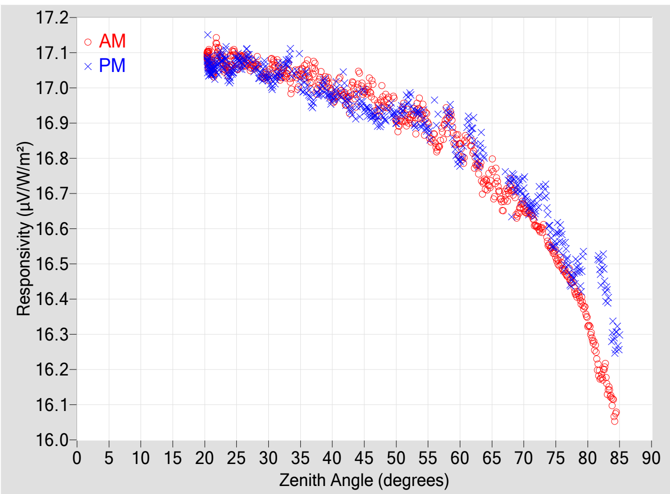


Figure 2. Responsivity vs Local Standard Time

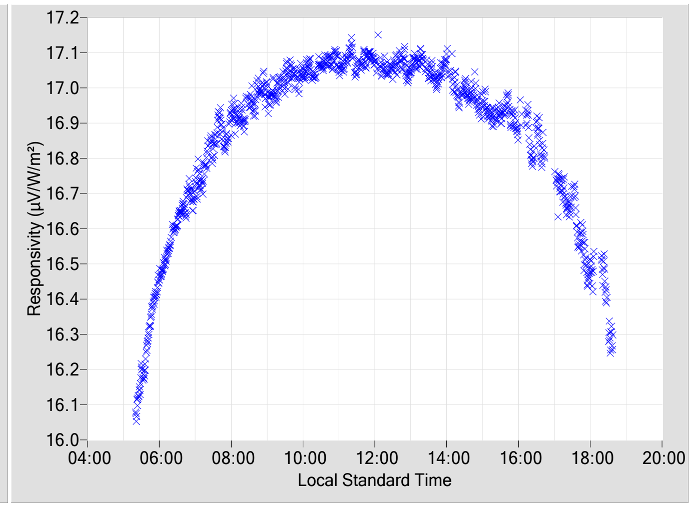


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	17.000	0.33	101.81	16.924	0.31	258.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	16.968	0.35	99.76	16.918	0.31	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	16.900	0.34	97.74	16.914	0.34	262.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	16.915	0.34	95.95	16.971	0.34	264.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	16.928	0.36	94.18	16.907	0.33	265.96
10	N/A	N/A	N/A	N/A	N/A	N/A	56	16.852	0.37	92.39	16.966	0.47	267.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	16.914	0.34	90.71	16.915	0.36	269.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	16.826	0.36	89.03	16.797	0.37	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	16.819	0.36	87.40	16.884	0.36	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	16.728	0.37	85.81	16.801	0.37	274.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	16.716	0.38	84.21	N/A	N/A	N/A
22	17.109	0.31	155.65	17.065	0.33	204.74	68	16.721	0.40	82.66	16.742	0.40	277.48
24	17.067	0.32	143.97	17.039	0.32	216.18	70	16.664	0.43	81.08	16.714	0.43	279.07
26	17.079	0.32	136.28	17.072	0.32	223.86	72	16.607	0.46	79.50	16.664	0.46	280.65
28	17.067	0.32	130.37	17.061	0.31	229.79	74	16.552	0.50	77.94	16.605	0.51	282.21
30	17.038	0.34	125.47	17.026	0.32	234.67	76	16.490	0.57	76.33	16.559	0.57	283.79
32	17.034	0.30	121.26	17.045	0.31	238.81	78	16.423	N/A	74.71	16.476	N/A	285.41
34	17.040	0.30	117.15	17.042	0.30	242.49	80	16.338	N/A	73.13	N/A	N/A	N/A
36	17.053	0.31	114.34	17.013	0.35	245.74	82	16.182	N/A	71.45	16.483	N/A	288.73
38	17.025	0.32	111.41	16.986	0.30	248.68	84	16.094	N/A	69.76	16.290	N/A	290.39
40	16.984	0.33	108.76	16.968	0.32	251.37	86	N/A	N/A	N/A	N/A	N/A	N/A
42	16.971	0.30	106.30	16.977	0.34	253.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.016	0.32	103.97	16.960	0.39	256.11	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

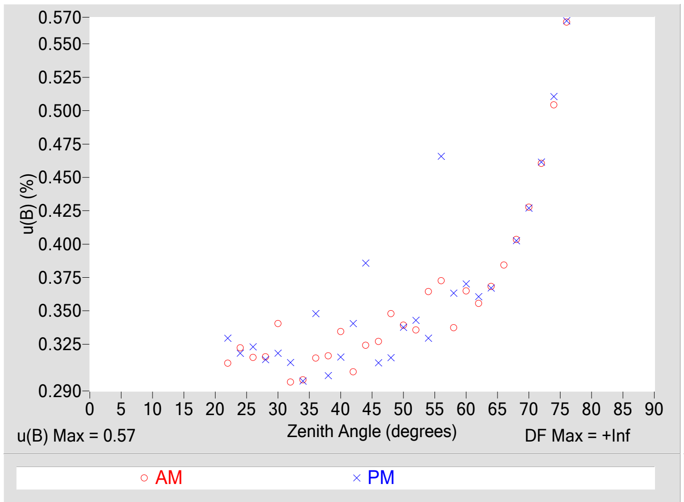


Figure 4. Residuals from Spline Interpolation

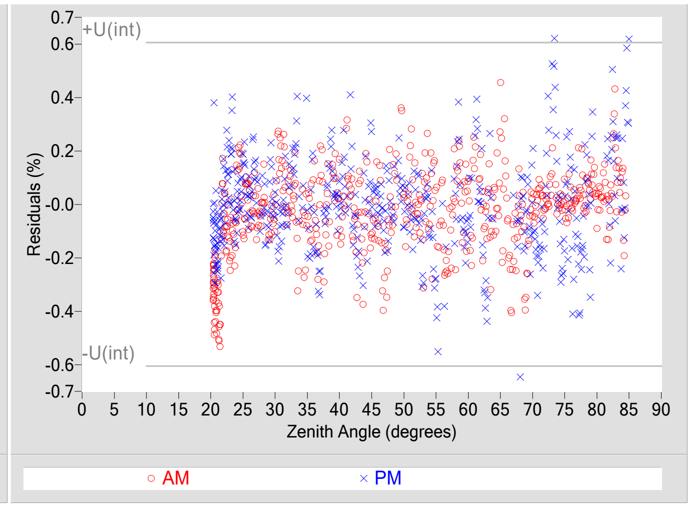


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	20253
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

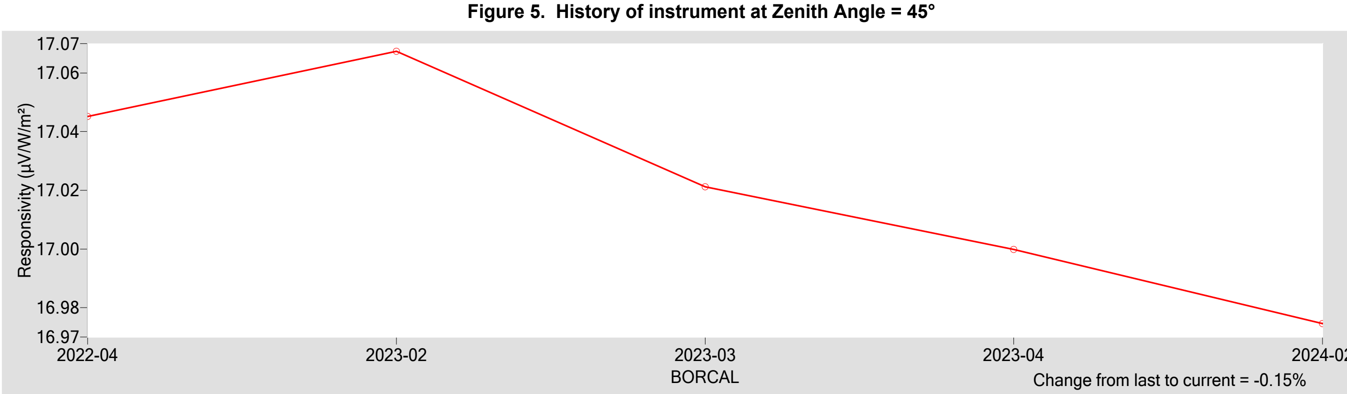
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
16.975	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+0.46 / -1.0
Expanded Uncertainty, U (%)	+1.4 / -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 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:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	194362
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — 05/21/2024 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

194362 Kipp & Zonen SP-LITE2

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

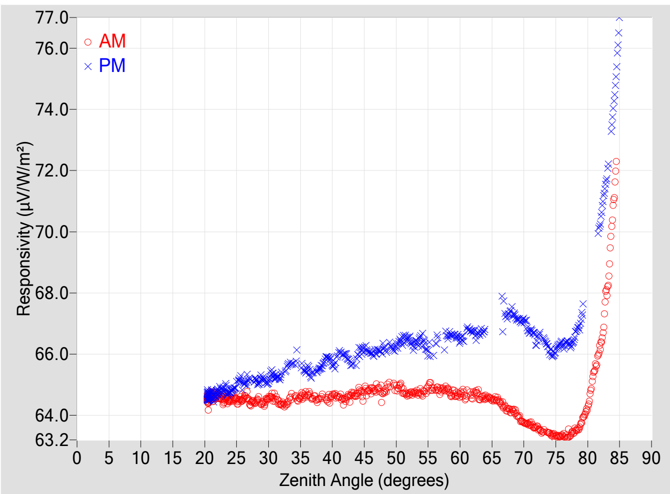


Figure 2. Responsivity vs Local Standard Time

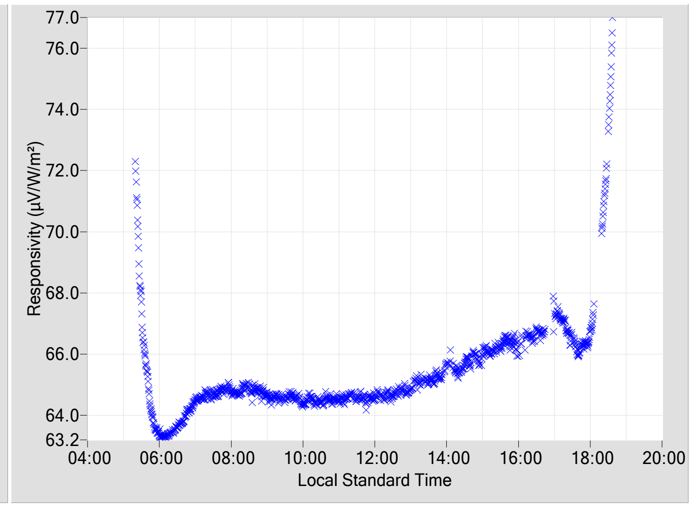


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	64.838	0.32	101.84	66.049	0.31	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	64.692	0.33	99.79	66.200	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	64.894	0.33	97.81	66.222	0.32	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	64.699	0.33	95.93	66.497	0.34	264.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	64.741	0.34	94.15	66.472	0.35	265.99
10	N/A	N/A	N/A	N/A	N/A	N/A	56	64.842	0.44	92.39	66.218	0.38	267.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	64.878	0.36	90.73	66.608	0.36	269.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	64.702	0.34	89.05	66.490	0.35	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	64.655	0.35	87.42	66.754	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	64.582	0.36	85.79	66.768	0.36	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	64.495	0.38	84.23	N/A	N/A	N/A
22	64.676	0.31	155.25	64.742	0.31	204.60	68	64.154	0.40	82.64	67.385	0.43	277.46
24	64.497	0.31	144.04	64.770	0.29	216.10	70	63.762	0.42	81.06	67.109	0.42	279.05
26	64.529	0.31	136.34	65.027	0.32	223.92	72	63.608	0.46	79.48	66.461	0.45	280.62
28	64.450	0.31	130.31	65.142	0.32	229.79	74	63.410	0.50	77.92	66.146	0.50	282.19
30	64.559	0.33	125.35	65.114	0.31	234.72	76	63.341	0.56	76.35	66.314	0.56	283.81
32	64.367	0.31	121.21	65.286	0.33	238.67	78	63.491	N/A	74.73	66.622	N/A	285.43
34	64.602	0.34	117.29	65.676	0.32	242.36	80	64.275	N/A	73.11	N/A	N/A	N/A
36	64.672	0.31	114.34	65.504	0.31	245.75	82	66.299	N/A	71.43	70.429	N/A	288.71
38	64.539	0.32	111.52	65.536	0.31	248.64	84	70.870	N/A	69.74	74.008	N/A	290.41
40	64.660	0.30	108.76	65.688	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	64.505	0.32	106.26	65.964	0.32	253.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	64.743	0.33	103.99	65.936	0.37	256.12	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

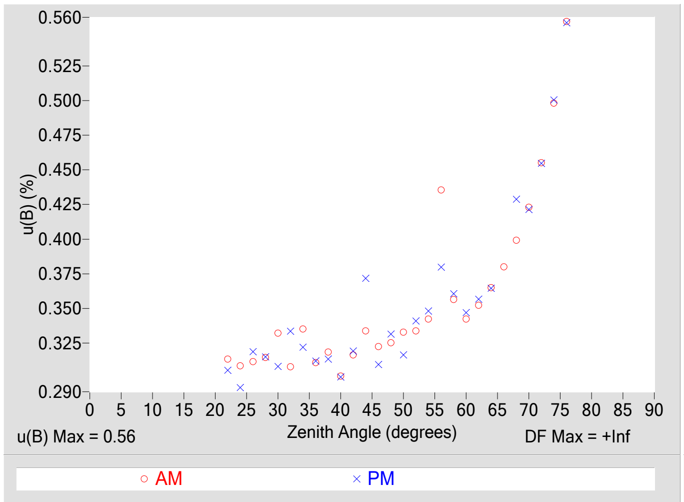


Figure 4. Residuals from Spline Interpolation

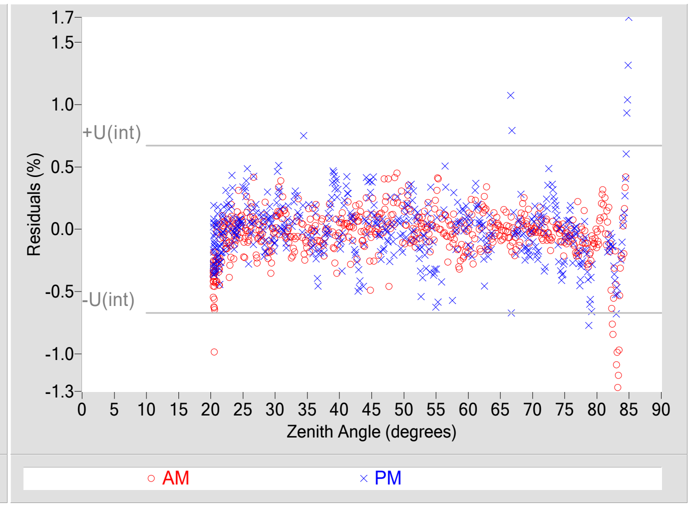


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	14062
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

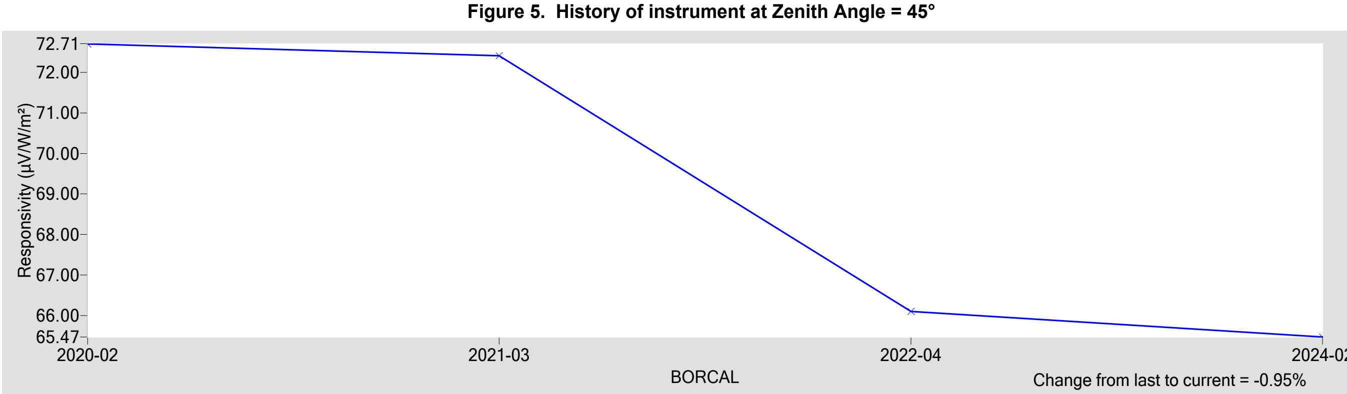
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
65.473	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+1.7 / -1.7
Expanded Uncertainty, U (%)	+2.6 / -2.5
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

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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).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	210757
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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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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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

______________________________ 05/21/2024

Ibrahim Reda, 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

210757 Kipp & Zonen CMP22

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

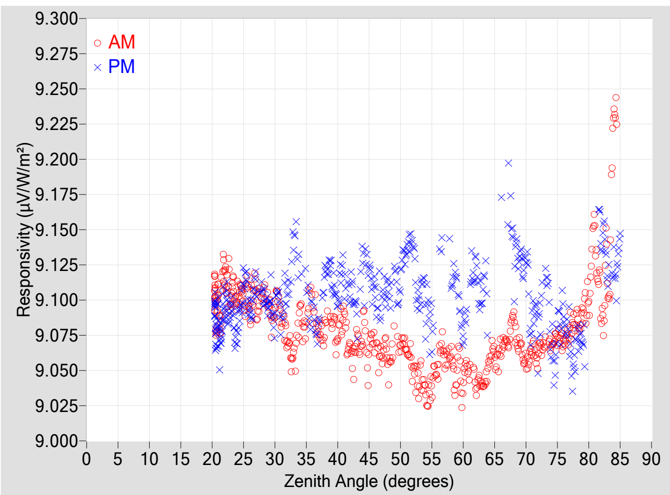


Figure 2. Responsivity vs Local Standard Time

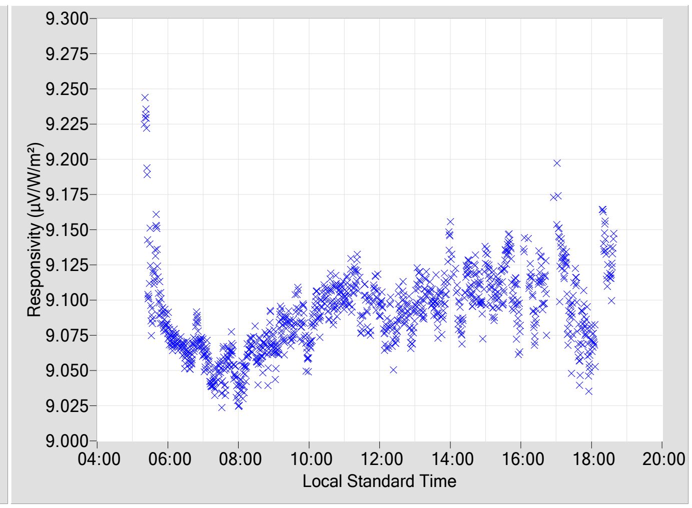


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.0697	0.33	101.79	9.1031	0.33	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0550	0.31	99.79	9.1080	0.33	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0672	0.34	97.82	9.1139	0.35	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0495	0.34	95.93	9.1372	0.35	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0343	0.34	94.15	9.0957	0.35	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0533	0.35	92.42	9.1363	0.34	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0603	0.38	90.69	9.1183	0.37	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0389	0.35	89.05	9.0787	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0399	0.38	87.42	9.1233	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0529	0.40	85.79	9.0898	0.44	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0652	0.41	84.23	9.1729	N/A	275.96
22	9.1168	0.32	155.05	9.0958	0.31	204.25	68	9.0847	0.41	82.64	9.1327	0.41	277.47
24	9.1009	0.32	144.03	9.0789	0.31	216.23	70	9.0561	0.43	81.06	9.1296	0.43	279.05
26	9.0965	0.30	136.22	9.0919	0.33	223.99	72	9.0630	0.47	79.48	9.0794	0.47	280.62
28	9.1024	0.33	130.13	9.1035	0.32	229.91	74	9.0679	0.51	77.93	9.0708	0.52	282.19
30	9.0958	0.32	125.36	9.0894	0.31	234.69	76	9.0681	0.58	76.36	9.0889	0.58	283.82
32	9.0708	0.30	121.22	9.1043	0.34	238.77	78	9.0856	N/A	74.74	9.0694	N/A	285.39
34	9.0908	0.31	117.63	9.1256	0.30	242.54	80	9.1008	N/A	73.11	N/A	N/A	N/A
36	9.0935	0.30	114.27	9.0948	0.30	245.83	82	9.0991	N/A	71.48	9.1443	N/A	288.71
38	9.0790	0.33	111.42	9.1181	0.32	248.72	84	9.2237	N/A	69.78	9.1206	N/A	290.41
40	9.0735	0.32	108.73	9.0988	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0663	0.31	106.27	9.1068	0.34	253.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0781	0.34	104.00	9.1234	0.41	256.18	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

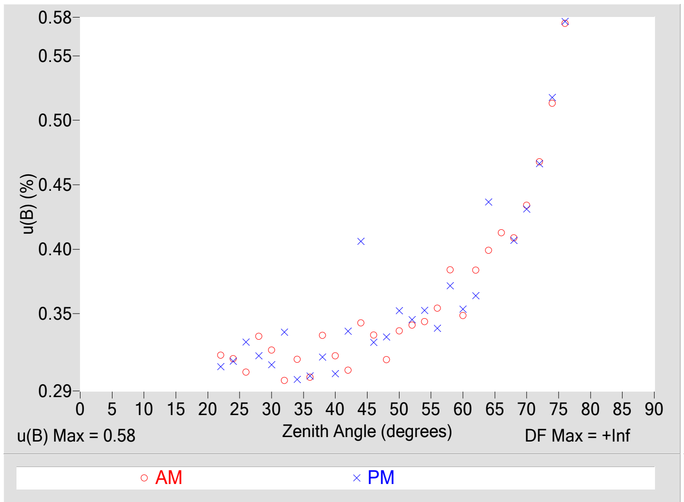


Figure 4. Residuals from Spline Interpolation

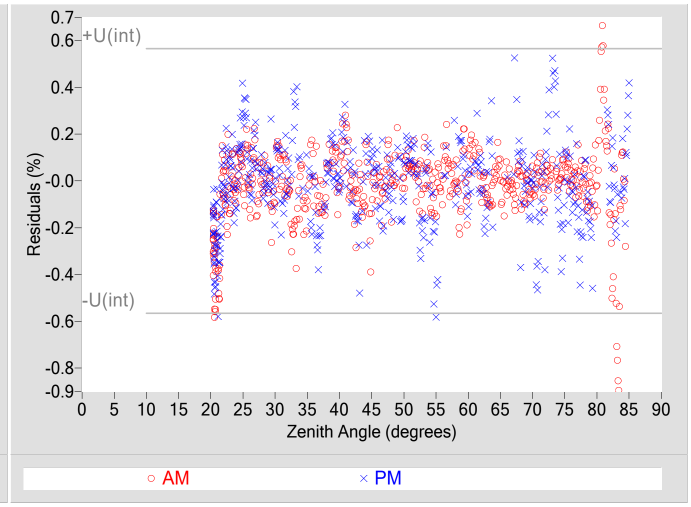


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	26086
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

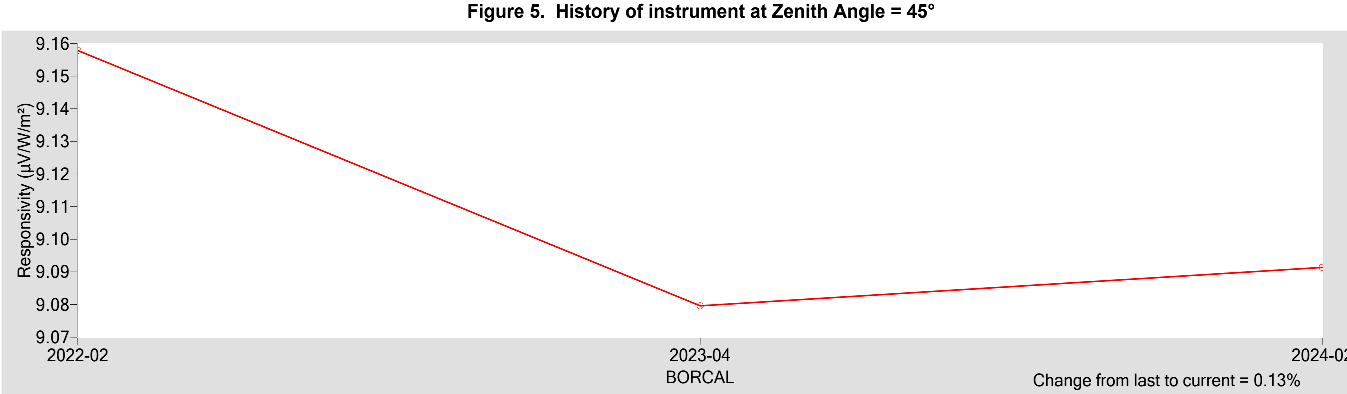
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0914	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+0.50 / -0.63
Expanded Uncertainty, U (%)	+1.3 / -1.4
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:	Black and White Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	21096
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

21096 Eppley 8-48

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 - 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

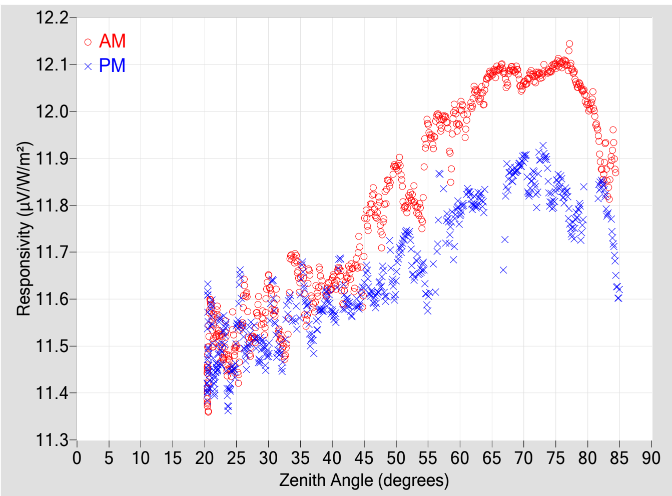


Figure 2. Responsivity vs Local Standard Time

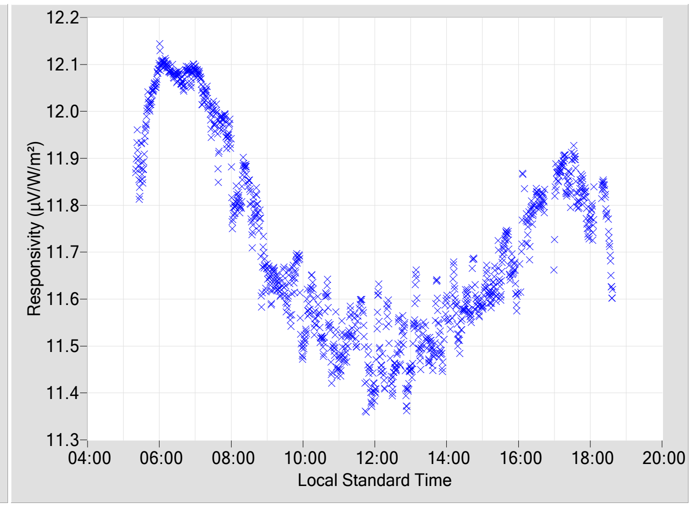


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	11.799	0.33	101.76	11.612	0.31	258.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.769	0.33	99.76	11.640	0.33	260.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.881	0.36	97.80	11.645	0.32	262.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.814	0.32	95.96	11.737	0.32	264.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.779	0.36	94.13	11.667	0.35	265.97
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.951	0.38	92.39	11.645	0.41	267.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.976	0.36	90.76	11.754	0.34	269.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.994	0.39	89.03	11.781	0.35	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.026	0.38	87.40	11.804	0.36	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.051	0.39	85.82	11.809	0.37	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	12.090	0.38	84.21	N/A	N/A	N/A
22	11.541	0.31	155.35	11.470	0.32	204.72	68	12.090	0.40	82.66	11.865	0.40	277.49
24	11.459	0.30	144.02	11.419	0.29	216.04	70	12.058	0.43	81.08	11.902	0.43	279.07
26	11.585	0.30	136.15	11.534	0.33	223.79	72	12.076	0.49	79.51	11.830	0.50	280.64
28	11.541	0.31	130.26	11.517	0.35	229.65	74	12.084	0.51	77.90	11.822	0.51	282.22
30	11.635	0.33	125.38	11.512	0.31	234.78	76	12.103	0.57	76.33	11.836	0.56	283.79
32	11.511	0.30	121.17	11.470	0.31	238.81	78	12.073	N/A	74.76	11.762	N/A	285.41
34	11.686	0.36	117.42	11.564	0.32	242.67	80	12.015	N/A	73.09	N/A	N/A	N/A
36	11.592	0.31	114.23	11.588	0.33	245.72	82	11.898	N/A	71.46	11.844	N/A	288.69
38	11.640	0.33	111.42	11.573	0.33	248.69	84	11.914	N/A	69.72	11.713	N/A	290.44
40	11.638	0.32	108.76	11.569	0.32	251.31	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.624	0.34	106.30	11.600	0.32	253.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.694	0.32	103.97	11.587	0.33	256.16	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

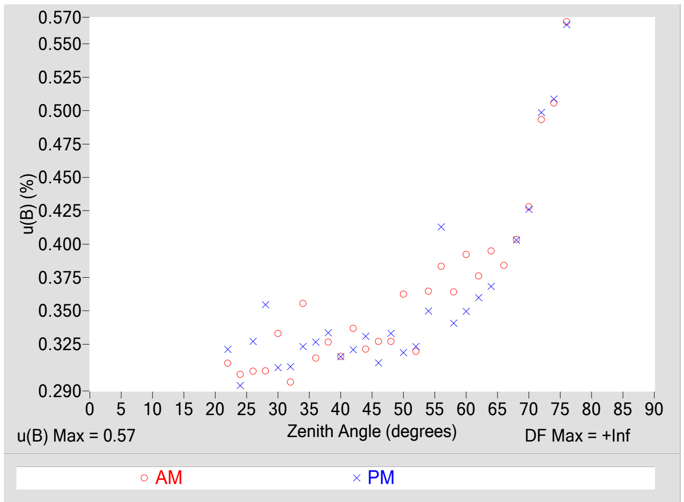


Figure 4. Residuals from Spline Interpolation

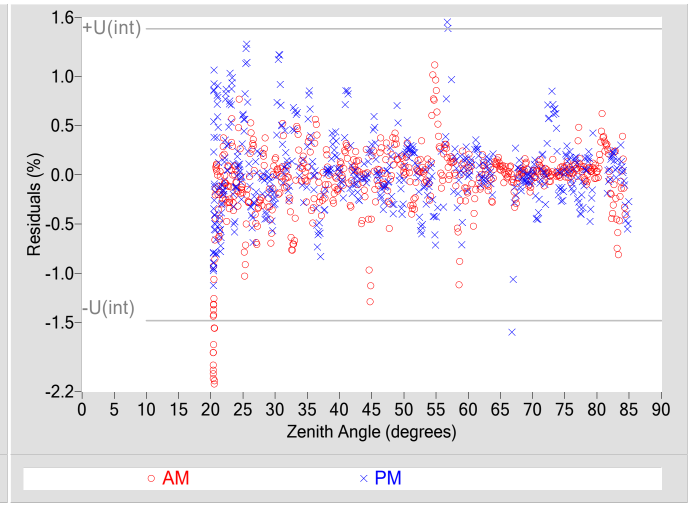


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.74
Combined Standard Uncertainty, u(c) (%)	±0.93
Effective degrees of freedom, DF(c)	2553
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.8
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

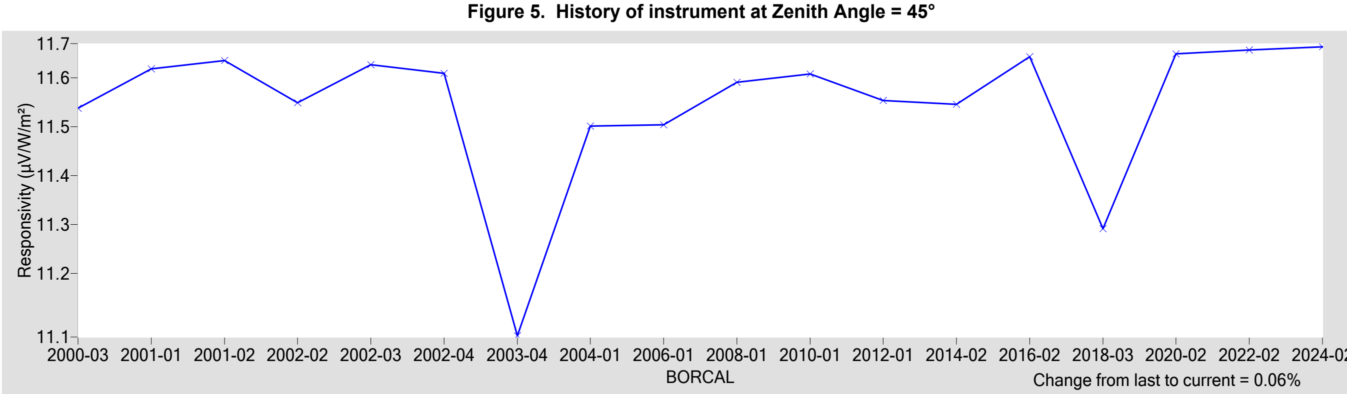
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.663	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.81
Offset Uncertainty, U(off) (%)	+2.8 / -1.7
Expanded Uncertainty, U (%)	+3.6 / -2.5
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

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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).

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:**	2530
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager　　05/21/2024 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

2530 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

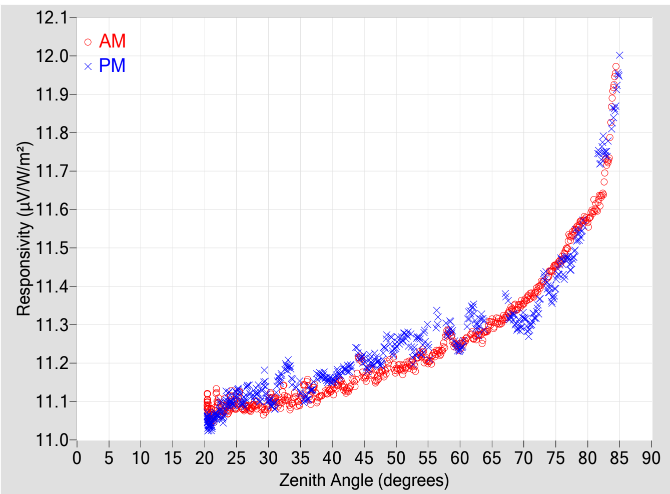


Figure 2. Responsivity vs Local Standard Time

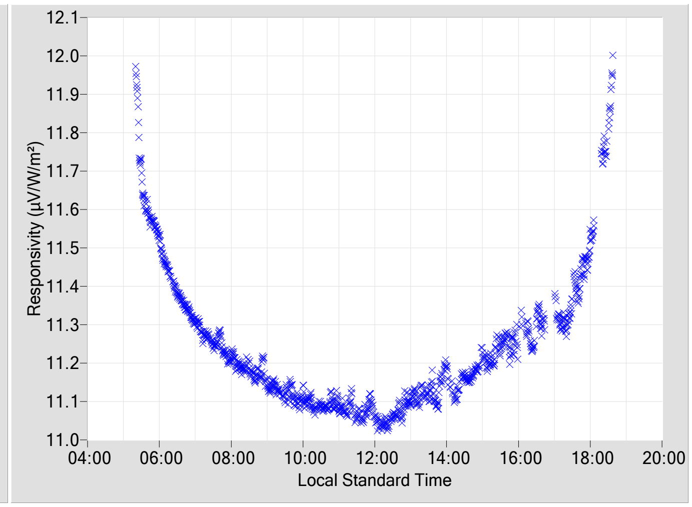


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	11.182	0.33	101.83	11.205	0.33	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.175	0.35	99.78	11.226	0.32	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.181	0.39	97.81	11.249	0.35	262.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.196	0.32	95.92	11.268	0.35	264.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.226	0.36	94.15	11.237	0.35	265.94
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.223	0.35	92.41	11.292	0.45	267.91
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.280	0.34	90.68	11.283	0.36	269.44
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.244	0.35	89.04	11.237	0.35	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.270	0.38	87.42	11.344	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.282	0.37	85.79	11.287	0.50	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.308	0.38	84.22	N/A	N/A	N/A
22	11.100	0.31	155.17	11.064	0.33	204.49	68	11.339	0.40	82.63	11.321	0.40	277.44
24	11.098	0.31	143.88	11.098	0.30	216.24	70	11.358	0.46	81.10	11.320	0.43	279.04
26	11.082	0.32	136.07	11.097	0.34	223.96	72	11.388	0.46	79.52	11.333	0.46	280.61
28	11.091	0.29	130.30	11.121	0.32	229.89	74	11.434	0.51	77.92	11.387	0.51	282.23
30	11.097	0.33	125.35	11.106	0.30	234.71	76	11.469	0.57	76.35	11.454	0.57	283.81
32	11.106	0.33	121.21	11.160	0.32	238.75	78	11.544	N/A	74.73	11.505	N/A	285.43
34	11.109	0.33	117.59	11.148	0.34	242.52	80	11.570	N/A	73.11	N/A	N/A	N/A
36	11.150	0.33	114.18	11.110	0.32	245.80	82	11.629	N/A	71.47	11.736	N/A	288.71
38	11.113	0.34	111.37	11.169	0.32	248.78	84	11.909	N/A	69.78	11.843	N/A	290.41
40	11.130	0.30	108.72	11.154	0.32	251.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.129	0.30	106.26	11.184	0.35	253.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.189	0.37	103.99	11.223	0.36	256.17	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

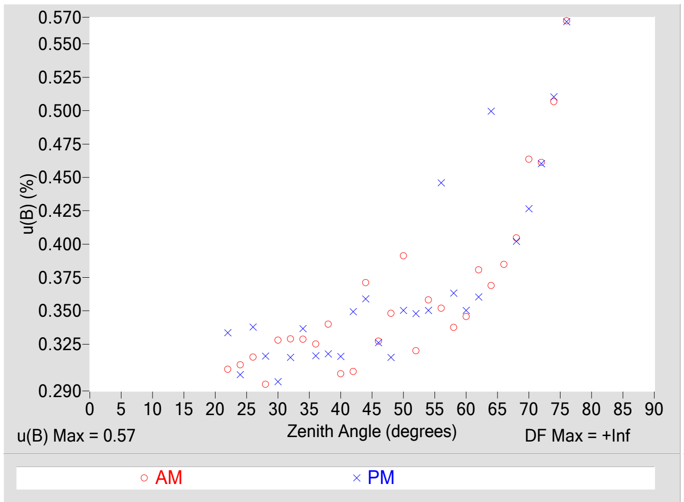


Figure 4. Residuals from Spline Interpolation

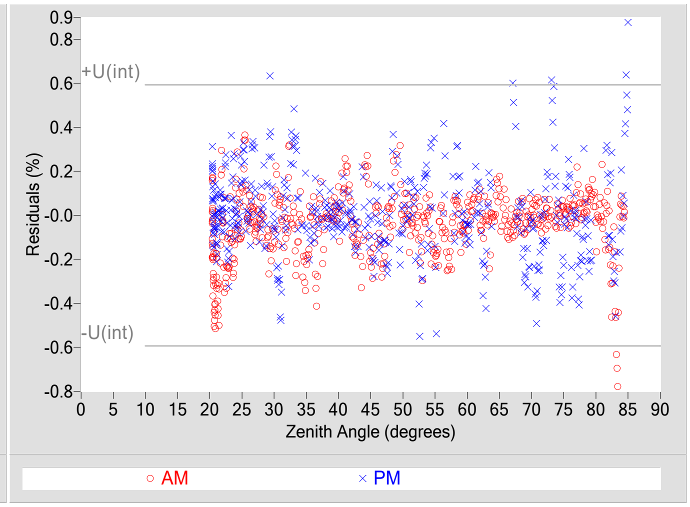


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	21533
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

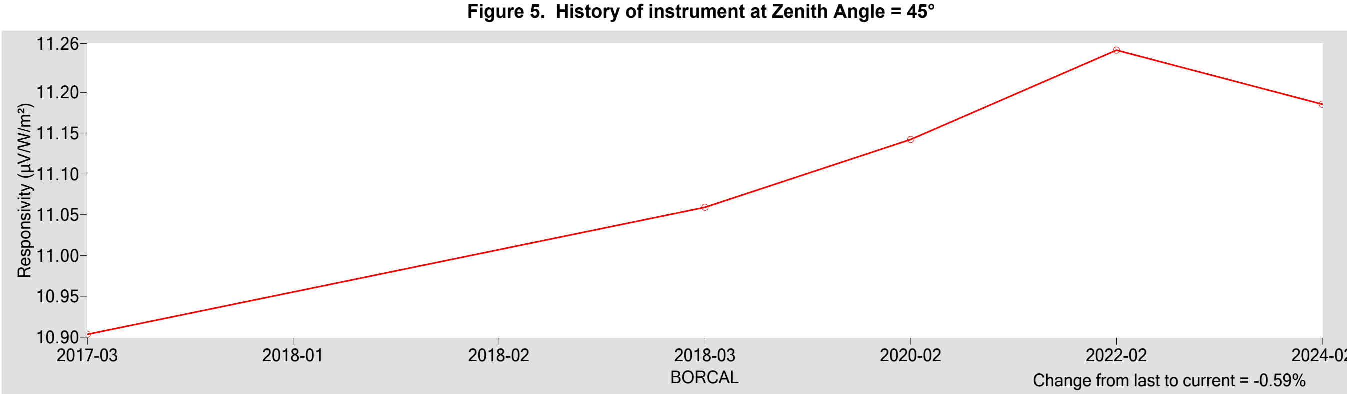
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
11.186	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+0.95 / -0.79
Expanded Uncertainty, U (%)	+1.8 / -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 (Ventilated)	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2543
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

2543 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 - 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

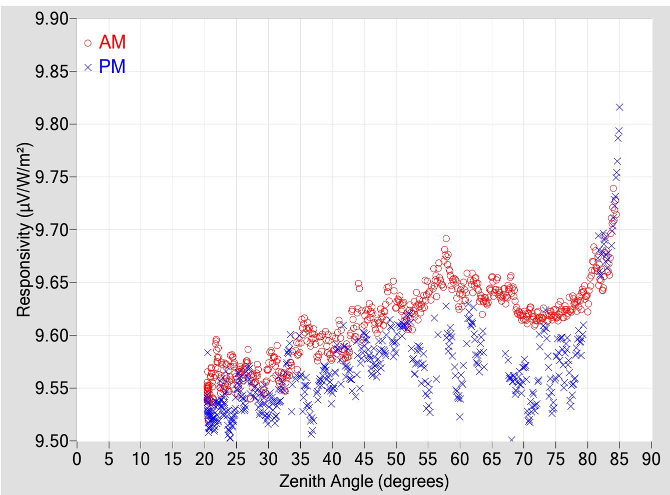


Figure 2. Responsivity vs Local Standard Time

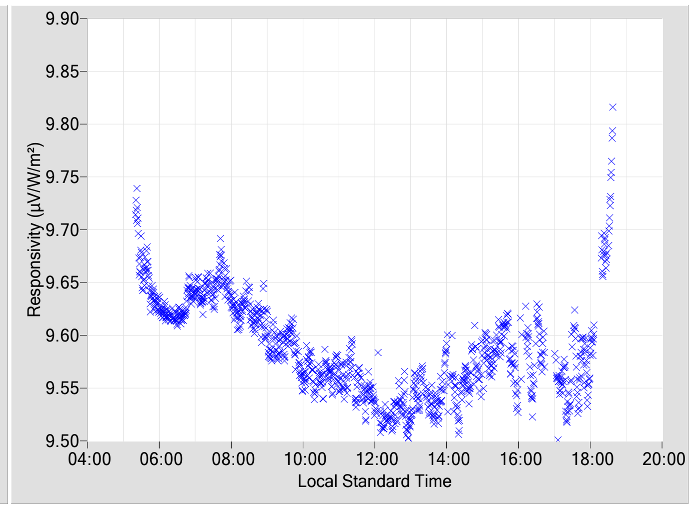


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.6233	0.33	101.81	9.5723	0.31	258.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.6178	0.35	99.76	9.5870	0.32	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6294	0.34	97.74	9.5962	0.34	262.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6167	0.34	95.95	9.6143	0.34	264.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.6272	0.37	94.18	9.5735	0.33	265.96
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6525	0.37	92.39	9.6163	0.47	267.69
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6746	0.34	90.71	9.6004	0.36	269.42
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.6345	0.37	89.03	9.5437	0.37	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6492	0.36	87.40	9.6120	0.36	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.6322	0.37	85.81	9.5700	0.37	274.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.6440	0.39	84.21	N/A	N/A	N/A
22	9.5804	0.31	155.65	9.5291	0.33	204.74	68	9.6481	0.41	82.66	9.5581	0.40	277.48
24	9.5621	0.32	143.97	9.5141	0.32	216.18	70	9.6183	0.43	81.08	9.5690	0.43	279.07
26	9.5628	0.32	136.28	9.5361	0.32	223.86	72	9.6164	0.46	79.50	9.5423	0.46	280.65
28	9.5597	0.32	130.37	9.5438	0.31	229.79	74	9.6186	0.51	77.94	9.5580	0.51	282.21
30	9.5719	0.34	125.47	9.5297	0.32	234.67	76	9.6206	0.57	76.33	9.5835	0.57	283.79
32	9.5570	0.30	121.26	9.5462	0.31	238.81	78	9.6297	N/A	74.71	9.5683	N/A	285.41
34	9.5925	0.30	117.15	9.5561	0.30	242.49	80	9.6343	N/A	73.13	N/A	N/A	N/A
36	9.6041	0.32	114.34	9.5464	0.35	245.74	82	9.6541	N/A	71.45	9.6685	N/A	288.73
38	9.5903	0.32	111.41	9.5530	0.30	248.68	84	9.7173	N/A	69.76	9.7083	N/A	290.39
40	9.5844	0.34	108.76	9.5465	0.32	251.37	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5837	0.31	106.30	9.5764	0.34	253.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.6296	0.32	103.97	9.5765	0.39	256.11	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

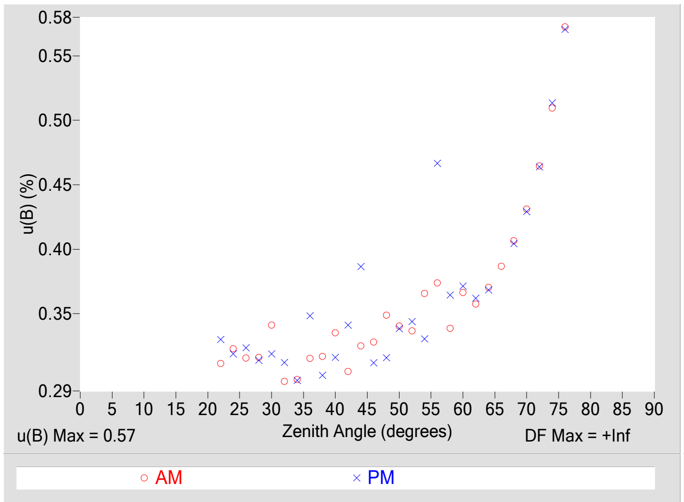


Figure 4. Residuals from Spline Interpolation

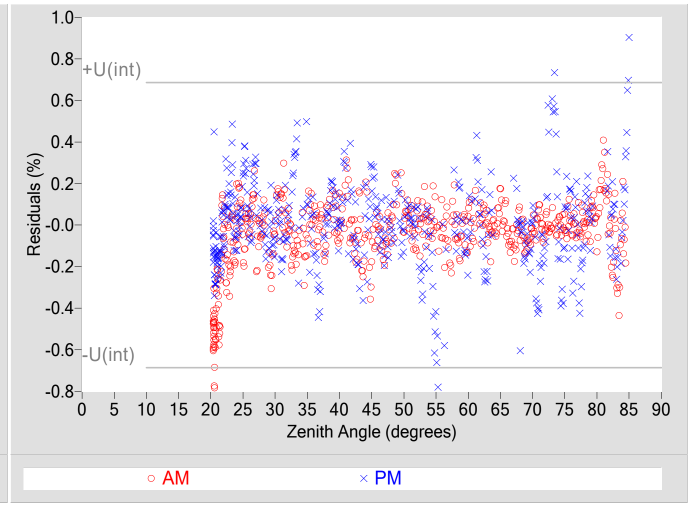


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	14279
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

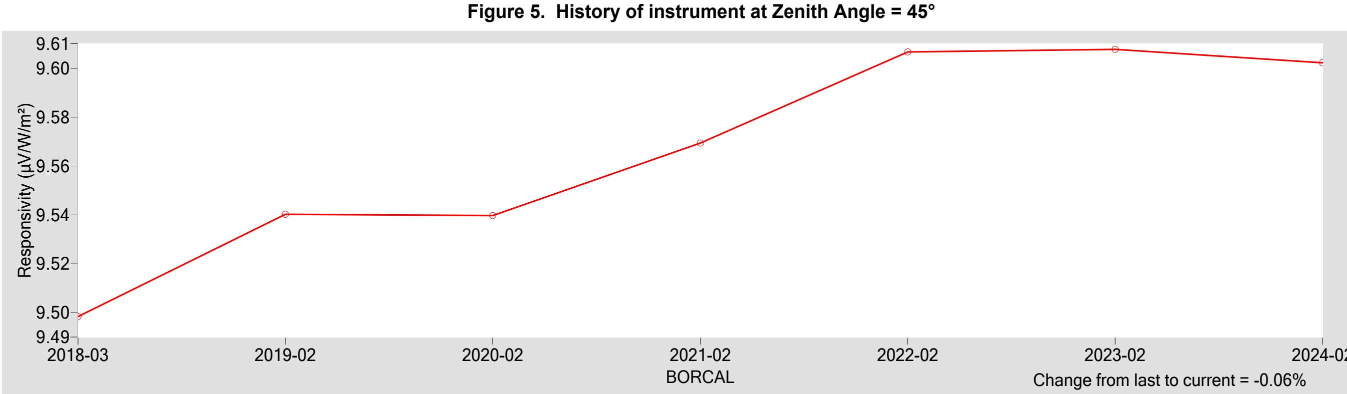
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.6022	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+0.75 / -0.76
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 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:**	28402F3
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager 05/21/2024 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

28402F3 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

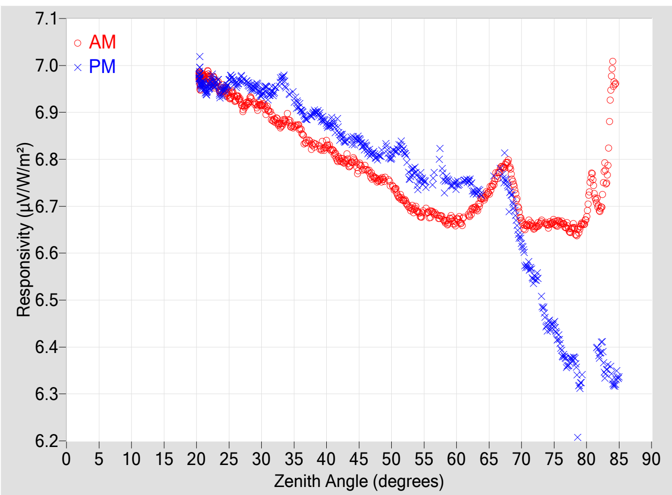


Figure 2. Responsivity vs Local Standard Time

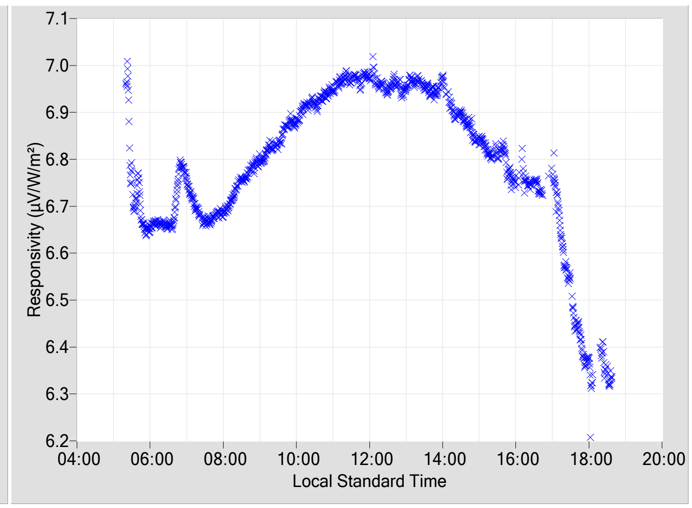


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	6.7805	0.38	101.83	6.8267	0.33	258.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.7545	0.36	99.75	6.8050	0.34	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.7432	0.40	97.75	6.8072	0.36	262.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.7114	0.37	95.95	6.8138	0.41	264.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.6908	0.38	94.17	6.7552	0.40	265.97
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.6838	0.40	92.39	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.6708	0.39	90.68	6.7576	0.38	269.41
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.6671	0.41	89.06	6.7466	0.41	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.6822	0.40	87.39	6.7534	0.41	272.68
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.7167	0.41	85.81	6.7231	0.42	274.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.7586	0.45	84.21	6.7645	N/A	275.67
22	6.9757	0.32	155.64	6.9578	0.33	204.61	68	6.7900	0.45	82.66	6.7304	0.48	277.48
24	6.9480	0.34	143.94	6.9461	0.32	216.21	70	6.6696	0.48	81.08	6.6204	0.50	279.07
26	6.9300	0.35	136.27	6.9597	0.32	223.77	72	6.6552	0.52	79.50	6.5446	0.58	280.64
28	6.9214	0.33	130.36	6.9595	0.36	229.76	74	6.6601	0.58	77.94	6.4471	0.64	282.21
30	6.9159	0.33	125.40	6.9394	0.33	234.66	76	6.6654	0.65	76.33	6.4033	0.72	283.79
32	6.8827	0.31	121.26	6.9449	0.33	238.80	78	6.6531	N/A	74.71	6.3746	N/A	285.41
34	6.8849	0.33	117.45	6.9458	0.31	242.49	80	6.6794	N/A	73.13	N/A	N/A	N/A
36	6.8642	0.33	114.39	6.9073	0.33	245.78	82	6.6954	N/A	71.45	6.3899	N/A	288.72
38	6.8308	0.32	111.41	6.8989	0.33	248.68	84	6.9744	N/A	69.76	6.3318	N/A	290.38
40	6.8298	0.38	108.76	6.8741	0.32	251.41	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.7995	0.33	106.29	6.8543	0.34	253.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.7970	0.35	103.96	6.8398	0.39	256.11	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

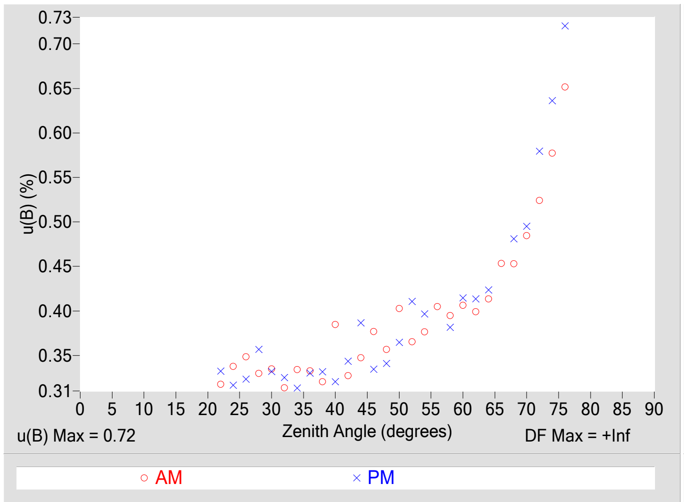


Figure 4. Residuals from Spline Interpolation

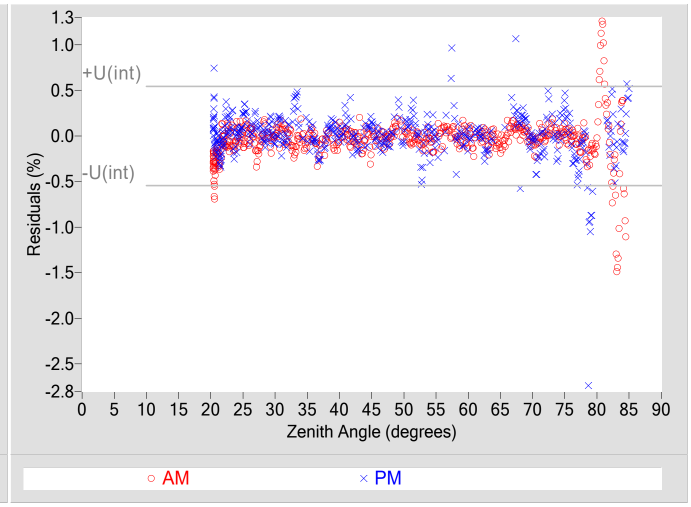


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.72
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	63593
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

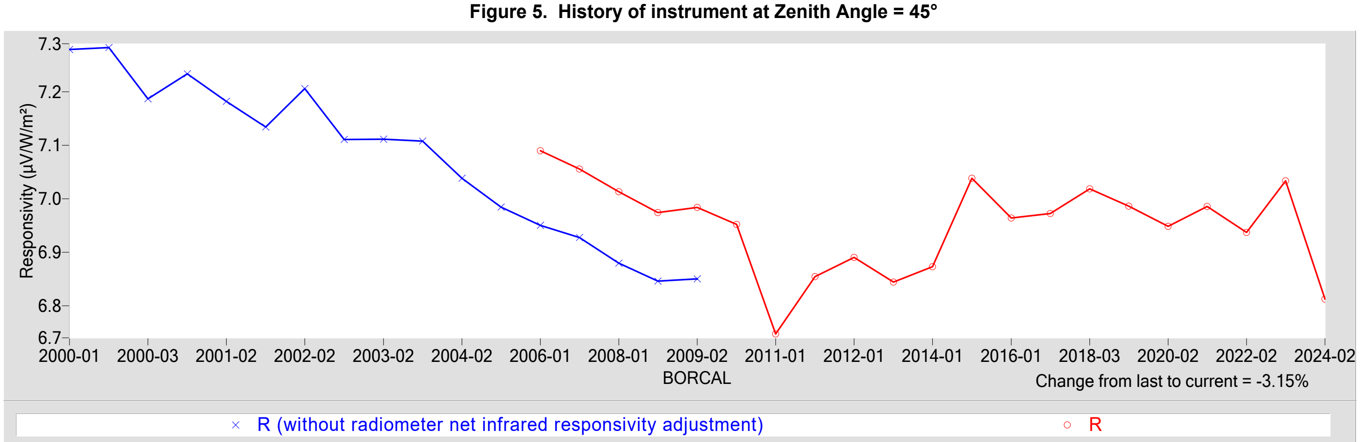
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
6.8123	0.64000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.81
Offset Uncertainty, U(off) (%)	+2.0 / -2.1
Expanded Uncertainty, U (%)	+2.8 / -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

[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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31137E6
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

31137E6 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

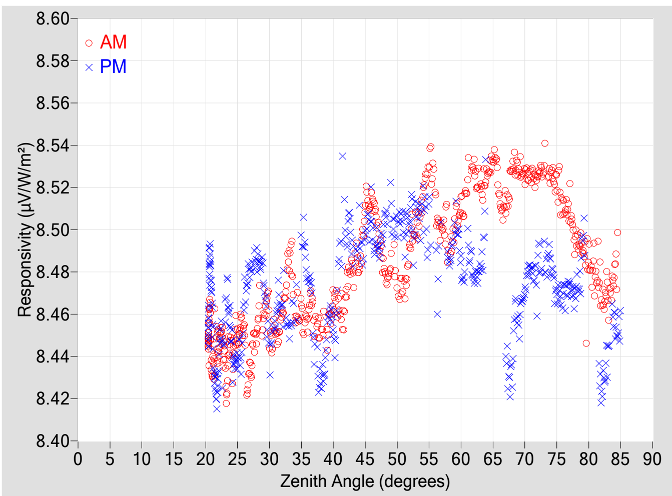


Figure 2. Responsivity vs Local Standard Time

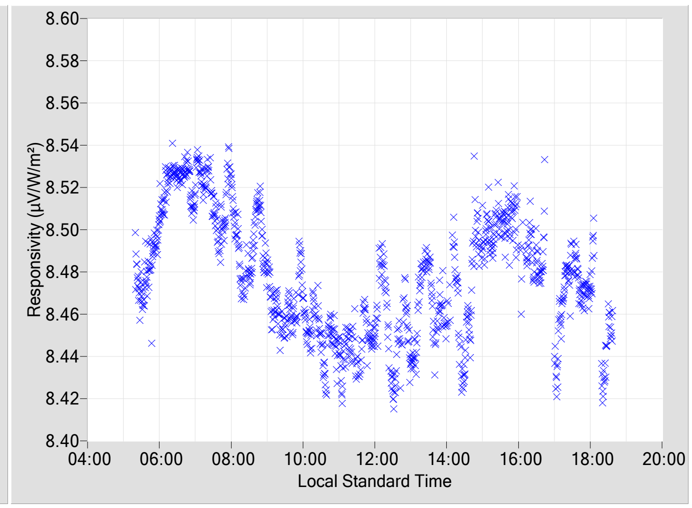


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5126	0.30	101.82	8.5048	0.29	258.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4803	0.30	99.77	8.5042	0.29	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4739	0.29	97.85	8.5039	0.30	262.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4919	0.29	95.96	8.5067	0.30	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5157	0.33	94.13	8.5100	0.30	265.98
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5140	0.32	92.37	8.4752	0.33	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4955	0.32	90.81	8.4861	0.30	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5109	0.31	89.03	8.4830	0.30	271.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5291	0.30	87.40	8.4776	0.30	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5249	0.30	85.82	8.5210	0.30	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5155	0.30	84.21	N/A	N/A	N/A
22	8.4452	0.30	155.33	8.4336	0.29	204.64	68	8.5290	0.30	82.63	8.4376	0.31	277.49
24	8.4416	0.30	144.03	8.4481	0.32	216.05	70	8.5268	0.31	81.08	8.4720	0.32	279.08
26	8.4513	0.29	136.29	8.4612	0.31	223.70	72	8.5257	0.31	79.51	8.4788	0.32	280.65
28	8.4524	0.29	130.27	8.4855	0.32	229.75	74	8.5259	0.31	77.91	8.4853	0.31	282.22
30	8.4579	0.32	125.46	8.4449	0.31	234.63	76	8.5111	0.32	76.34	8.4709	0.32	283.79
32	8.4612	0.29	121.18	8.4655	0.31	238.88	78	8.4949	N/A	74.72	8.4711	N/A	285.42
34	8.4608	0.30	117.51	8.4654	0.31	242.68	80	8.4860	N/A	73.10	N/A	N/A	N/A
36	8.4587	0.30	114.31	8.4771	0.29	245.74	82	8.4703	N/A	71.46	8.4256	N/A	288.69
38	8.4523	0.31	111.44	8.4286	0.30	248.69	84	8.4804	N/A	69.72	8.4561	N/A	290.45
40	8.4659	0.30	108.77	8.4509	0.29	251.31	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4703	0.33	106.24	8.5000	0.32	253.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4829	0.31	103.97	8.4942	0.32	256.03	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

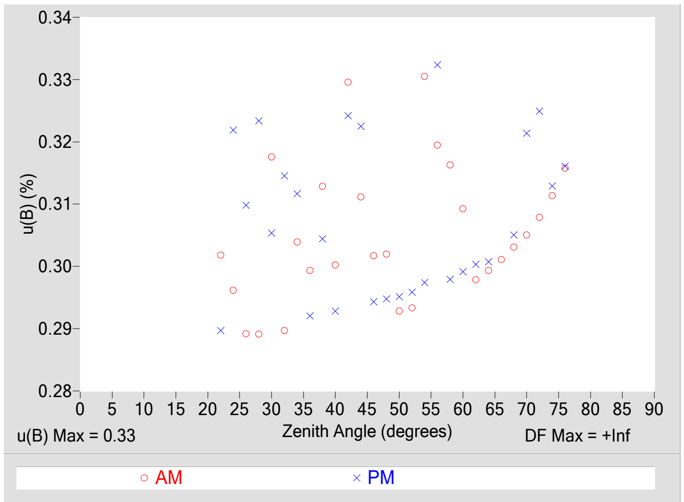


Figure 4. Residuals from Spline Interpolation

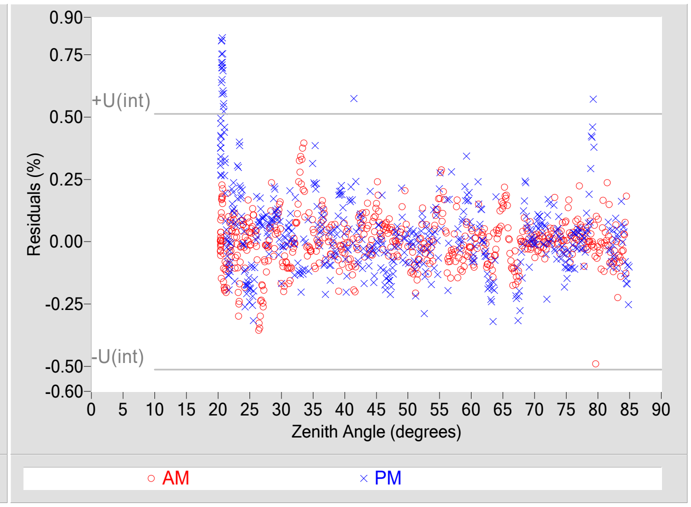


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.42
Effective degrees of freedom, DF(c)	7233
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.82
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

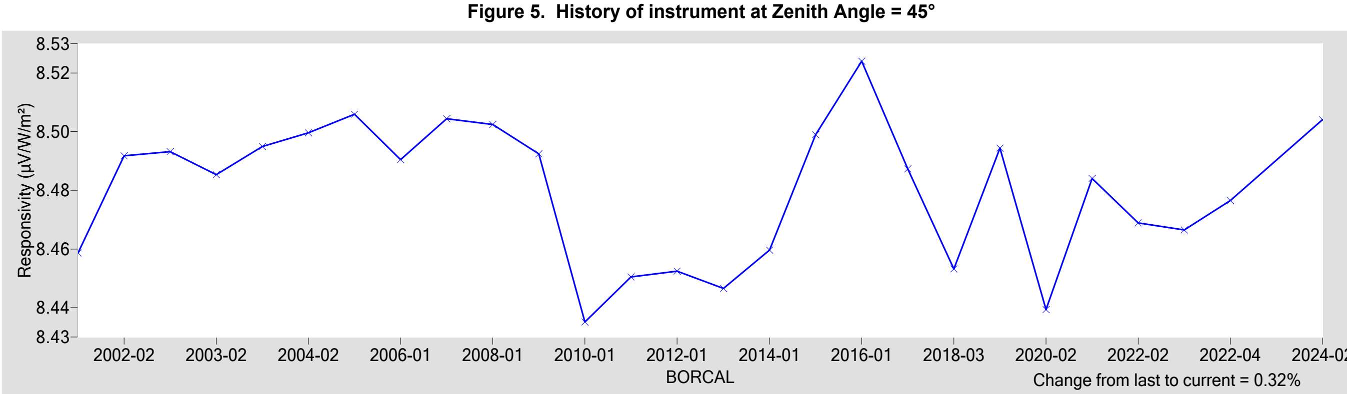
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.5040	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+0.14 / -0.89
Expanded Uncertainty, U (%)	+0.79 / -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

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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:	Black and White Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	34722
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

34722 Eppley 8-48

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

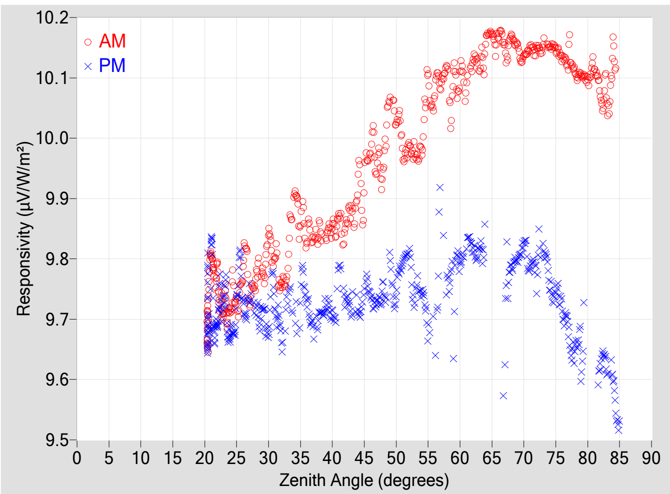


Figure 2. Responsivity vs Local Standard Time

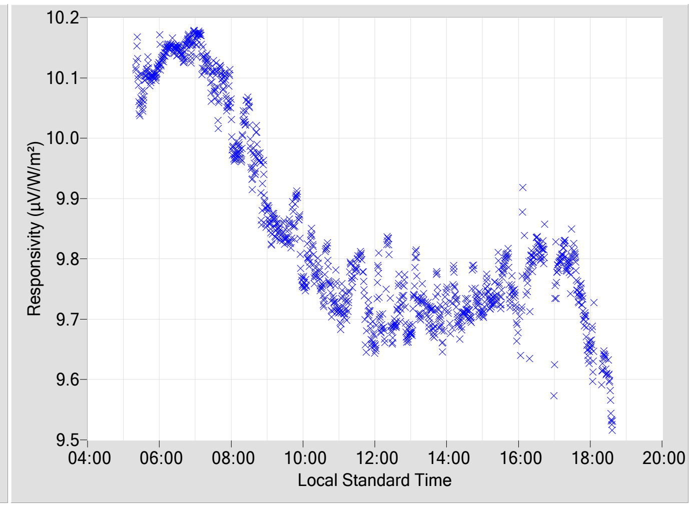


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.9833	0.33	101.76	9.7388	0.31	258.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.9541	0.33	99.76	9.7494	0.33	260.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.029	0.36	97.80	9.7457	0.32	262.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.9859	0.32	95.96	9.8093	0.32	264.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.9853	0.37	94.13	9.7435	0.35	265.97
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.072	0.38	92.39	9.6724	0.41	267.70
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.117	0.37	90.76	9.7596	0.34	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.102	0.39	89.03	9.7927	0.35	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.125	0.38	87.40	9.8187	0.36	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.148	0.40	85.82	9.8299	0.37	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.171	0.39	84.21	N/A	N/A	N/A
22	9.7634	0.31	155.35	9.7026	0.32	204.72	68	10.167	0.41	82.66	9.7846	0.40	277.49
24	9.7163	0.30	144.02	9.6758	0.29	216.04	70	10.135	0.43	81.08	9.8262	0.43	279.07
26	9.7882	0.31	136.15	9.7310	0.33	223.79	72	10.148	0.50	79.51	9.7800	0.50	280.64
28	9.7646	0.31	130.26	9.7171	0.35	229.65	74	10.151	0.51	77.90	9.7609	0.51	282.22
30	9.8354	0.33	125.38	9.6924	0.31	234.78	76	10.134	0.57	76.33	9.7169	0.57	283.79
32	9.7573	0.30	121.17	9.6715	0.31	238.81	78	10.110	N/A	74.76	9.6520	N/A	285.41
34	9.9067	0.36	117.42	9.7107	0.32	242.67	80	10.097	N/A	73.09	N/A	N/A	N/A
36	9.8392	0.32	114.23	9.7329	0.33	245.72	82	10.073	N/A	71.46	9.6248	N/A	288.69
38	9.8426	0.33	111.42	9.7081	0.33	248.69	84	10.132	N/A	69.72	9.5930	N/A	290.44
40	9.8517	0.32	108.76	9.7056	0.32	251.31	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8480	0.34	106.30	9.7349	0.32	253.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.9259	0.32	103.97	9.7163	0.33	256.16	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

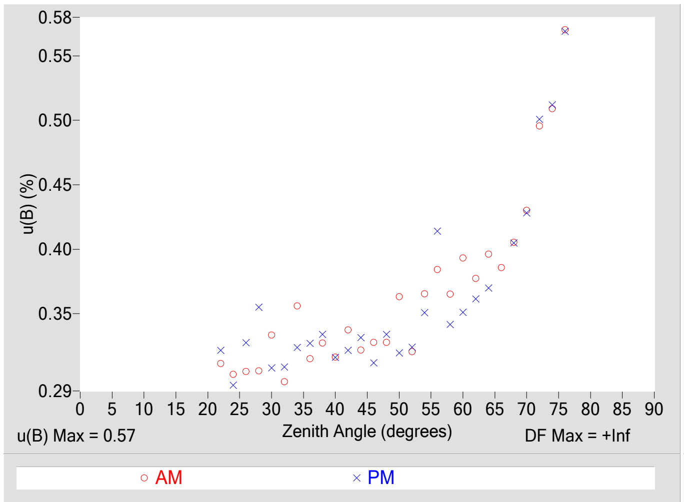


Figure 4. Residuals from Spline Interpolation

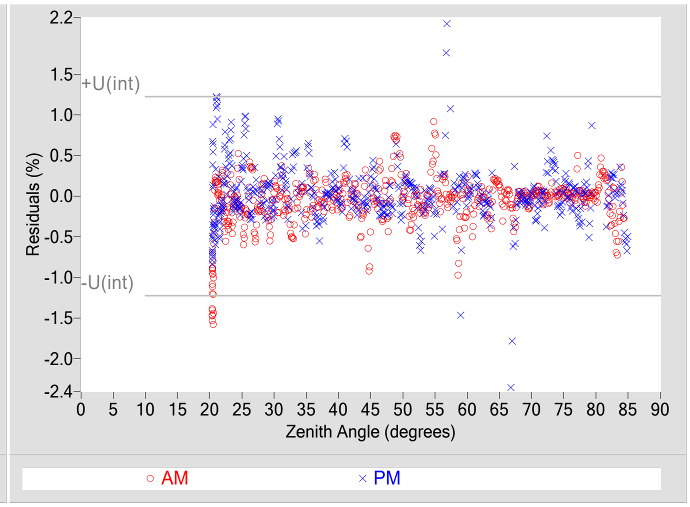


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.61
Combined Standard Uncertainty, u(c) (%)	±0.84
Effective degrees of freedom, DF(c)	3543
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

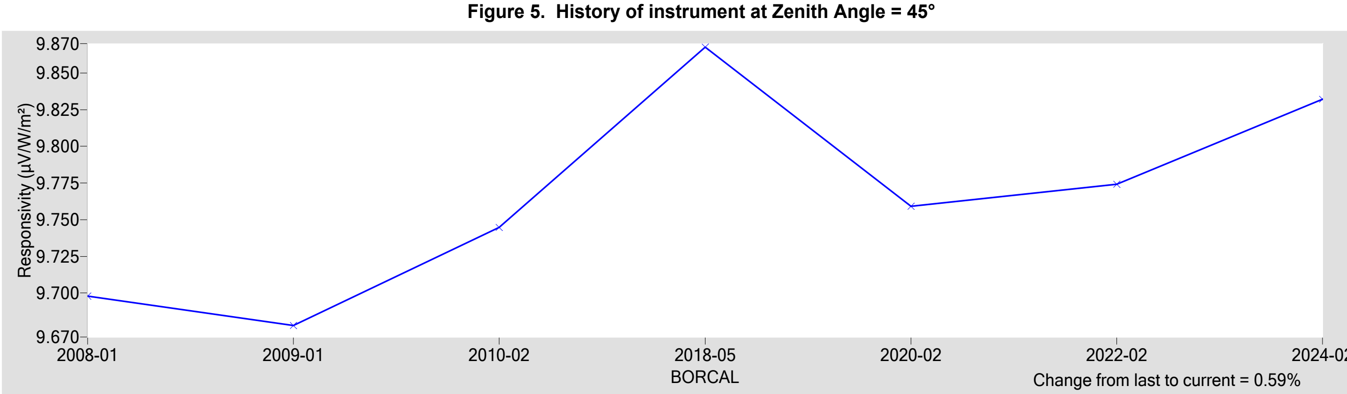
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.8322	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.81
Offset Uncertainty, U(off) (%)	+2.9 / -1.6
Expanded Uncertainty, U (%)	+3.7 / -2.4
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:	GPP Pyranometer	**Manufacturer:**	Eppley
Model:	GPP	**Serial Number:**	37831F3
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — 05/21/2024 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

37831F3 Eppley GPP

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

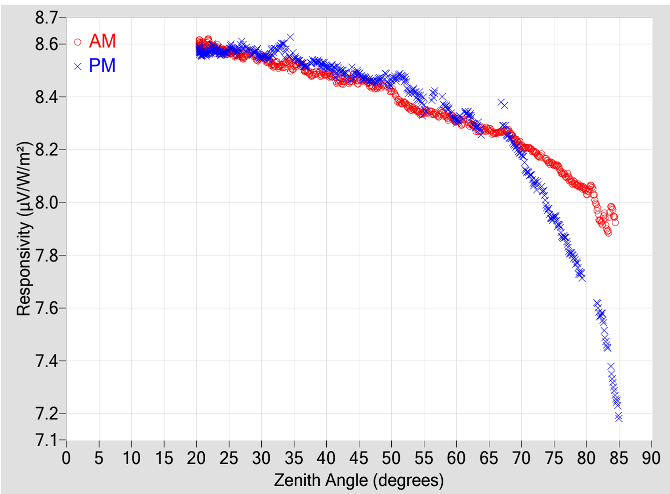


Figure 2. Responsivity vs Local Standard Time

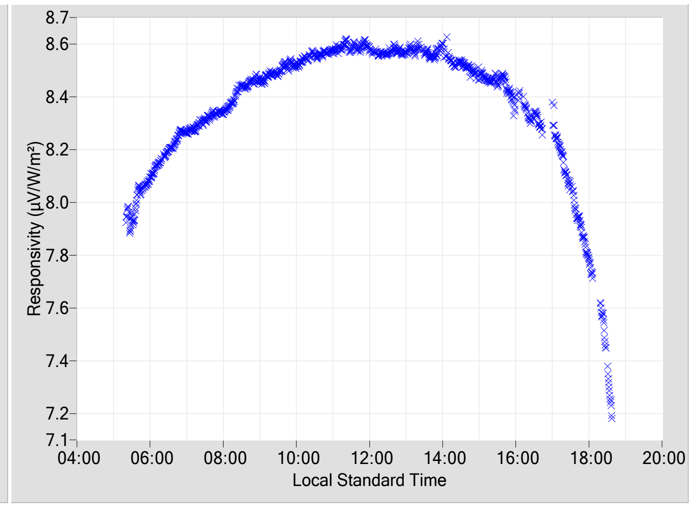


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	8.4603	0.38	101.83	8.4682	0.34	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4392	0.32	99.77	8.4641	0.32	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4225	0.34	97.78	8.4576	0.32	262.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3765	0.33	95.92	8.4667	0.33	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3457	0.38	94.14	8.4026	0.34	265.98
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3448	0.41	92.34	8.3863	0.45	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3362	0.36	90.72	8.3754	0.35	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3104	0.39	89.04	8.3101	0.36	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2993	0.41	87.41	8.3335	0.37	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2785	0.38	85.83	8.2551	0.38	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2627	0.39	84.22	N/A	N/A	N/A
22	8.6026	0.33	155.35	8.5719	0.32	204.67	68	8.2695	0.42	82.63	8.2472	0.44	277.50
24	8.5752	0.32	143.86	8.5651	0.31	216.26	70	8.2162	0.44	81.09	8.1819	0.44	279.04
26	8.5608	0.31	136.18	8.5690	0.33	224.11	72	8.1913	0.47	79.52	8.0684	0.48	280.65
28	8.5647	0.31	130.29	8.5787	0.30	229.76	74	8.1568	0.52	77.91	7.9736	0.53	282.23
30	8.5499	0.31	125.33	8.5491	0.32	234.70	76	8.1195	0.59	76.34	7.8924	0.60	283.80
32	8.5207	0.31	121.20	8.5718	0.30	238.74	78	8.0745	N/A	74.72	7.7923	N/A	285.42
34	8.5357	0.30	117.52	8.5656	0.30	242.52	80	8.0387	N/A	73.10	N/A	N/A	N/A
36	8.5221	0.32	114.40	8.5295	0.32	245.81	82	7.9415	N/A	71.47	7.5773	N/A	288.70
38	8.4849	0.34	111.36	8.5338	0.30	248.71	84	7.9685	N/A	69.78	7.3273	N/A	290.40
40	8.4878	0.35	108.75	8.5110	0.31	251.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4618	0.31	106.32	8.4988	0.33	253.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4712	0.34	103.98	8.4788	0.35	256.11	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

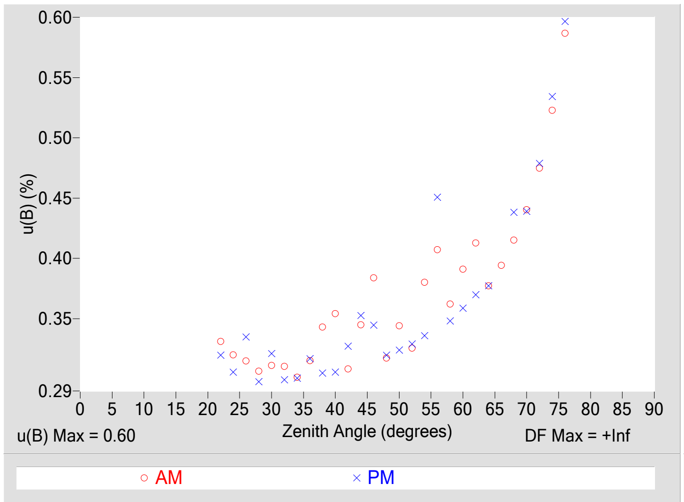


Figure 4. Residuals from Spline Interpolation

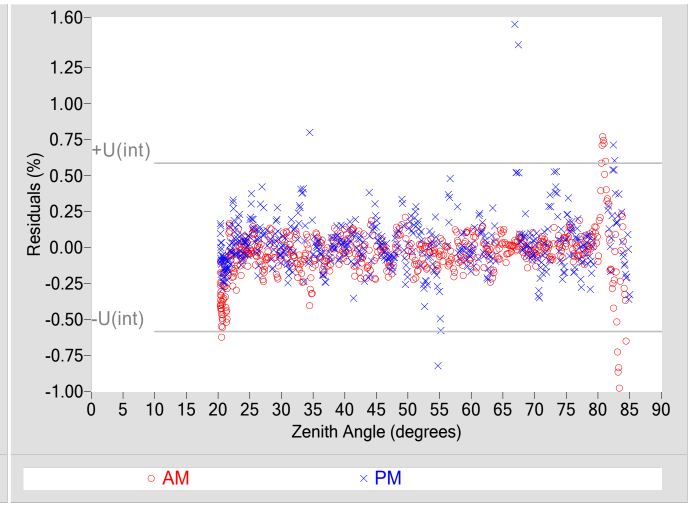


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	26581
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

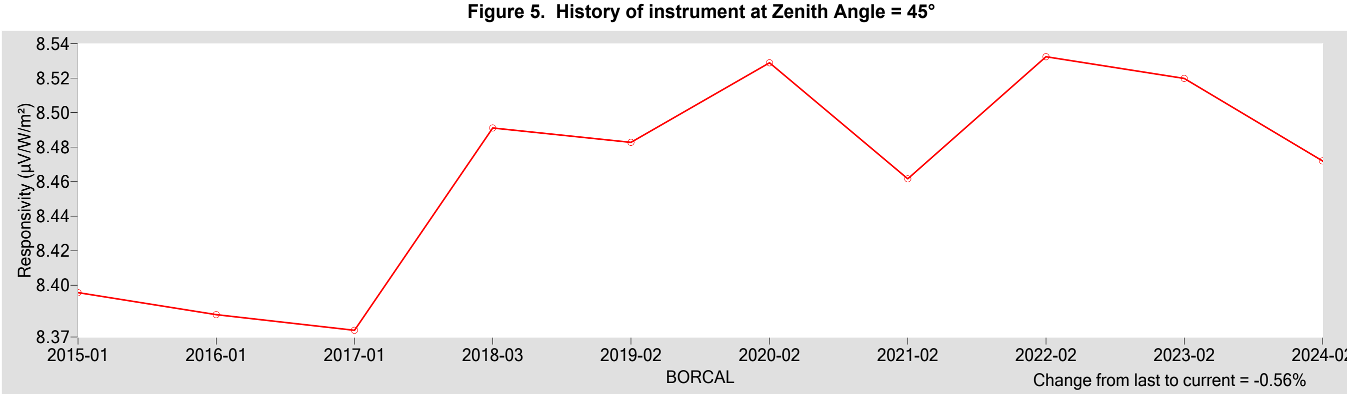
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4721	0.15000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+1.2 / -1.9
Expanded Uncertainty, U (%)	+2.1 / -2.8
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:	Standard Precision Pyranometer	**Manufacturer:**	Eppley
Model:	SPP	**Serial Number:**	37839F3
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager   05/21/2024 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

37839F3 Eppley SPP

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

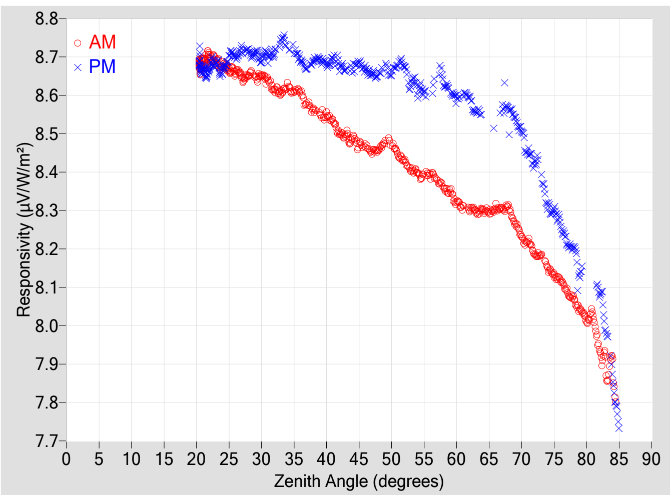


Figure 2. Responsivity vs Local Standard Time

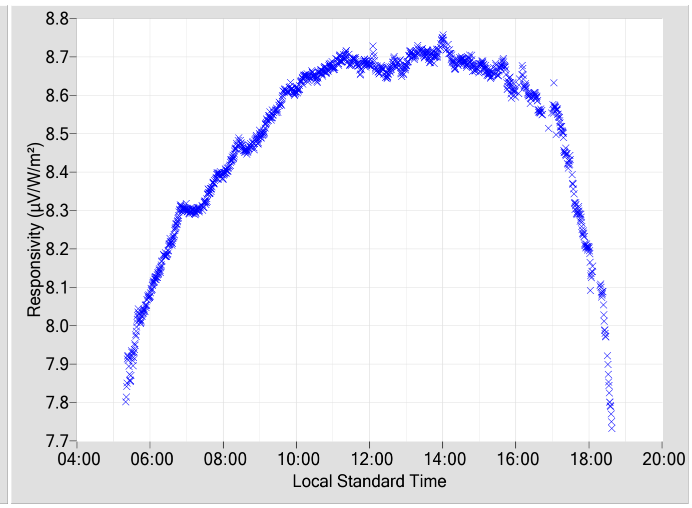


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4691	0.37	101.83	8.6681	0.32	258.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4577	0.34	99.75	8.6551	0.33	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4708	0.39	97.75	8.6582	0.35	262.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4277	0.35	95.95	8.6730	0.40	264.19
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3997	0.36	94.17	8.6154	0.38	265.97
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3932	0.39	92.39	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3593	0.38	90.68	8.6331	0.36	269.41
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3220	0.39	89.06	8.5938	0.39	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3027	0.38	87.39	8.5931	0.39	272.68
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3017	0.39	85.81	8.5499	0.40	274.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3038	0.43	84.21	8.5139	N/A	275.67
22	8.7031	0.31	155.64	8.6727	0.33	204.61	68	8.3081	0.43	82.66	8.5551	0.46	277.48
24	8.6765	0.33	143.94	8.6678	0.31	216.21	70	8.2331	0.46	81.08	8.5083	0.46	279.07
26	8.6599	0.34	136.27	8.6987	0.32	223.77	72	8.1870	0.50	79.50	8.4216	0.54	280.64
28	8.6516	0.32	130.36	8.7148	0.35	229.76	74	8.1521	0.55	77.94	8.3148	0.58	282.21
30	8.6508	0.33	125.40	8.6930	0.33	234.66	76	8.1182	0.62	76.33	8.2648	0.65	283.79
32	8.6133	0.31	121.26	8.7096	0.32	238.80	78	8.0690	N/A	74.71	8.2024	N/A	285.41
34	8.6234	0.33	117.45	8.7227	0.31	242.49	80	8.0154	N/A	73.13	N/A	N/A	N/A
36	8.6086	0.32	114.39	8.6920	0.32	245.78	82	7.9364	N/A	71.45	8.0853	N/A	288.72
38	8.5622	0.31	111.41	8.6887	0.32	248.68	84	7.8934	N/A	69.76	7.8694	N/A	290.38
40	8.5467	0.38	108.76	8.6798	0.31	251.41	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5021	0.32	106.29	8.6780	0.33	253.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4893	0.34	103.96	8.6696	0.38	256.11	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

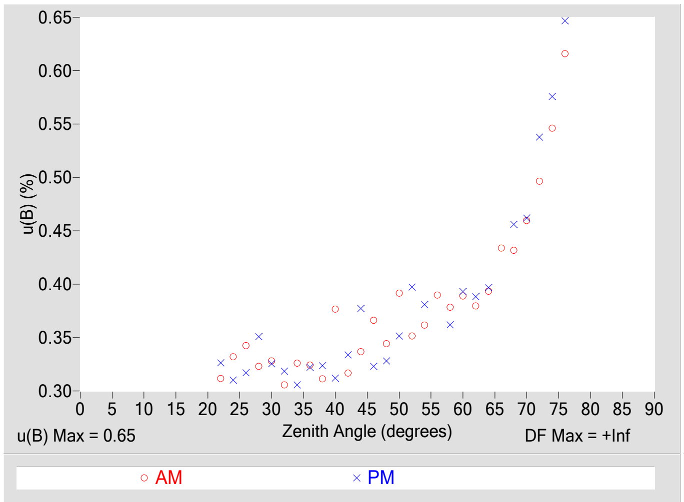


Figure 4. Residuals from Spline Interpolation

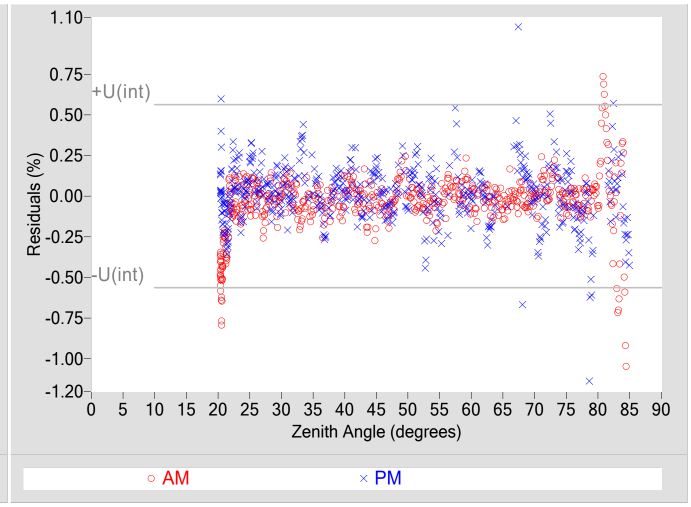


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.71
Effective degrees of freedom, DF(c)	38812
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

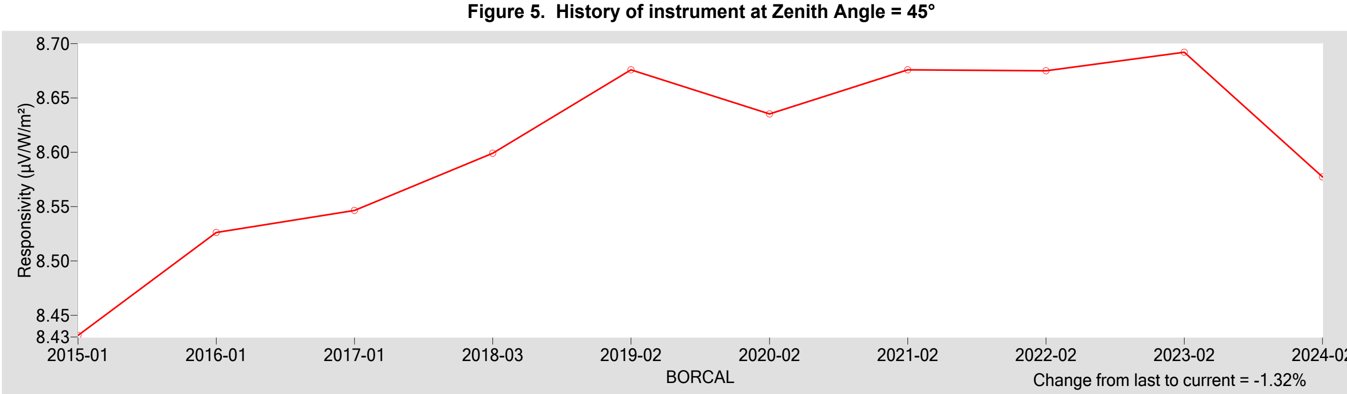
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5775	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.7 / -3.0
Expanded Uncertainty, U (%)	+2.5 / -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:**	37882E6
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

37882E6 Eppley sNIP

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

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

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

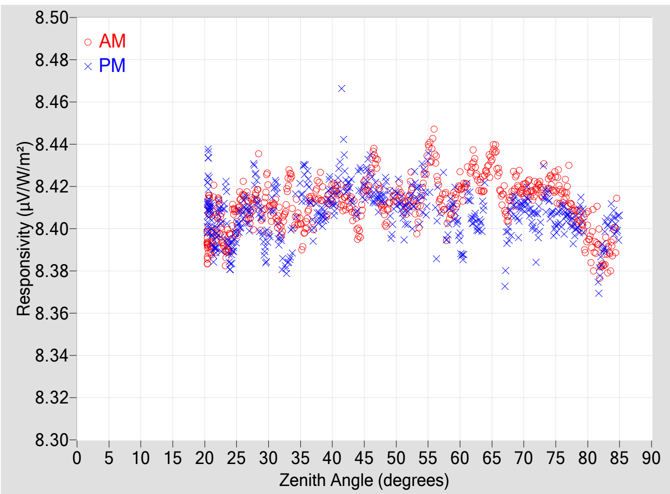


Figure 2. Responsivity vs Local Standard Time

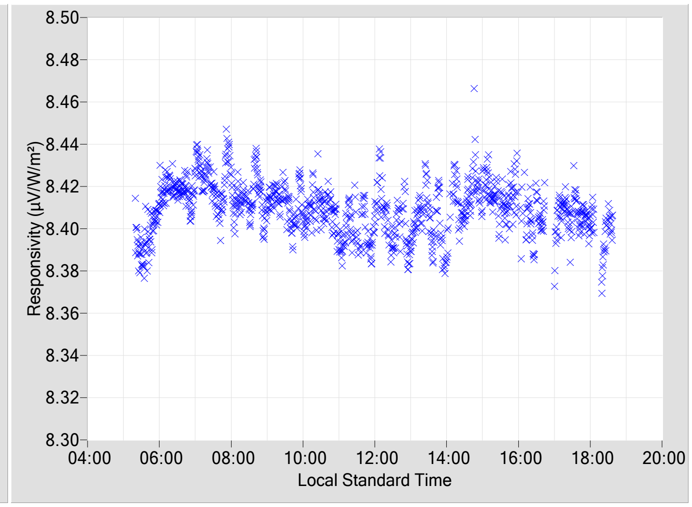


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4252	0.30	101.82	8.4240	0.29	258.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4084	0.30	99.77	8.4156	0.29	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4139	0.29	97.85	8.4172	0.30	262.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4154	0.29	95.96	8.4097	0.30	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4163	0.33	94.13	8.4178	0.30	265.98
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4382	0.32	92.37	8.3979	0.33	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4047	0.32	90.81	8.3996	0.30	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4209	0.31	89.03	8.3929	0.30	271.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4315	0.30	87.40	8.4043	0.30	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4248	0.30	85.82	8.4163	0.30	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4254	0.30	84.21	N/A	N/A	N/A
22	8.4042	0.30	155.33	8.4013	0.29	204.64	68	8.4144	0.30	82.63	8.4067	0.31	277.49
24	8.3947	0.30	144.03	8.3859	0.32	216.05	70	8.4190	0.31	81.08	8.4112	0.32	279.08
26	8.4153	0.29	136.29	8.4086	0.31	223.70	72	8.4202	0.31	79.51	8.3987	0.32	280.65
28	8.4147	0.29	130.27	8.4218	0.32	229.75	74	8.4221	0.31	77.91	8.4112	0.31	282.22
30	8.4154	0.32	125.46	8.3966	0.31	234.63	76	8.4150	0.32	76.34	8.4084	0.32	283.79
32	8.4000	0.29	121.18	8.3908	0.31	238.88	78	8.4067	N/A	74.72	8.3995	N/A	285.42
34	8.4044	0.30	117.51	8.4074	0.31	242.68	80	8.4001	N/A	73.10	N/A	N/A	N/A
36	8.4042	0.30	114.31	8.4230	0.29	245.74	82	8.3863	N/A	71.46	8.3818	N/A	288.69
38	8.4180	0.31	111.44	8.4056	0.30	248.69	84	8.3958	N/A	69.72	8.4035	N/A	290.45
40	8.4167	0.30	108.77	8.4126	0.29	251.31	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4141	0.33	106.24	8.4274	0.32	253.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3992	0.31	103.97	8.4135	0.32	256.03	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

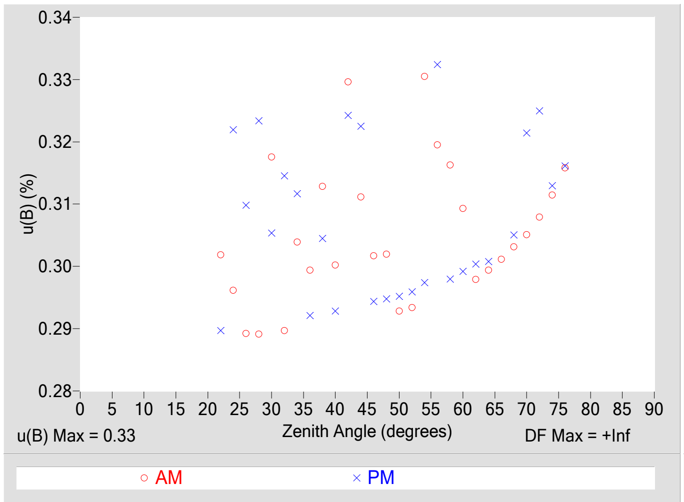


Figure 4. Residuals from Spline Interpolation

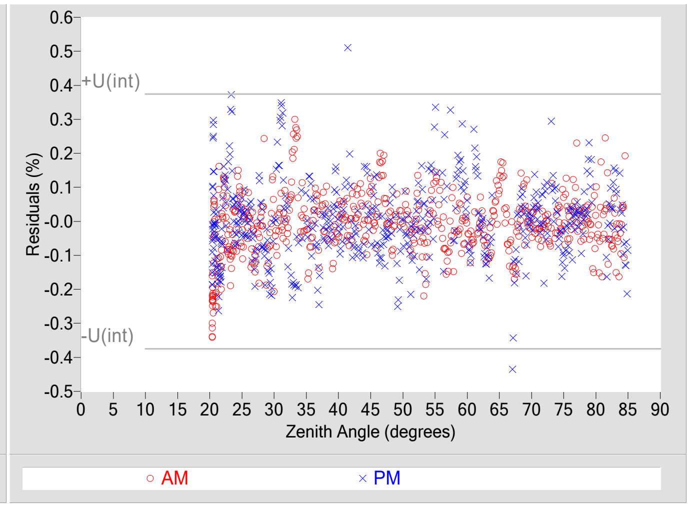


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	17357
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

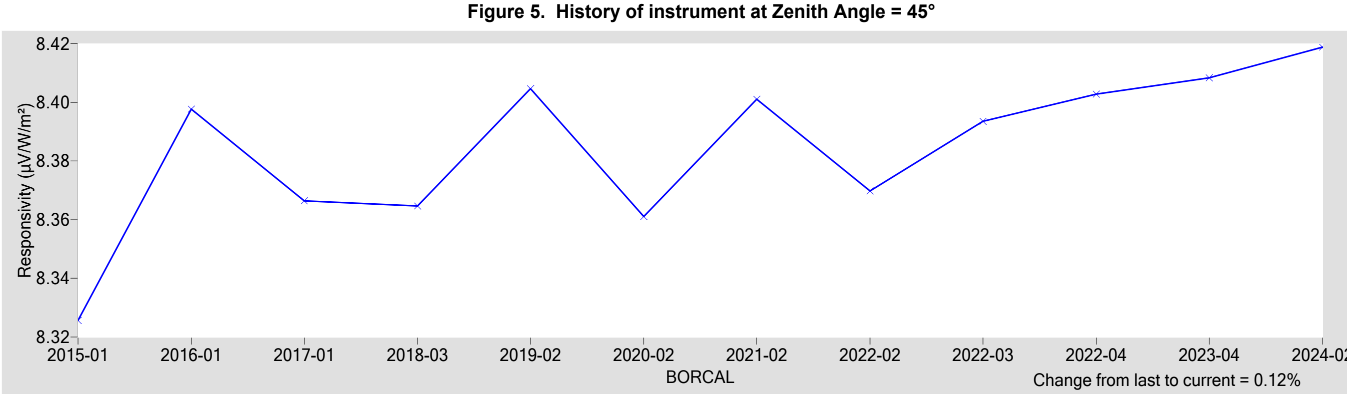
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4189	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+0.23 / -0.33
Expanded Uncertainty, U (%)	+0.88 / -0.98
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:	Si pyranometer	**Manufacturer:**	Apogee
Model:	SP-110	**Serial Number:**	40337
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — 05/21/2024 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

40337 Apogee SP-110

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

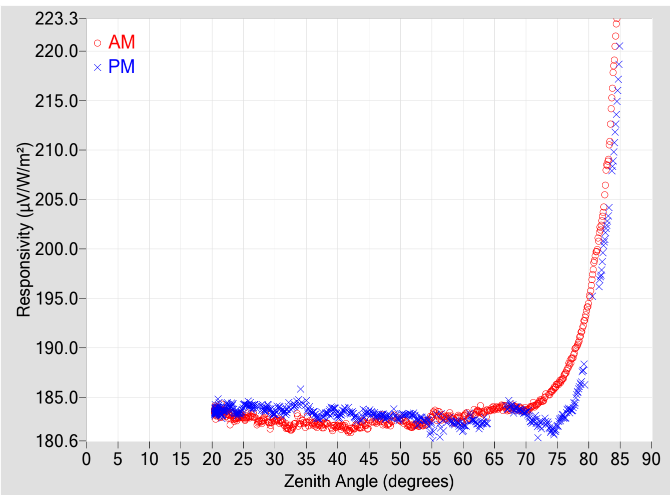


Figure 2. Responsivity vs Local Standard Time

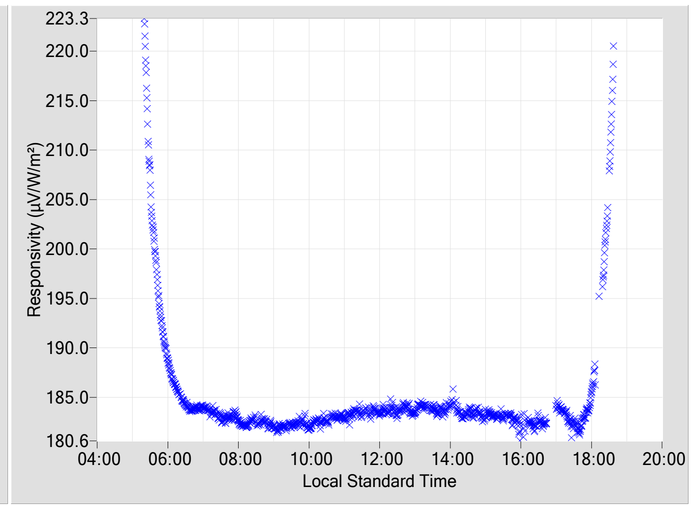


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	182.56	0.33	101.75	183.16	0.33	258.28
2	N/A	N/A	N/A	N/A	N/A	N/A	48	182.29	0.31	99.70	183.07	0.35	260.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	182.70	0.33	97.85	183.02	0.32	262.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	182.09	0.32	95.96	183.23	0.34	264.14
8	N/A	N/A	N/A	N/A	N/A	N/A	54	182.40	0.36	94.13	182.63	0.35	265.97
10	N/A	N/A	N/A	N/A	N/A	N/A	56	183.14	0.36	92.39	181.64	0.45	267.89
12	N/A	N/A	N/A	N/A	N/A	N/A	58	183.15	0.36	90.75	182.60	0.34	269.47
14	N/A	N/A	N/A	N/A	N/A	N/A	60	182.86	0.37	89.02	181.91	0.37	271.06
16	N/A	N/A	N/A	N/A	N/A	N/A	62	183.52	0.35	87.40	182.51	0.36	272.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	183.71	0.36	85.81	182.35	0.36	274.14
20	N/A	N/A	N/A	N/A	N/A	N/A	66	184.08	0.38	84.21	N/A	N/A	N/A
22	183.61	0.32	155.27	183.78	0.31	204.50	68	184.01	0.40	82.66	183.79	0.40	277.49
24	182.94	0.32	143.97	183.39	0.29	216.03	70	183.72	0.42	81.08	183.44	0.42	279.07
26	183.13	0.32	136.26	184.14	0.34	223.86	72	184.46	0.45	79.50	181.94	0.49	280.64
28	182.62	0.30	130.26	183.96	0.31	229.81	74	185.51	0.50	77.94	181.71	0.50	282.21
30	182.73	0.29	125.45	183.50	0.32	234.77	76	187.10	0.56	76.33	183.06	0.55	283.79
32	181.91	0.31	121.17	183.81	0.32	238.81	78	190.00	N/A	74.76	185.01	N/A	285.41
34	182.39	0.34	117.63	184.83	0.36	242.67	80	194.82	N/A	73.09	N/A	N/A	N/A
36	182.38	0.31	114.22	183.50	0.30	245.76	82	202.54	N/A	71.45	197.94	N/A	288.68
38	182.28	0.30	111.41	183.29	0.32	248.69	84	218.95	N/A	69.72	210.38	N/A	290.43
40	182.11	0.30	108.76	183.08	0.32	251.37	86	N/A	N/A	N/A	N/A	N/A	N/A
42	181.65	0.34	106.29	183.54	0.33	253.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	182.35	0.33	103.97	183.14	0.33	256.15	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

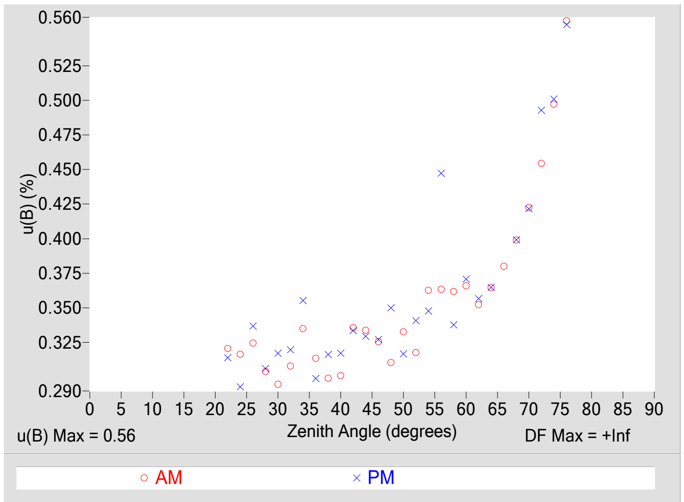


Figure 4. Residuals from Spline Interpolation

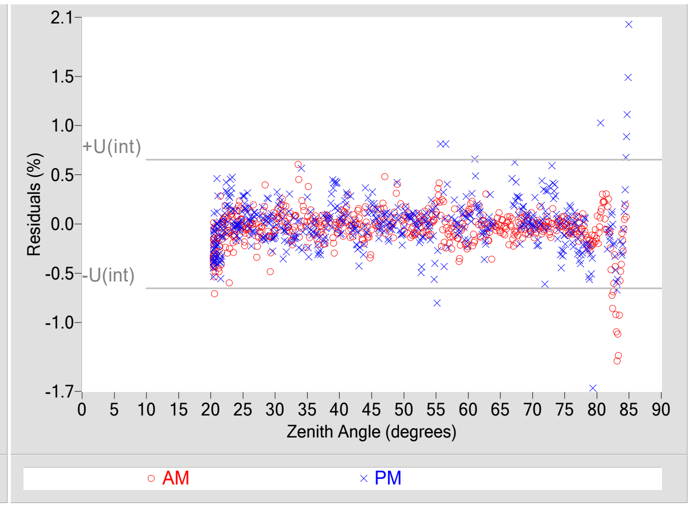


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	15307
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

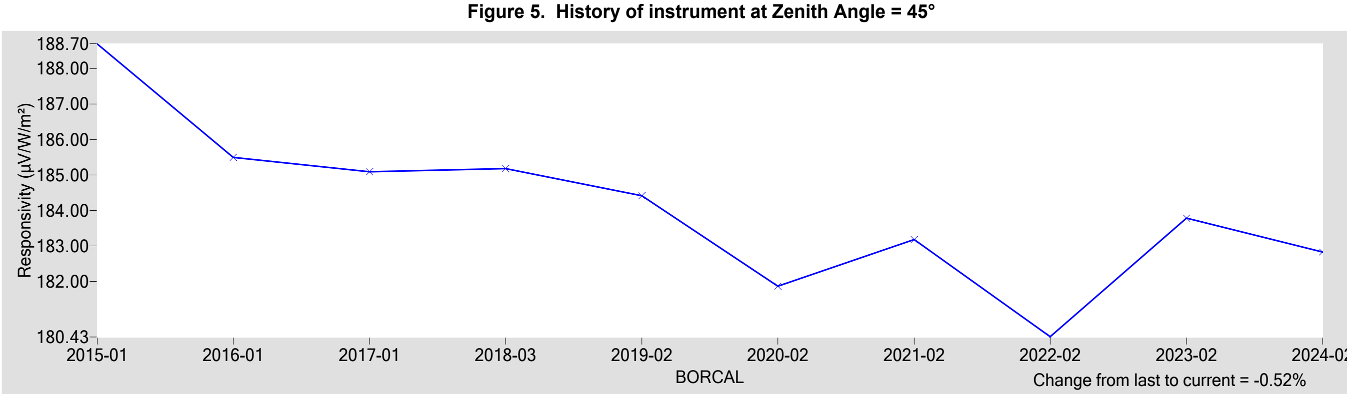
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
182.83	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+1.1 / -0.65
Expanded Uncertainty, U (%)	+2.0 / -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

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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:**	65089
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

______________________________ 05/21/2024

Ibrahim Reda, 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

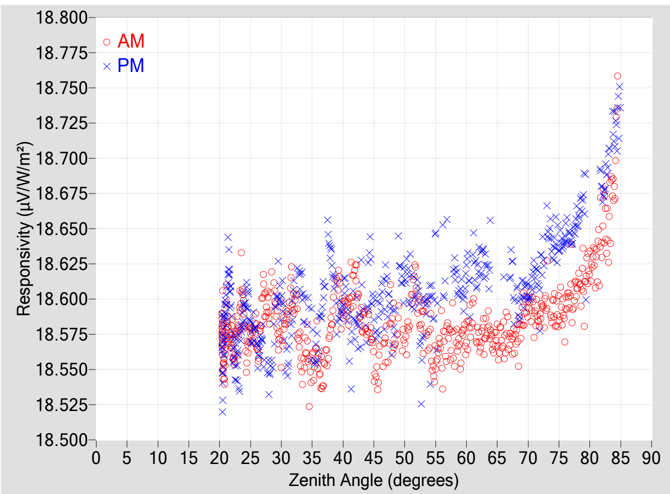


Figure 2. Responsivity vs Local Standard Time

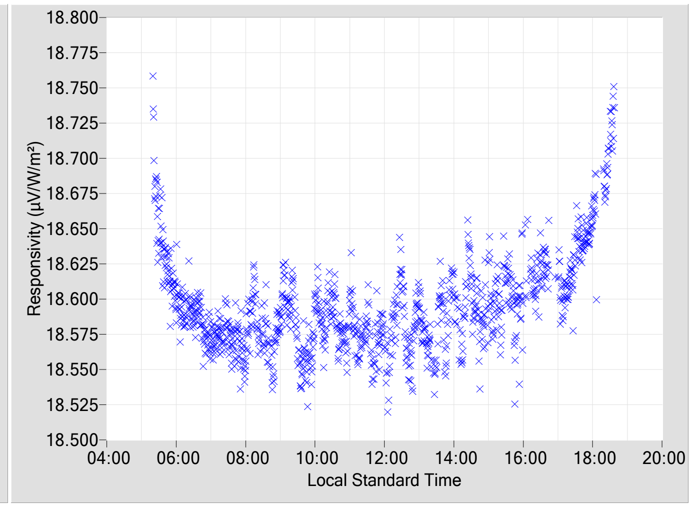


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	18.556	0.31	102.00	18.598	0.32	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	18.584	0.30	99.77	18.575	0.31	260.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	18.570	0.32	97.80	18.611	0.29	262.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	18.604	0.29	95.97	18.608	0.31	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	18.575	0.30	94.14	18.588	0.30	266.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	18.565	0.30	92.41	18.628	0.30	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	18.571	0.33	90.77	18.621	0.30	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	18.569	0.29	89.04	18.622	0.30	271.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	18.570	0.30	87.41	18.623	0.30	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	18.573	0.31	85.83	18.638	0.30	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	18.570	0.30	84.22	18.616	N/A	275.90
22	18.569	0.31	155.24	18.582	0.30	204.69	68	18.573	0.30	82.63	18.605	0.30	277.53
24	18.588	0.31	144.12	18.593	0.31	216.07	70	18.595	0.30	81.09	18.603	0.30	279.08
26	18.573	0.29	136.32	18.568	0.33	223.85	72	18.588	0.31	79.52	18.613	0.31	280.65
28	18.595	0.29	130.36	18.547	0.31	229.84	74	18.593	0.31	77.91	18.634	0.31	282.23
30	18.573	0.32	125.47	18.600	0.30	234.70	76	18.589	0.31	76.35	18.644	0.31	283.80
32	18.596	0.29	121.19	18.601	0.29	238.74	78	18.610	N/A	74.73	18.657	N/A	285.42
34	18.567	0.30	117.61	18.595	0.31	242.69	80	18.624	N/A	73.10	N/A	N/A	N/A
36	18.558	0.31	114.32	18.568	0.31	245.65	82	18.652	N/A	71.42	18.678	N/A	288.70
38	18.579	0.31	111.43	18.634	0.29	248.63	84	18.689	N/A	69.73	18.719	N/A	290.40
40	18.591	0.32	108.78	18.599	0.30	251.32	86	N/A	N/A	N/A	N/A	N/A	N/A
42	18.617	0.30	106.25	18.585	0.31	253.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	18.581	0.29	103.98	18.599	0.31	256.11	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

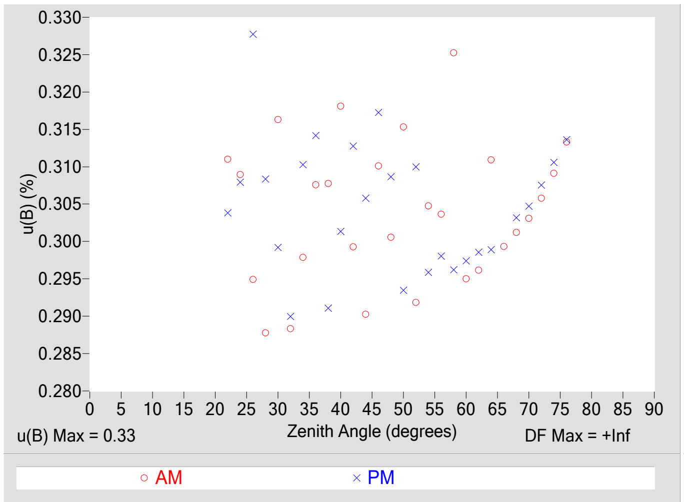


Figure 4. Residuals from Spline Interpolation

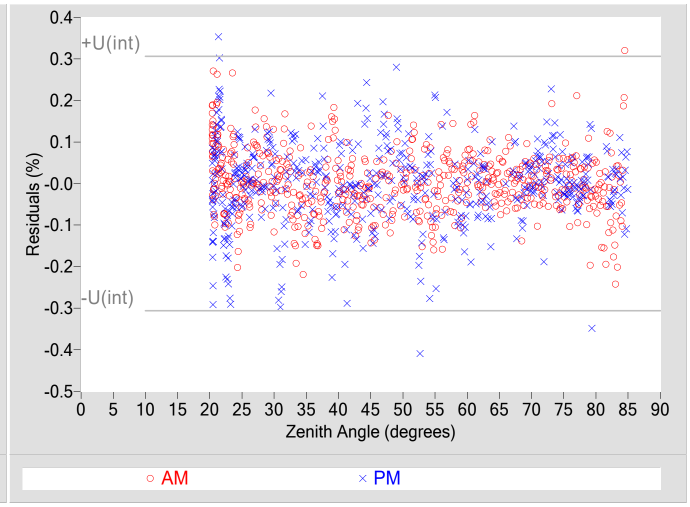


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	31270
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.71
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

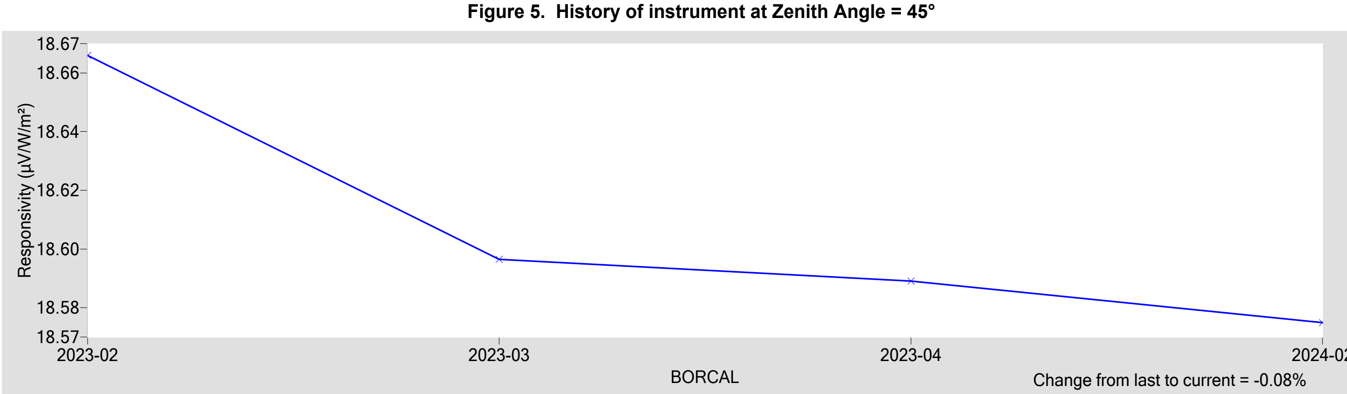
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
18.575	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.32 / -0.10
Expanded Uncertainty, U (%)	+0.95 / -0.74
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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[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:	DR02	**Serial Number:**	9206
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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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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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

9206 Hukseflux DR02

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 - 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

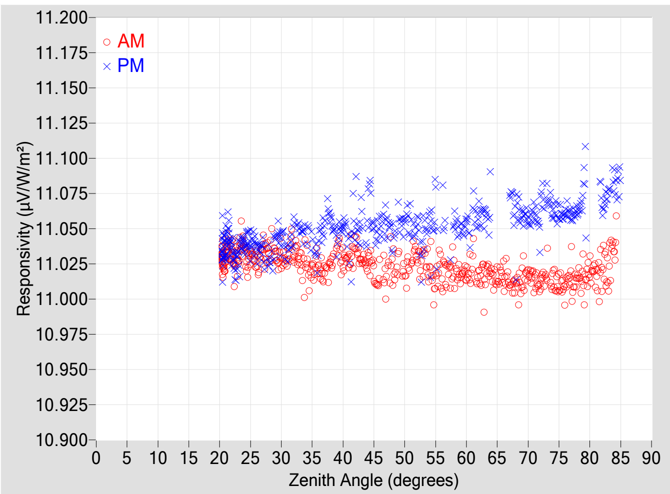


Figure 2. Responsivity vs Local Standard Time

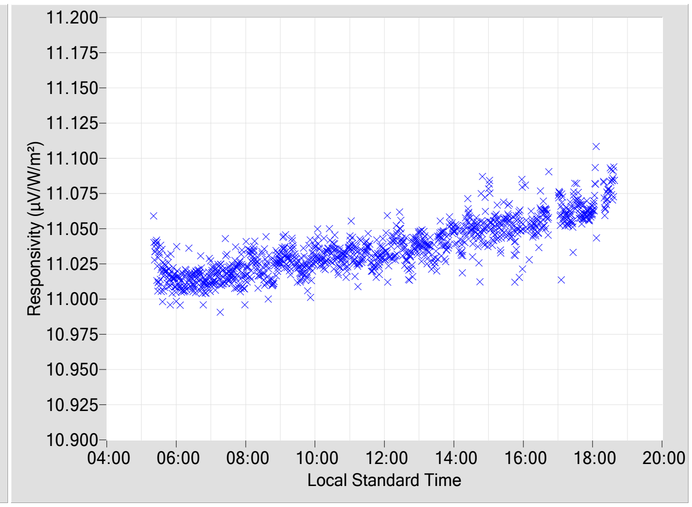


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	11.017	0.31	102.00	11.053	0.32	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.027	0.30	99.77	11.041	0.31	260.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.017	0.32	97.80	11.053	0.29	262.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.031	0.29	95.97	11.055	0.31	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.023	0.31	94.14	11.048	0.30	266.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.018	0.30	92.41	11.065	0.30	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.022	0.33	90.77	11.054	0.30	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.018	0.30	89.04	11.056	0.30	271.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.016	0.30	87.41	11.059	0.30	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.018	0.31	85.83	11.074	0.30	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.015	0.30	84.22	N/A	N/A	N/A
22	11.031	0.31	155.24	11.034	0.30	204.69	68	11.011	0.30	82.63	11.067	0.30	277.50
24	11.037	0.31	144.12	11.038	0.31	216.07	70	11.018	0.30	81.09	11.055	0.31	279.08
26	11.027	0.30	136.32	11.037	0.33	223.85	72	11.011	0.31	79.52	11.060	0.31	280.65
28	11.035	0.29	130.36	11.029	0.31	229.84	74	11.014	0.31	77.91	11.061	0.31	282.23
30	11.027	0.31	125.44	11.042	0.30	234.70	76	11.008	0.31	76.35	11.061	0.31	283.80
32	11.030	0.29	121.19	11.050	0.29	238.74	78	11.015	N/A	74.73	11.063	N/A	285.42
34	11.026	0.30	117.61	11.048	0.31	242.69	80	11.020	N/A	73.10	N/A	N/A	N/A
36	11.024	0.31	114.32	11.035	0.31	245.65	82	11.023	N/A	71.42	11.068	N/A	288.70
38	11.025	0.31	111.43	11.057	0.29	248.63	84	11.039	N/A	69.73	11.082	N/A	290.40
40	11.026	0.32	108.78	11.051	0.30	251.32	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.038	0.30	106.25	11.056	0.31	253.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.026	0.29	103.98	11.057	0.31	256.11	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

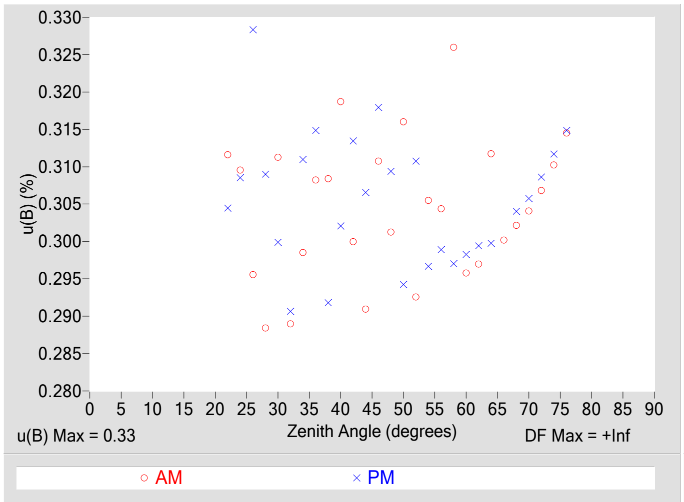


Figure 4. Residuals from Spline Interpolation

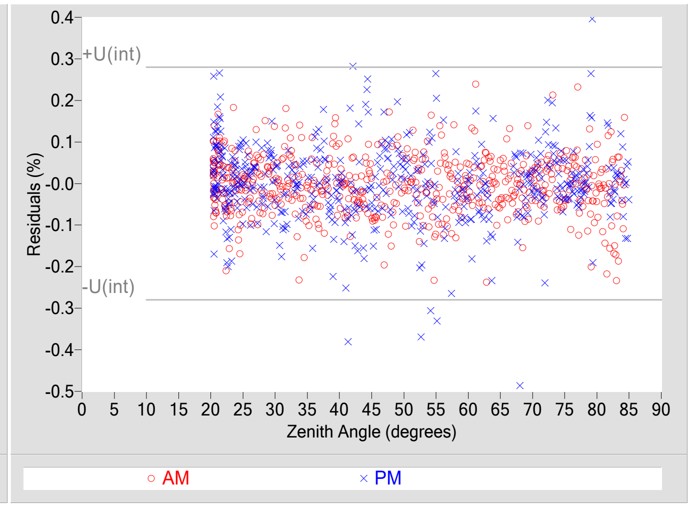


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.14
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	42463
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.70
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

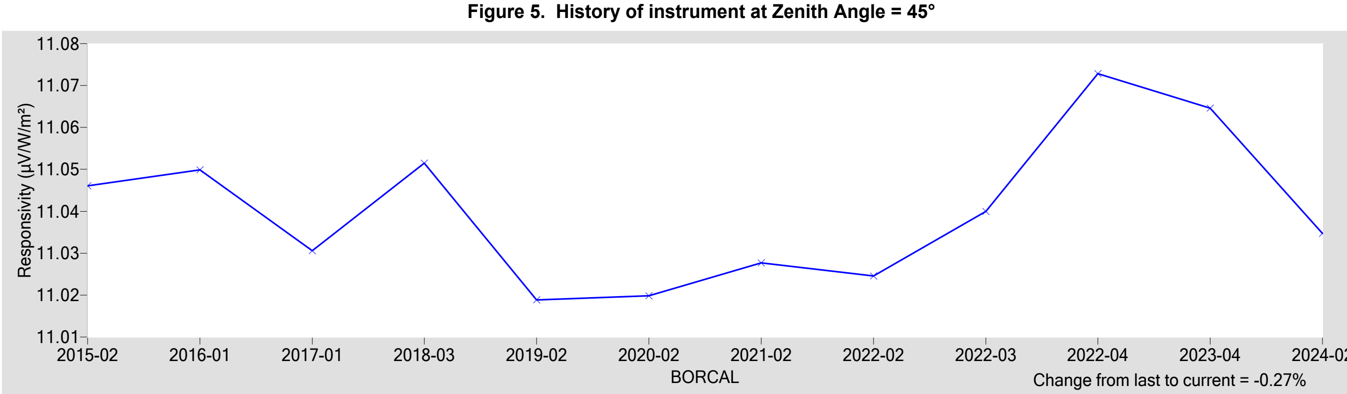
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
11.035	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.27 / -0.16
Expanded Uncertainty, U (%)	+0.91 / -0.80
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:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE	**Serial Number:**	970003
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

970003 Kipp & Zonen SP-LITE

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

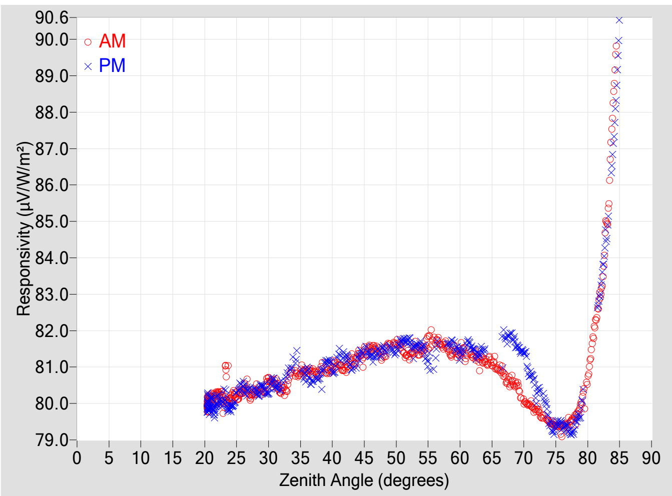


Figure 2. Responsivity vs Local Standard Time

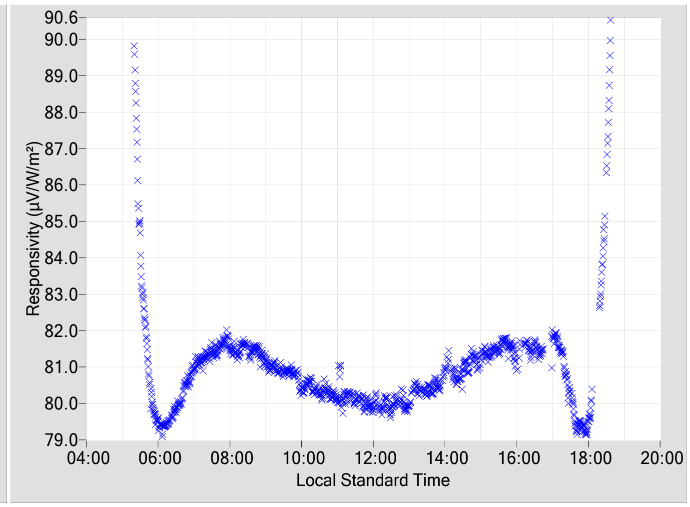


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	81.532	0.32	101.84	81.324	0.31	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	81.342	0.33	99.79	81.533	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	81.651	0.33	97.81	81.420	0.32	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	81.333	0.33	95.93	81.734	0.34	264.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	81.463	0.34	94.15	81.568	0.35	265.99
10	N/A	N/A	N/A	N/A	N/A	N/A	56	81.736	0.44	92.39	81.228	0.38	267.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	81.545	0.36	90.73	81.642	0.38	269.49
14	N/A	N/A	N/A	N/A	N/A	N/A	60	81.434	0.34	89.05	81.372	0.35	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	81.325	0.35	87.42	81.510	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	81.140	0.36	85.79	81.470	0.36	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	80.955	0.38	84.23	N/A	N/A	N/A
22	80.250	0.31	155.25	80.060	0.31	204.60	68	80.599	0.40	82.64	81.879	0.43	277.46
24	80.125	0.31	144.04	79.888	0.29	216.10	70	80.049	0.42	81.01	81.418	0.42	279.05
26	80.362	0.31	136.34	80.461	0.32	223.92	72	79.834	0.46	79.48	80.285	0.45	280.62
28	80.342	0.31	130.31	80.337	0.32	229.79	74	79.483	0.50	77.92	79.535	0.50	282.19
30	80.637	0.33	125.35	80.336	0.31	234.72	76	79.303	0.56	76.35	79.369	0.56	283.81
32	80.345	0.31	121.21	80.461	0.33	238.67	78	79.591	N/A	74.73	79.410	N/A	285.43
34	80.827	0.34	117.29	81.119	0.32	242.36	80	80.736	N/A	73.07	N/A	N/A	N/A
36	80.857	0.31	114.34	80.845	0.31	245.75	82	83.032	N/A	71.43	83.162	N/A	288.71
38	80.867	0.32	111.52	80.765	0.31	248.64	84	88.357	N/A	69.74	87.112	N/A	290.41
40	81.008	0.30	108.76	80.919	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	80.954	0.32	106.26	81.285	0.32	253.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	81.332	0.33	103.99	81.178	0.37	256.12	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

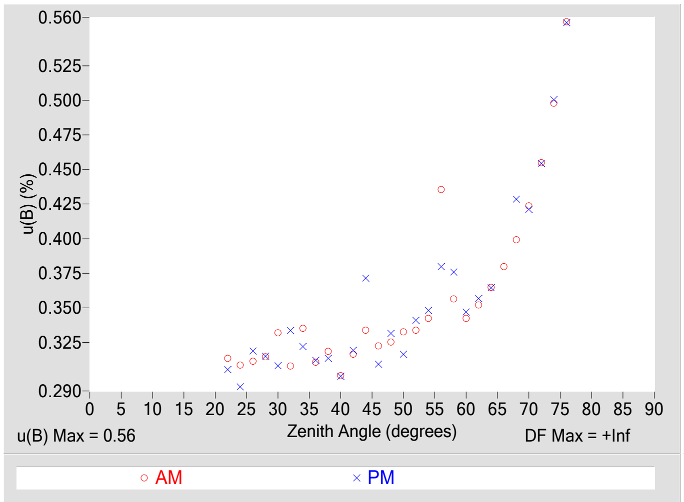


Figure 4. Residuals from Spline Interpolation

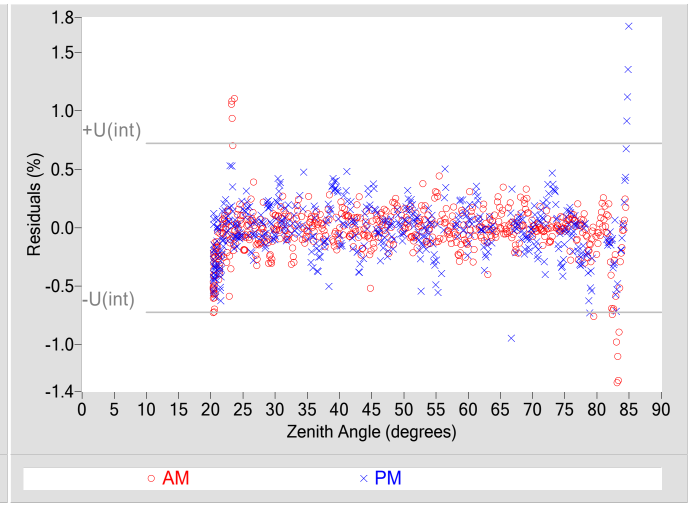


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.36
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	11297
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

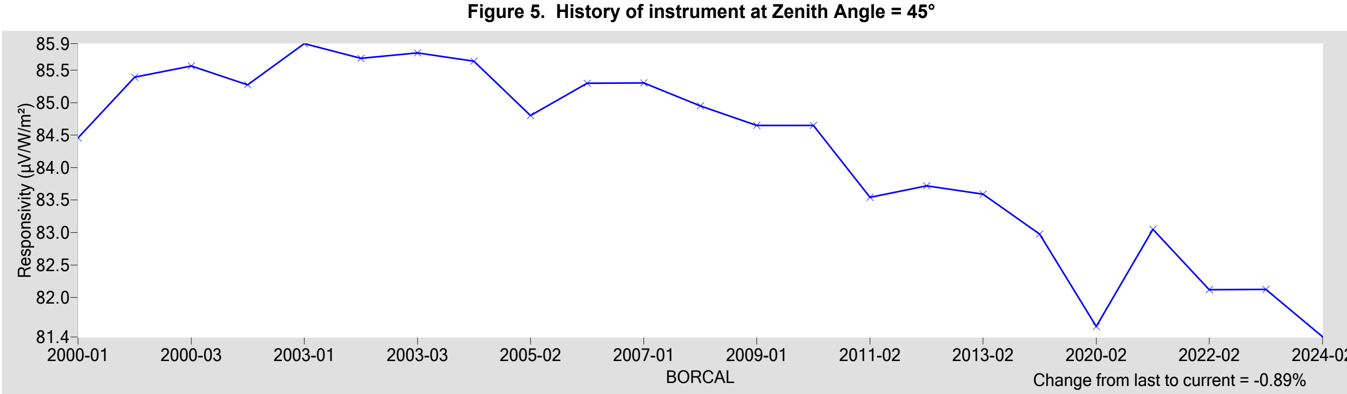
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
81.395	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+0.42 / -1.3
Expanded Uncertainty, U (%)	+1.3 / -2.2
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 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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[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:	Sunshine Pyranometer - Global Output	**Manufacturer:**	Delta-T
Model:	SPN1	**Serial Number:**	A360
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

______________________________ 05/21/2024

Ibrahim Reda, 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

A360 Delta-T SPN1

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

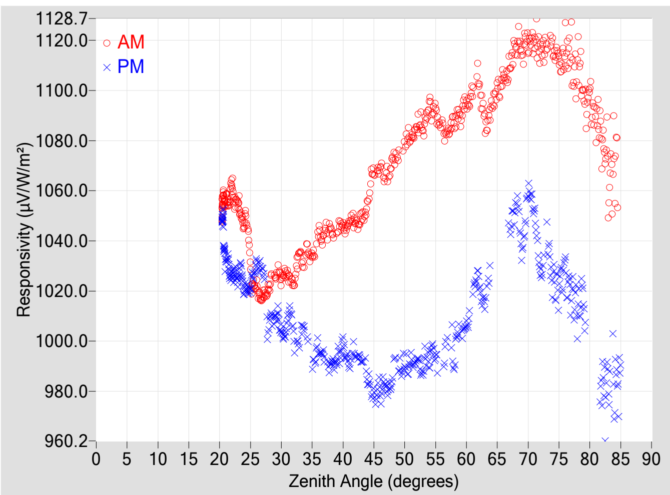


Figure 2. Responsivity vs Local Standard Time

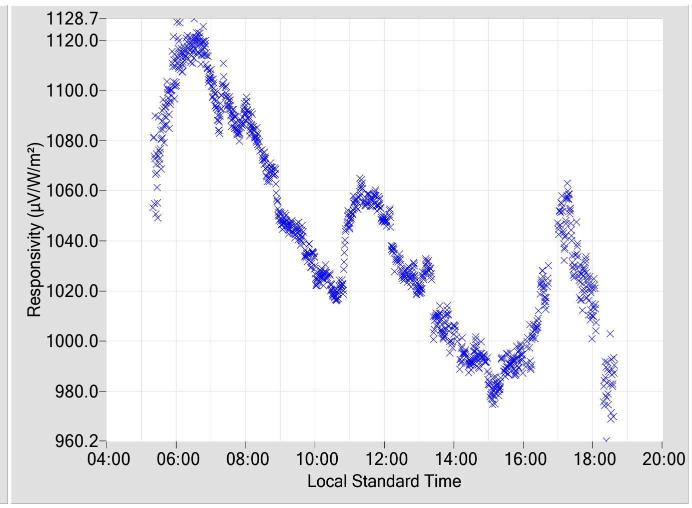


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	1068.9	0.31	101.79	980.48	0.32	258.27
2	N/A	N/A	N/A	N/A	N/A	N/A	48	1072.5	0.31	99.74	985.90	0.36	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	1078.9	0.31	97.80	991.70	0.35	262.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	1085.6	0.37	95.94	992.69	0.35	264.20
8	N/A	N/A	N/A	N/A	N/A	N/A	54	1094.5	0.32	94.16	993.19	0.38	265.96
10	N/A	N/A	N/A	N/A	N/A	N/A	56	1086.8	0.40	92.41	989.86	0.34	267.97
12	N/A	N/A	N/A	N/A	N/A	N/A	58	1087.6	0.35	90.69	992.25	0.34	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	1094.9	0.34	89.06	1006.3	0.35	271.10
16	N/A	N/A	N/A	N/A	N/A	N/A	62	1103.5	0.42	87.43	1024.0	0.38	272.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	1092.8	0.39	85.80	1030.2	0.36	274.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	1105.3	0.38	84.24	N/A	N/A	N/A
22	1060.8	0.34	155.52	1026.0	0.32	204.90	68	1116.3	0.40	82.65	1053.2	0.43	277.47
24	1048.0	0.30	144.07	1021.0	0.30	216.14	70	1118.7	0.42	81.07	1058.6	0.42	279.06
26	1020.9	0.31	136.20	1029.9	0.33	223.69	72	1115.1	0.45	79.49	1028.0	0.49	280.63
28	1021.0	0.30	130.34	1006.1	0.32	229.85	74	1116.9	0.50	77.93	1025.5	0.50	282.20
30	1025.1	0.31	125.38	1003.8	0.30	234.74	76	1114.7	0.56	76.32	1028.4	0.56	283.82
32	1023.2	0.31	121.24	1002.2	0.33	238.79	78	1107.1	N/A	74.75	1013.9	N/A	285.40
34	1035.3	0.34	117.56	1003.8	0.30	242.47	80	1097.9	N/A	73.12	N/A	N/A	N/A
36	1042.9	0.30	114.31	996.96	0.33	245.75	82	1079.8	N/A	71.44	982.68	N/A	288.72
38	1044.8	0.31	111.46	990.71	0.31	248.66	84	1073.2	N/A	69.75	984.22	N/A	290.38
40	1045.7	0.33	108.74	997.90	0.31	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	1047.5	0.32	106.27	994.09	0.31	253.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	1054.3	0.32	104.04	984.80	0.34	256.14	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

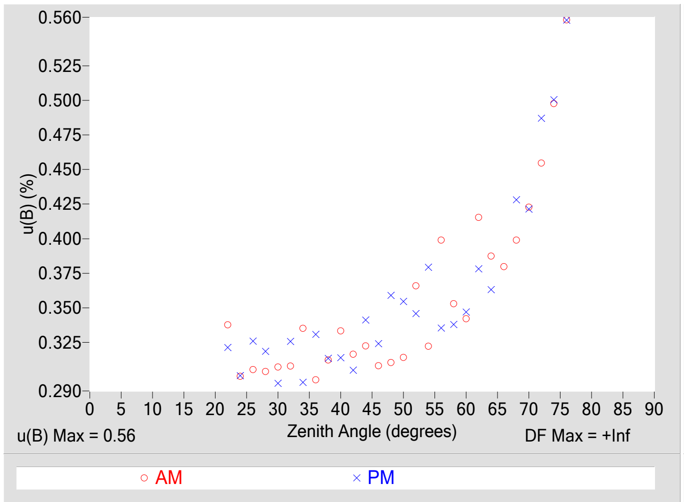


Figure 4. Residuals from Spline Interpolation

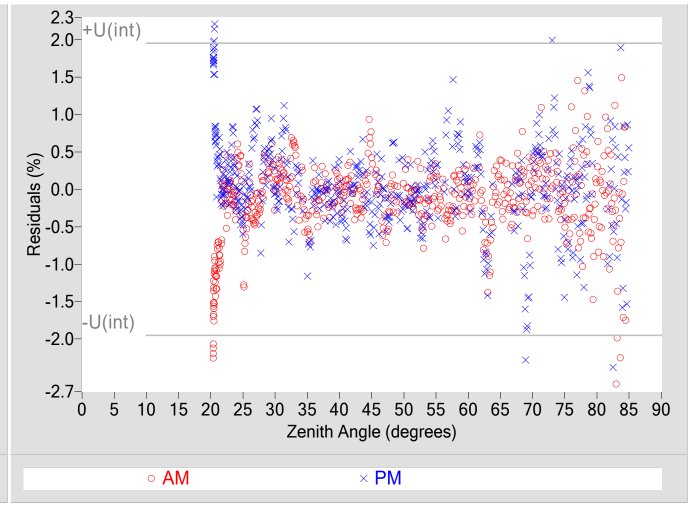


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.98
Combined Standard Uncertainty, u(c) (%)	±1.1
Effective degrees of freedom, DF(c)	1739
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±2.2
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

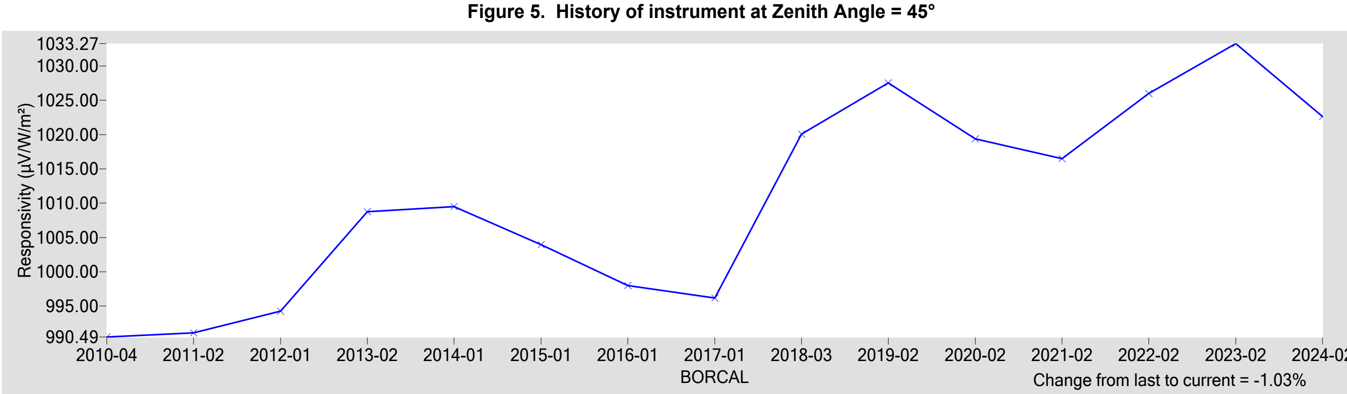
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
1022.7	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+7.1 / -4.1
Expanded Uncertainty, U (%)	+7.8 / -4.9
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

[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: EKO
Model: MS-802
Serial Number: F14077R
Calibration Date: 5/16/2024
Due Date: 5/16/2025
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/16

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager   05/21/2024
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

F14077R EKO MS-802

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 - 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

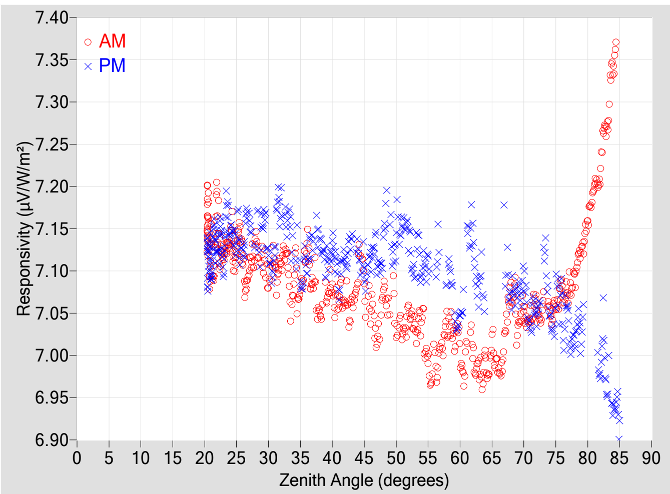


Figure 2. Responsivity vs Local Standard Time

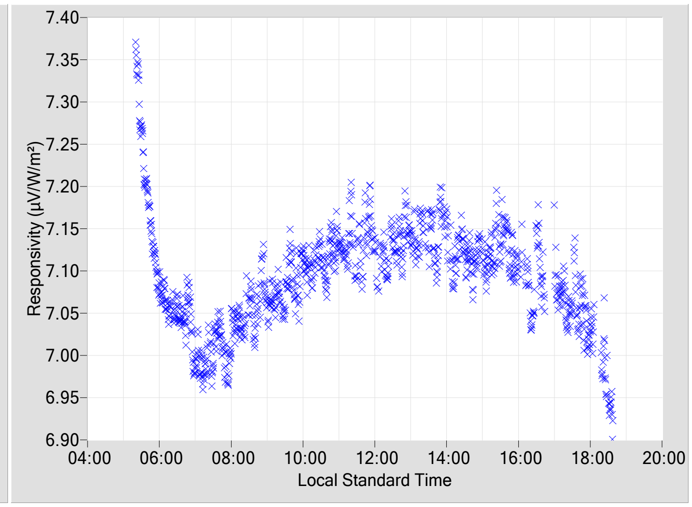


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.0599	0.39	101.83	7.1162	0.35	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.0761	0.32	99.77	7.1345	0.32	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.0295	0.35	97.78	7.1475	0.33	262.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.0507	0.33	95.92	7.1418	0.33	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.0447	0.39	94.14	7.0997	0.34	265.98
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.0012	0.41	92.34	7.0930	0.46	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.0358	0.37	90.72	7.0970	0.35	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.0063	0.40	89.04	7.0466	0.37	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.0069	0.42	87.41	7.1426	0.38	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9892	0.39	85.83	7.0519	0.39	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.9857	0.40	84.22	N/A	N/A	N/A
22	7.1591	0.33	155.35	7.1213	0.32	204.67	68	7.0703	0.42	82.63	7.0730	0.45	277.50
24	7.1407	0.32	143.86	7.1454	0.31	216.26	70	7.0552	0.45	81.09	7.0889	0.45	279.04
26	7.1097	0.32	136.18	7.1250	0.34	224.11	72	7.0597	0.49	79.52	7.0499	0.49	280.65
28	7.1264	0.31	130.29	7.1489	0.30	229.76	74	7.0548	0.54	77.91	7.0519	0.55	282.23
30	7.0921	0.31	125.33	7.1179	0.32	234.70	76	7.0788	0.60	76.34	7.0495	0.62	283.80
32	7.1131	0.31	121.20	7.1696	0.30	238.74	78	7.0960	N/A	74.72	7.0207	N/A	285.42
34	7.0948	0.30	117.52	7.1269	0.30	242.52	80	7.1592	N/A	73.10	N/A	N/A	N/A
36	7.1225	0.32	114.40	7.1077	0.32	245.81	82	7.2190	N/A	71.47	6.9861	N/A	288.70
38	7.0498	0.35	111.36	7.1357	0.31	248.71	84	7.3425	N/A	69.78	6.9386	N/A	290.40
40	7.0732	0.36	108.75	7.1265	0.31	251.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0666	0.31	106.32	7.1132	0.33	253.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.1000	0.35	103.98	7.1241	0.36	256.11	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

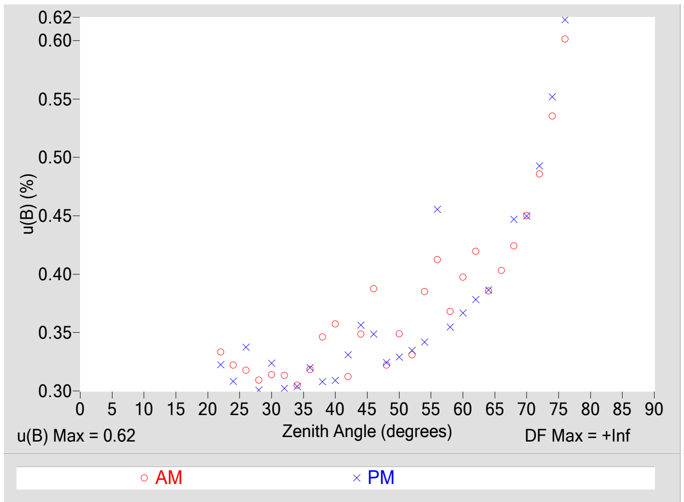


Figure 4. Residuals from Spline Interpolation

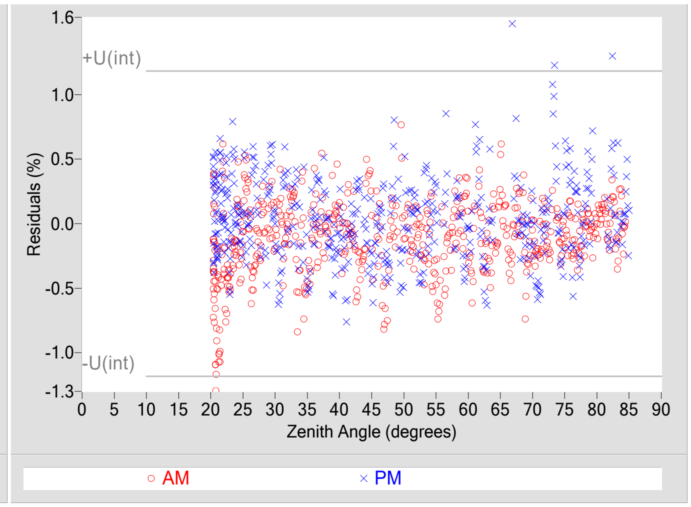


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.59
Combined Standard Uncertainty, u(c) (%)	±0.86
Effective degrees of freedom, DF(c)	4363
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.7
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

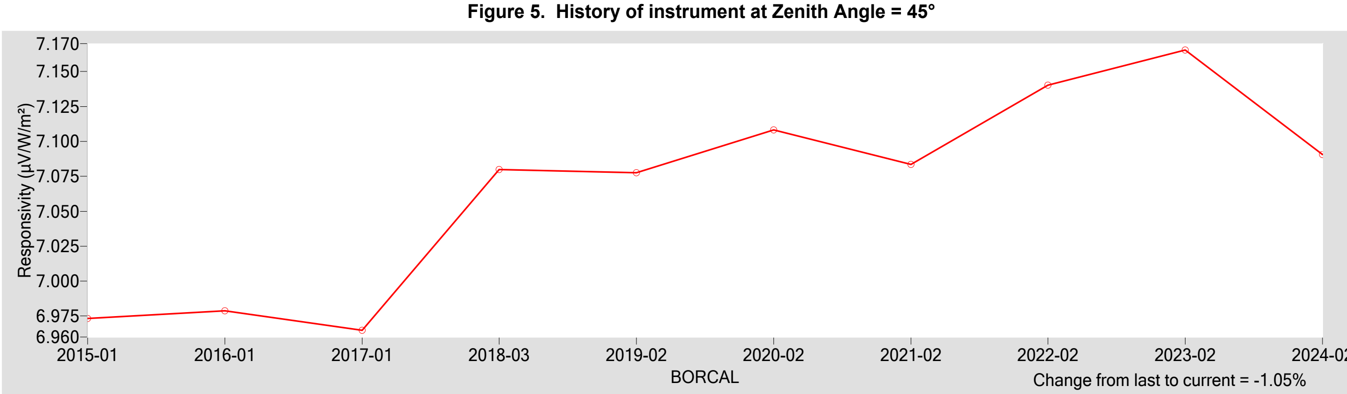
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.0906	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+1.1 / -1.3
Expanded Uncertainty, U (%)	+2.0 / -2.2
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:	Revised Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200R	**Serial Number:**	PY100360
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

PY100360 Licor LI200R

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

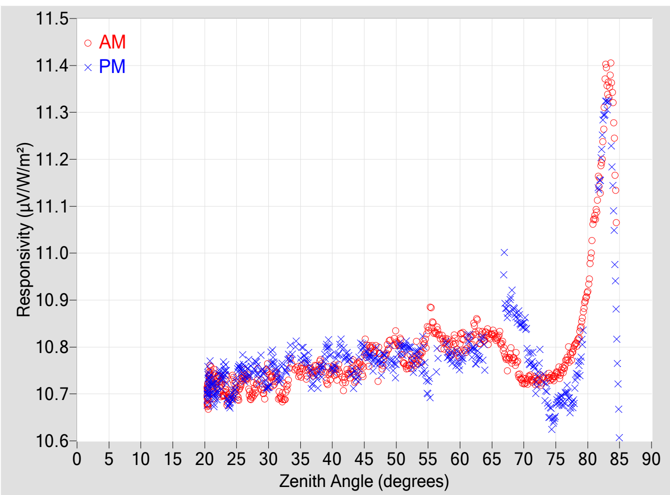


Figure 2. Responsivity vs Local Standard Time

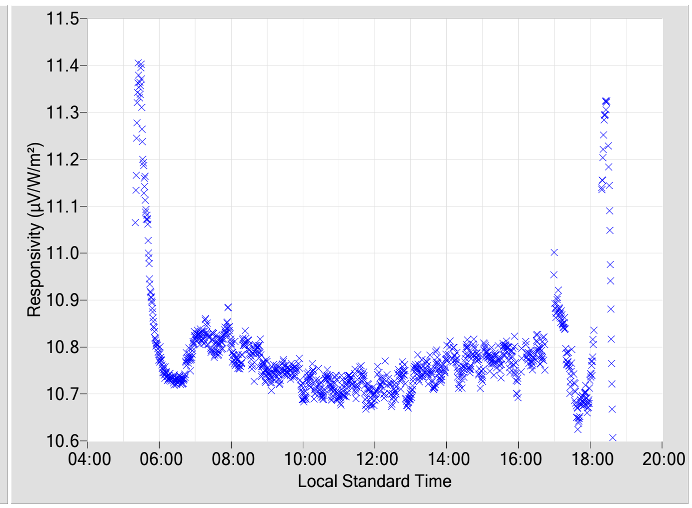


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.800	0.36	101.79	10.778	0.31	258.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.767	0.33	99.79	10.781	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.814	0.35	97.83	10.759	0.34	262.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.763	0.32	95.93	10.797	0.36	264.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.786	0.34	94.16	10.782	0.36	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.835	0.35	92.37	10.747	0.34	267.96
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.808	0.34	90.69	10.792	0.34	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.806	0.35	89.05	10.771	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.826	0.36	87.42	10.793	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.826	0.37	85.80	10.778	0.43	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.823	0.41	84.23	N/A	N/A	N/A
22	10.730	0.33	155.41	10.713	0.30	204.16	68	10.779	0.40	82.64	10.896	0.40	277.46
24	10.695	0.31	144.06	10.684	0.30	216.27	70	10.727	0.43	81.06	10.848	0.43	279.05
26	10.735	0.29	136.36	10.744	0.33	223.82	72	10.726	0.46	79.49	10.731	0.46	280.62
28	10.713	0.32	130.32	10.759	0.32	229.80	74	10.736	0.51	77.93	10.666	0.51	282.20
30	10.742	0.33	125.36	10.722	0.32	234.73	76	10.749	0.57	76.36	10.685	0.57	283.81
32	10.692	0.30	121.22	10.744	0.31	238.77	78	10.804	N/A	74.74	10.715	N/A	285.44
34	10.751	0.30	117.38	10.793	0.30	242.46	80	10.921	N/A	73.11	N/A	N/A	N/A
36	10.748	0.31	114.35	10.773	0.33	245.80	82	11.168	N/A	71.44	11.187	N/A	288.71
38	10.757	0.33	111.46	10.746	0.31	248.65	84	11.286	N/A	69.75	11.088	N/A	290.42
40	10.753	0.33	108.73	10.759	0.32	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.730	0.30	106.31	10.783	0.31	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.754	0.34	104.00	10.744	0.31	256.12	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

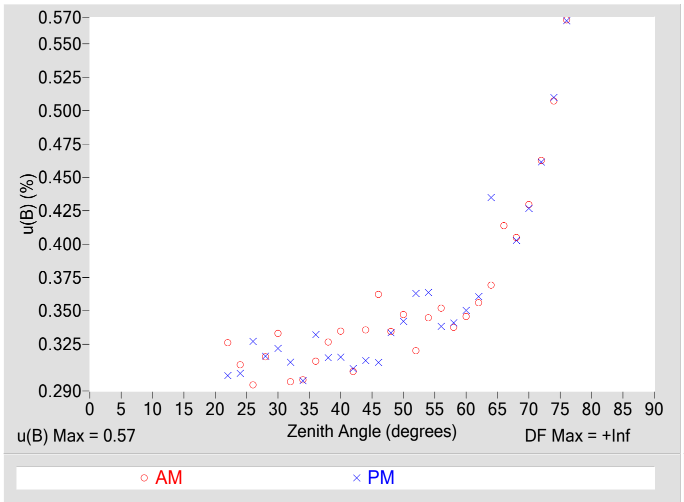


Figure 4. Residuals from Spline Interpolation

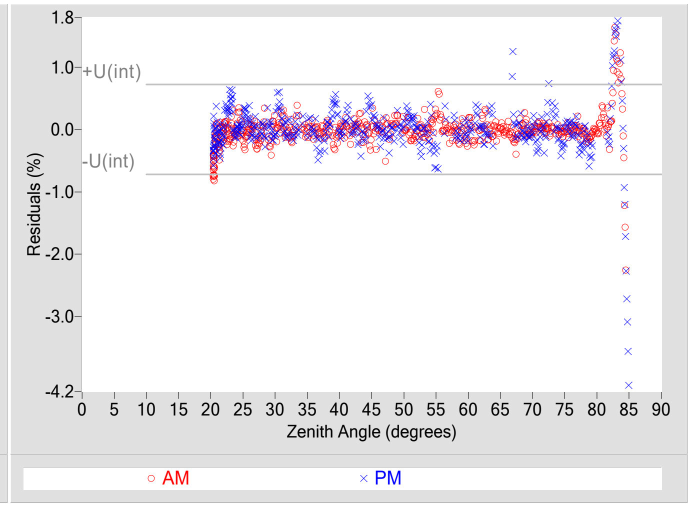


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.36
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	12008
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

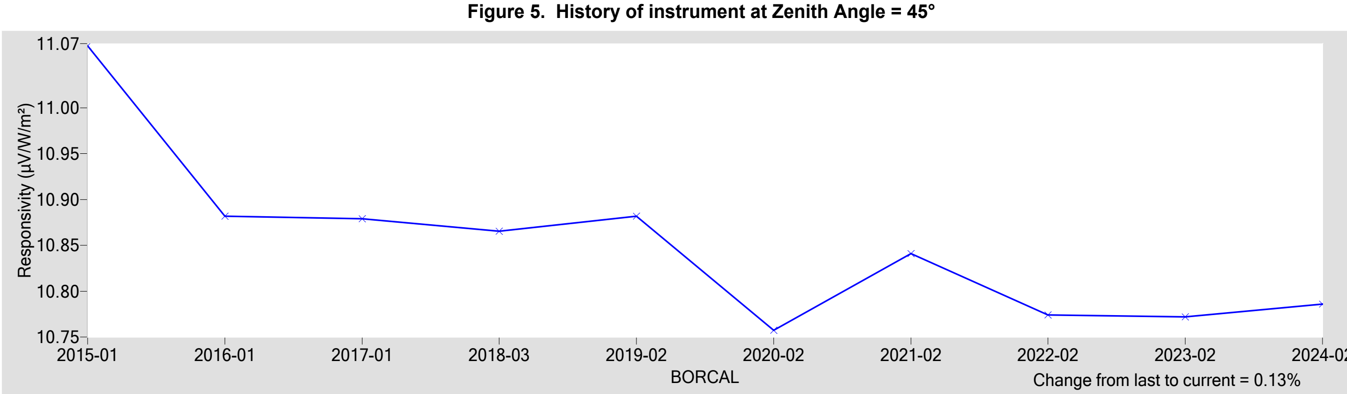
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.786	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.45 / -0.87
Expanded Uncertainty, U (%)	+1.2 / -1.6
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: Revised Silicon Pyranometer

Manufacturer: Licor

Model: LI200R

Serial Number: PY108623

Calibration Date: 5/16/2024

Due Date: 5/16/2025

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/16

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

________________________ 05/21/2024

Ibrahim Reda, 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

PY108623 Licor LI200R

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

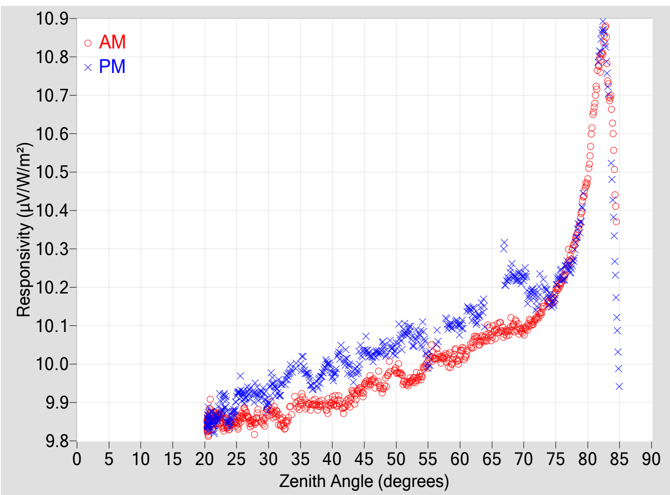


Figure 2. Responsivity vs Local Standard Time

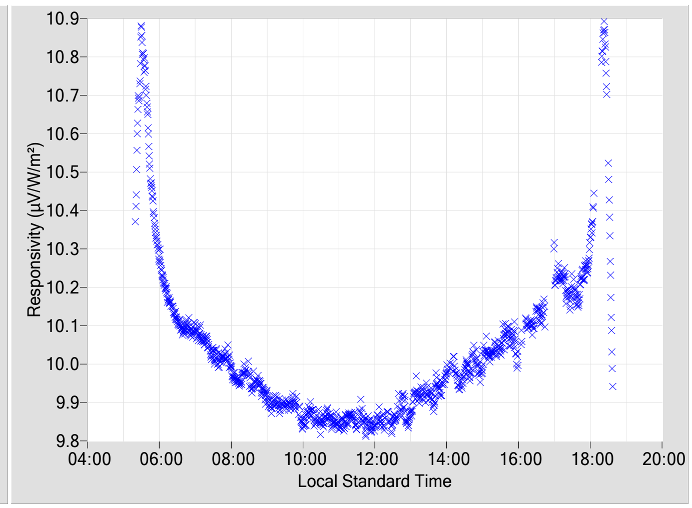


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.9574	0.36	101.79	10.020	0.31	258.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.9353	0.33	99.79	10.048	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.9816	0.35	97.83	10.039	0.34	262.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.9538	0.32	95.93	10.090	0.36	264.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.9727	0.35	94.16	10.075	0.36	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.017	0.35	92.37	10.051	0.34	267.96
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.013	0.34	90.69	10.106	0.34	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.021	0.35	89.05	10.095	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.054	0.36	87.42	10.133	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.072	0.37	85.80	10.123	0.44	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.094	0.41	84.23	N/A	N/A	N/A
22	9.8659	0.33	155.41	9.8640	0.30	204.16	68	10.098	0.41	82.64	10.240	0.40	277.46
24	9.8409	0.31	144.06	9.8518	0.30	216.27	70	10.087	0.43	81.06	10.231	0.43	279.05
26	9.8673	0.29	136.36	9.9159	0.32	223.80	72	10.122	0.46	79.49	10.166	0.46	280.62
28	9.8497	0.32	130.32	9.9252	0.32	229.80	74	10.163	0.51	77.93	10.170	0.51	282.20
30	9.8774	0.33	125.36	9.9049	0.32	234.73	76	10.217	0.57	76.36	10.227	0.57	283.81
32	9.8489	0.30	121.22	9.9369	0.31	238.77	78	10.321	N/A	74.74	10.303	N/A	285.44
34	9.9157	0.30	117.38	9.9840	0.30	242.46	80	10.487	N/A	73.11	N/A	N/A	N/A
36	9.8948	0.31	114.35	9.9751	0.33	245.80	82	10.791	N/A	71.44	10.835	N/A	288.71
38	9.8915	0.33	111.46	9.9580	0.32	248.65	84	10.566	N/A	69.75	10.379	N/A	290.42
40	9.8997	0.34	108.73	9.9713	0.32	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8902	0.30	106.31	10.013	0.31	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.9272	0.34	104.00	9.9936	0.31	256.12	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

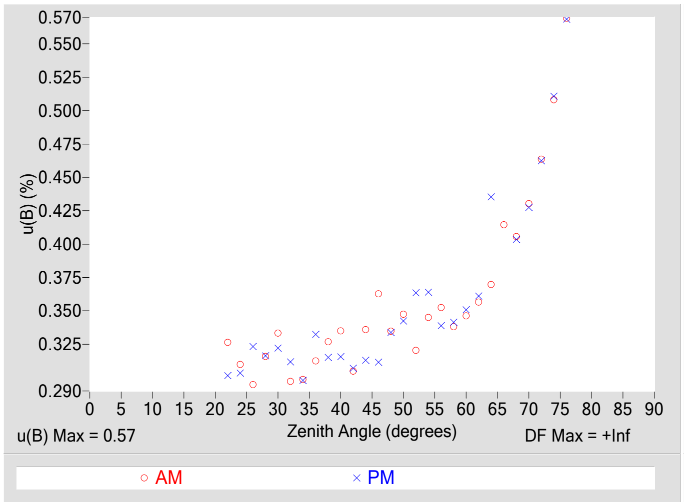


Figure 4. Residuals from Spline Interpolation

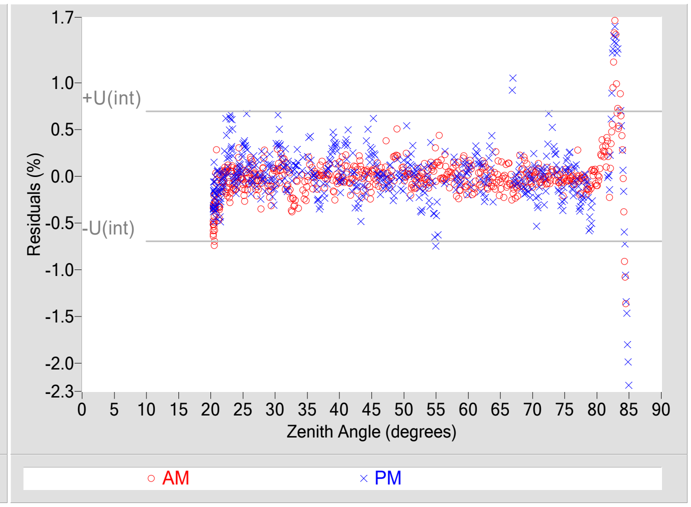


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.35
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	13441
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

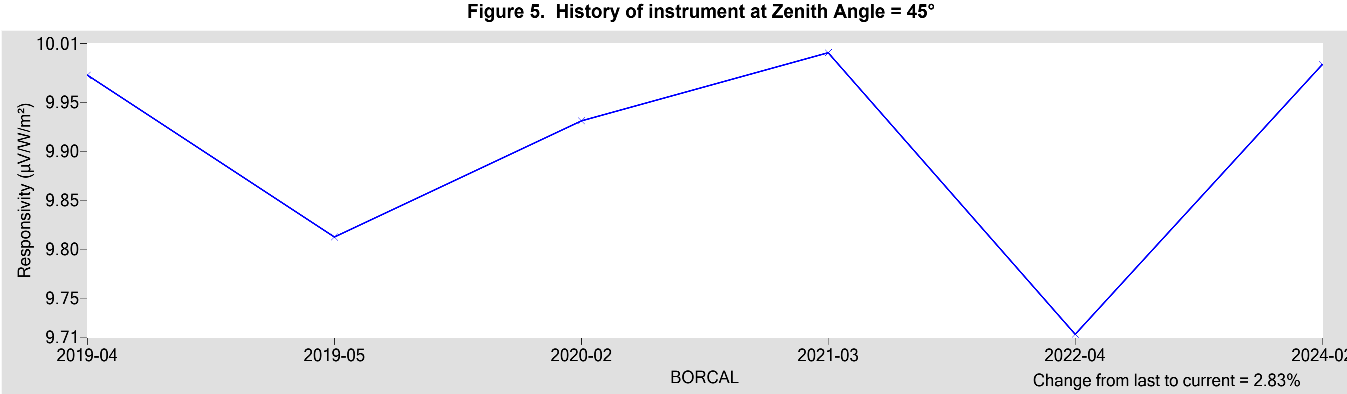
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.9883	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.2 / -1.4
Expanded Uncertainty, U (%)	+1.9 / -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

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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.

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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).

National Renewable Energy Laboratory
Solar Radiation Research Laboratory
Metrology Laboratory
Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY28257
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

PY28257 Licor LI200

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

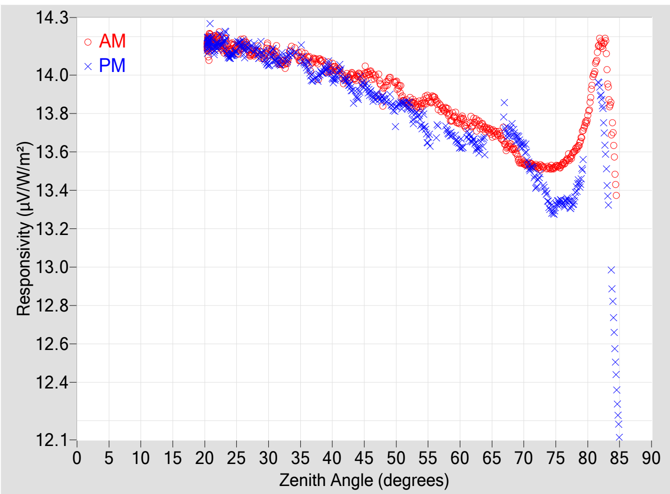


Figure 2. Responsivity vs Local Standard Time

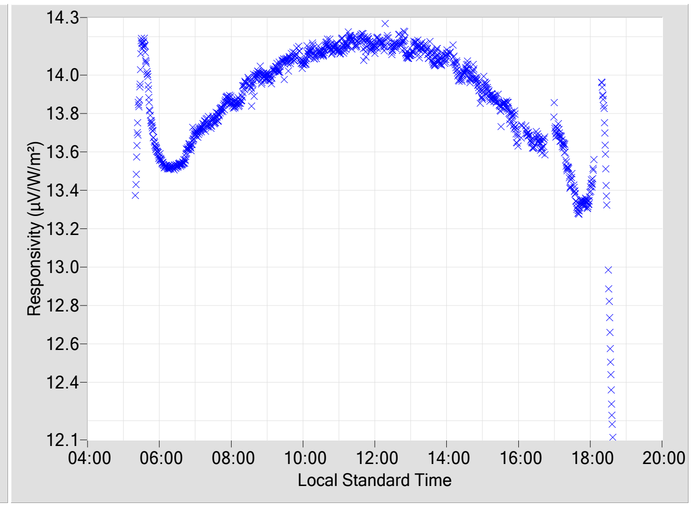


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	14.006	0.36	101.79	13.901	0.31	258.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.905	0.33	99.79	13.881	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.955	0.35	97.83	13.804	0.34	262.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.854	0.32	95.93	13.839	0.36	264.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.848	0.34	94.16	13.763	0.36	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	13.877	0.35	92.37	13.673	0.34	267.96
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.812	0.34	90.69	13.710	0.34	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.764	0.34	89.05	13.635	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.753	0.35	87.42	13.660	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.721	0.37	85.80	13.630	0.43	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	13.695	0.41	84.23	N/A	N/A	N/A
22	14.190	0.33	155.41	14.158	0.30	204.16	68	13.628	0.40	82.64	13.712	0.40	277.46
24	14.133	0.31	144.06	14.098	0.30	216.27	70	13.539	0.43	81.06	13.629	0.42	279.05
26	14.158	0.29	136.36	14.137	0.32	223.80	72	13.525	0.46	79.49	13.438	0.46	280.62
28	14.116	0.32	130.32	14.135	0.32	229.80	74	13.519	0.50	77.93	13.325	0.51	282.20
30	14.140	0.33	125.36	14.066	0.32	234.73	76	13.533	0.56	76.36	13.334	0.56	283.81
32	14.062	0.30	121.22	14.082	0.31	238.77	78	13.608	N/A	74.74	13.374	N/A	285.44
34	14.142	0.30	117.38	14.109	0.30	242.46	80	13.782	N/A	73.11	N/A	N/A	N/A
36	14.085	0.31	114.35	14.051	0.33	245.80	82	14.165	N/A	71.44	13.900	N/A	288.71
38	14.075	0.33	111.41	14.002	0.31	248.65	84	13.639	N/A	69.75	12.736	N/A	290.42
40	14.040	0.33	108.73	13.989	0.31	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	13.984	0.30	106.31	13.979	0.31	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	13.996	0.34	104.00	13.893	0.31	256.12	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

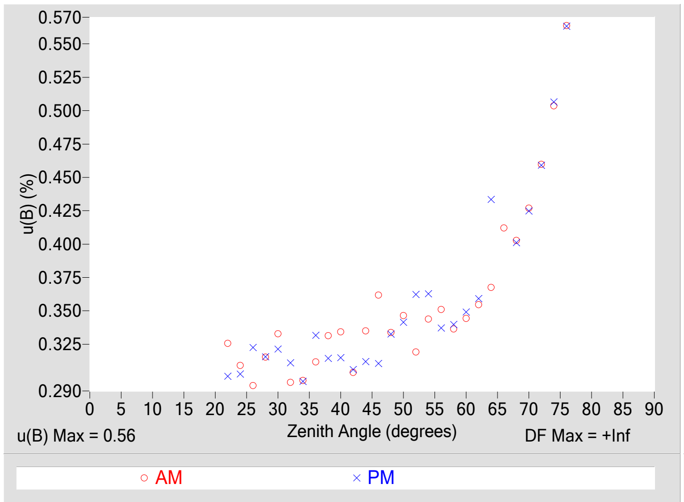


Figure 4. Residuals from Spline Interpolation

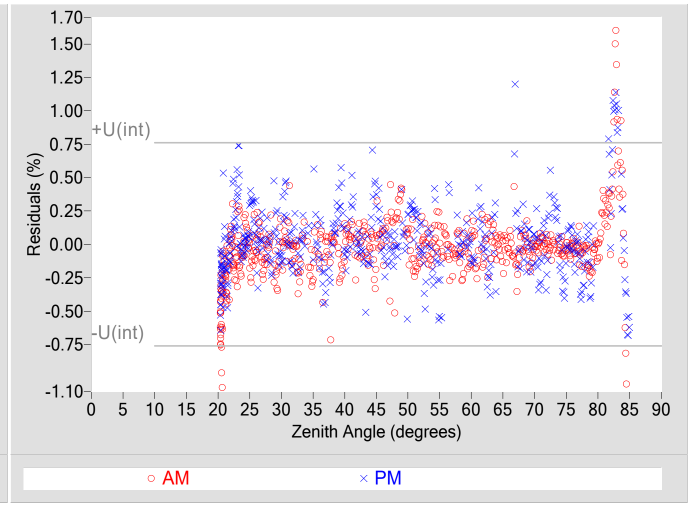


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.38
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	10144
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

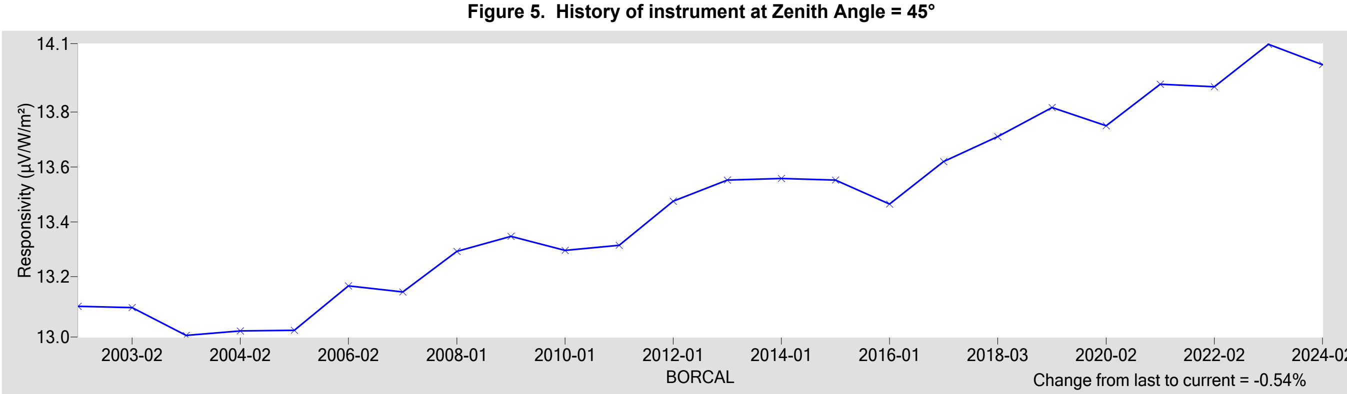
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
13.973	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.2 / -2.4
Expanded Uncertainty, U (%)	+1.9 / -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:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY66489
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

PY66489 Licor LI200

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

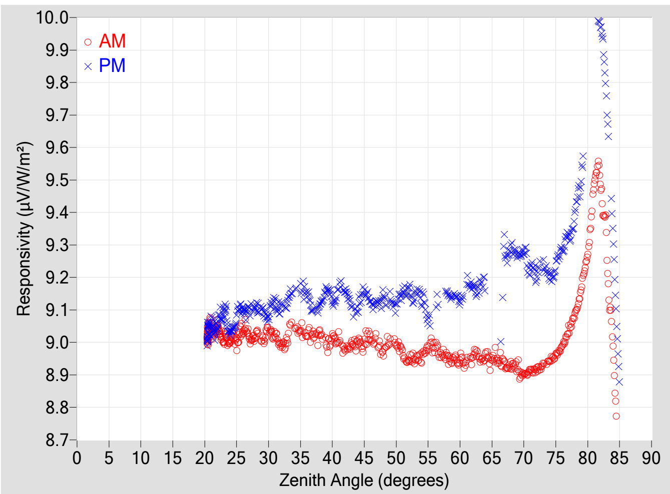


Figure 2. Responsivity vs Local Standard Time

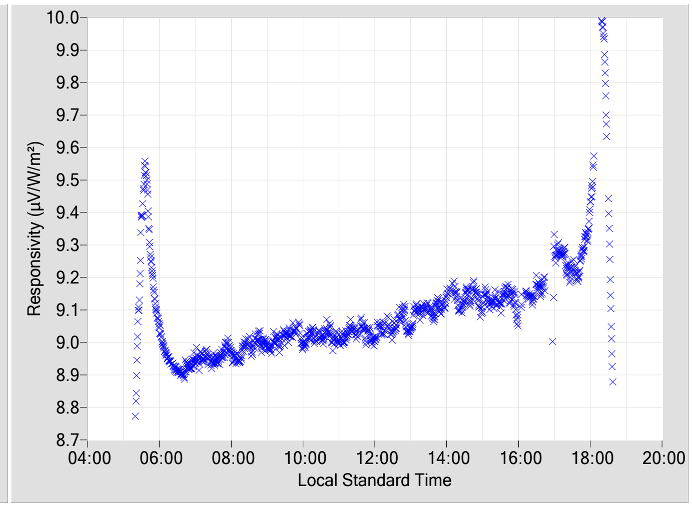


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.0106	0.36	101.79	9.1225	0.31	258.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9701	0.34	99.79	9.1434	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9944	0.35	97.83	9.1118	0.34	262.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9459	0.32	95.93	9.1620	0.36	264.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9548	0.35	94.16	9.1370	0.36	265.95
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9870	0.35	92.37	9.1075	0.34	267.96
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9545	0.34	90.69	9.1523	0.34	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9462	0.35	89.05	9.1295	0.35	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9554	0.36	87.42	9.1740	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9584	0.37	85.80	9.1801	0.44	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9423	0.42	84.23	N/A	N/A	N/A
22	9.0427	0.33	155.41	9.0554	0.30	204.16	68	8.9275	0.41	82.64	9.2863	0.40	277.46
24	9.0034	0.31	144.06	9.0322	0.30	216.27	70	8.9025	0.43	81.06	9.2821	0.43	279.05
26	9.0331	0.30	136.36	9.0987	0.32	223.80	72	8.9164	0.47	79.49	9.2058	0.46	280.62
28	9.0214	0.32	130.32	9.1057	0.32	229.80	74	8.9448	0.51	77.93	9.2072	0.51	282.20
30	9.0397	0.33	125.36	9.0824	0.32	234.73	76	8.9878	0.57	76.36	9.2857	0.57	283.81
32	8.9919	0.30	121.22	9.1093	0.31	238.77	78	9.0874	N/A	74.74	9.3998	N/A	285.44
34	9.0427	0.30	117.38	9.1571	0.30	242.46	80	9.2723	N/A	73.11	N/A	N/A	N/A
36	9.0242	0.31	114.35	9.1516	0.33	245.80	82	9.4858	N/A	71.44	9.9676	N/A	288.71
38	9.0279	0.32	111.38	9.1128	0.32	248.65	84	8.9592	N/A	69.75	9.2998	N/A	290.42
40	9.0169	0.34	108.73	9.1312	0.32	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9821	0.31	106.31	9.1579	0.31	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9997	0.34	104.00	9.1082	0.31	256.12	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

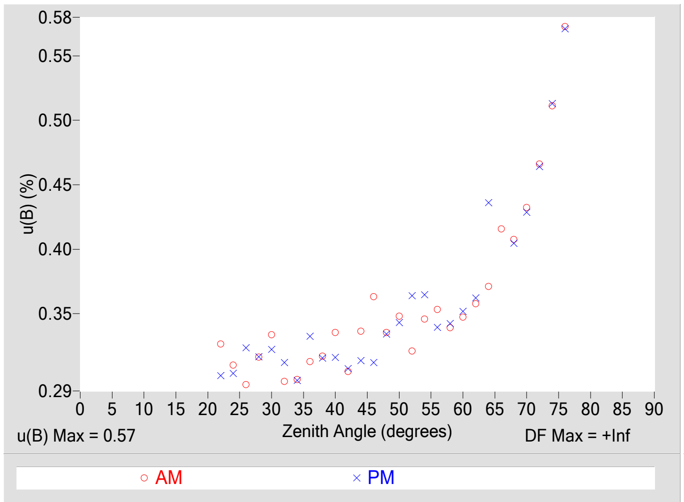


Figure 4. Residuals from Spline Interpolation

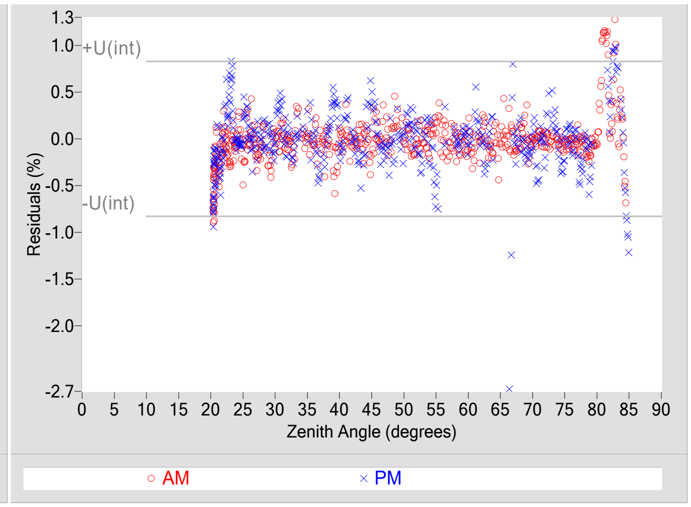


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.41
Combined Standard Uncertainty, u(c) (%)	±0.71
Effective degrees of freedom, DF(c)	8460
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

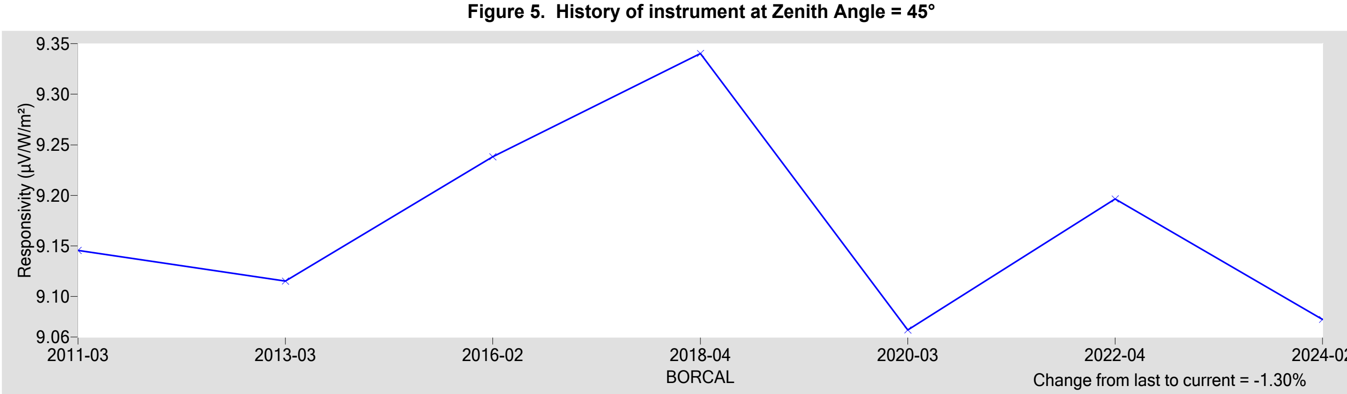
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0774	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.93 / -1.4
Expanded Uncertainty, U (%)	+1.6 / -2.2
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

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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

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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:	Semiconductor Pyrheliometer	**Manufacturer:**	Licor
Model:	LI201SB	**Serial Number:**	PYHR101
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

PYHR101 Licor LI201SB

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

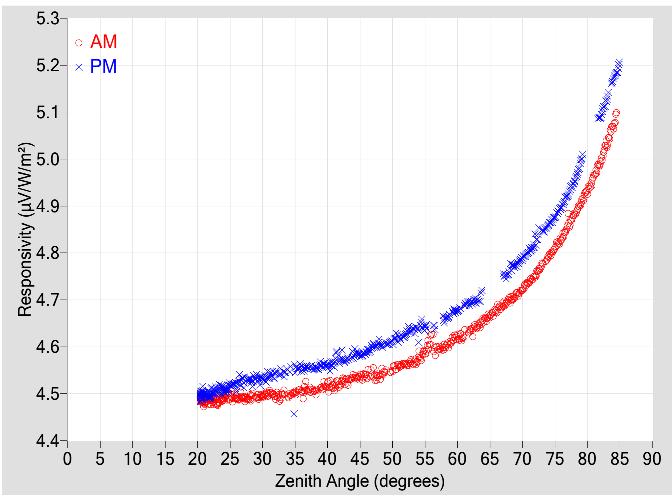


Figure 2. Responsivity vs Local Standard Time

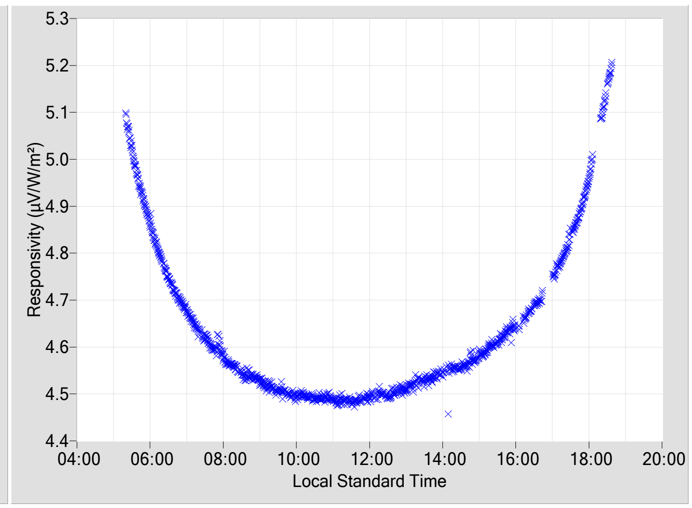


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	4.5403	0.32	101.79	4.5894	0.33	258.26
2	N/A	N/A	N/A	N/A	N/A	N/A	48	4.5386	0.31	99.74	4.6067	0.31	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	4.5529	0.33	97.78	4.6111	0.30	262.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	4.5633	0.30	95.94	4.6264	0.30	264.17
8	N/A	N/A	N/A	N/A	N/A	N/A	54	4.5762	0.31	94.16	4.6346	0.30	265.92
10	N/A	N/A	N/A	N/A	N/A	N/A	56	4.6203	0.31	92.40	4.6446	0.30	267.97
12	N/A	N/A	N/A	N/A	N/A	N/A	58	4.5990	0.32	90.69	4.6588	0.30	269.40
14	N/A	N/A	N/A	N/A	N/A	N/A	60	4.6216	0.30	89.05	4.6772	0.32	271.09
16	N/A	N/A	N/A	N/A	N/A	N/A	62	4.6350	0.31	87.43	4.6935	0.31	272.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	4.6568	0.30	85.80	4.7203	0.30	274.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	4.6788	0.33	84.24	N/A	N/A	N/A
22	4.4865	0.33	155.42	4.4997	0.33	204.66	68	4.7006	0.31	82.65	4.7620	0.32	277.46
24	4.4890	0.31	144.06	4.5078	0.30	216.13	70	4.7208	0.31	81.06	4.7891	0.31	279.05
26	4.4907	0.32	136.36	4.5180	0.32	223.68	72	4.7526	0.31	79.49	4.8244	0.32	280.63
28	4.4901	0.30	130.33	4.5290	0.31	229.81	74	4.7916	0.32	77.93	4.8598	0.32	282.20
30	4.4949	0.29	125.37	4.5332	0.31	234.74	76	4.8298	0.32	76.36	4.8988	0.32	283.82
32	4.4956	0.29	121.23	4.5422	0.30	238.78	78	4.8817	N/A	74.74	4.9540	N/A	285.44
34	4.4946	0.33	117.55	4.5497	0.33	242.46	80	4.9325	N/A	73.12	N/A	N/A	N/A
36	4.5020	0.31	114.31	4.5557	0.34	245.81	82	4.9927	N/A	71.44	5.0914	N/A	288.71
38	4.5048	0.29	111.46	4.5535	0.30	248.66	84	5.0709	N/A	69.75	5.1687	N/A	290.38
40	4.5162	0.29	108.74	4.5603	0.30	251.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	4.5204	0.30	106.27	4.5745	0.33	253.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	4.5346	0.34	104.01	4.5840	0.32	256.13	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

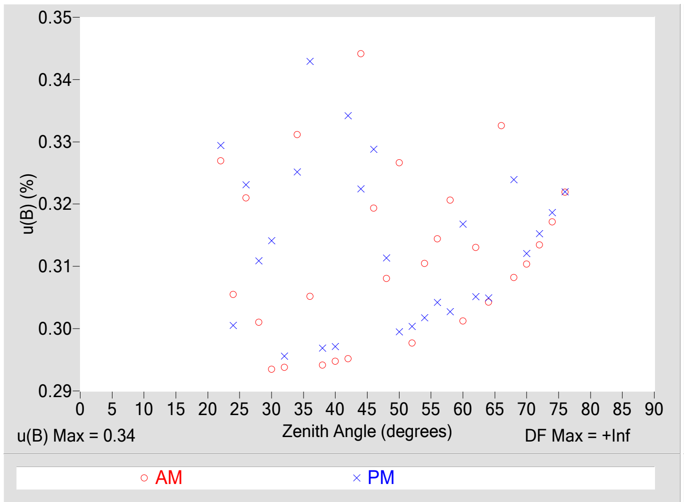


Figure 4. Residuals from Spline Interpolation

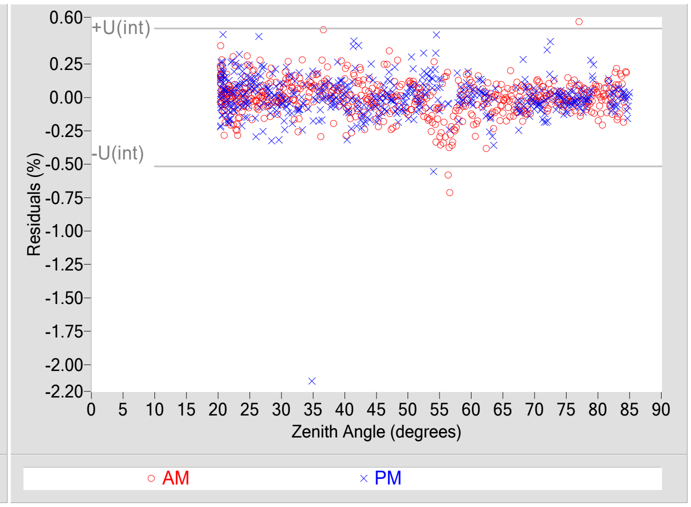


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.43
Effective degrees of freedom, DF(c)	7707
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.84
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

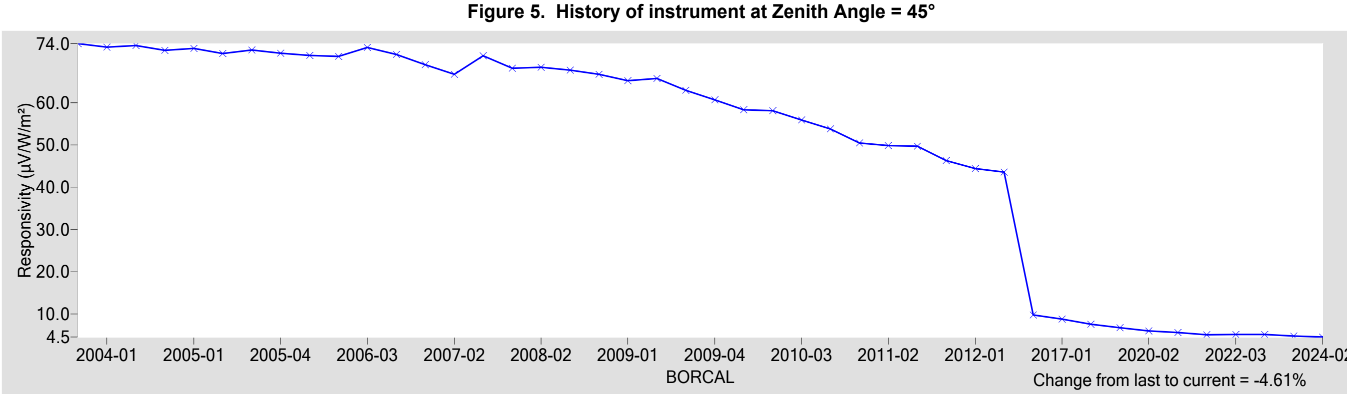
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
4.5596	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+2.6 / -1.4
Expanded Uncertainty, U (%)	+3.3 / -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	**Manufacturer:**	EKO
Model:	MS-602	**Serial Number:**	S13071483
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager　　05/21/2024 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

S13071483 EKO MS-602

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

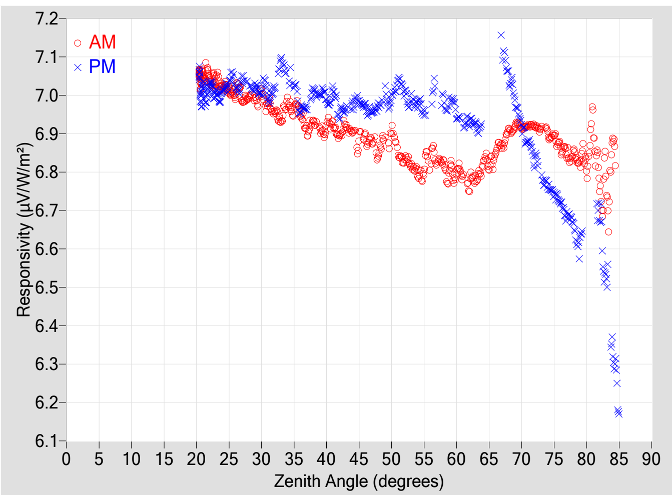


Figure 2. Responsivity vs Local Standard Time

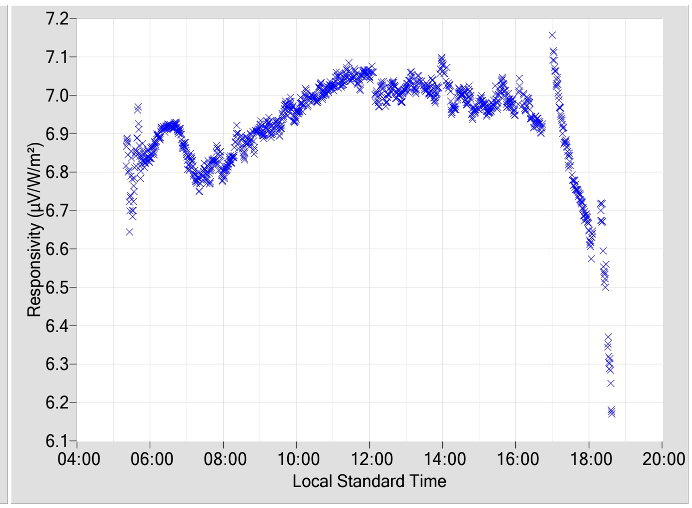


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	6.8860	0.40	101.83	6.9662	0.36	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.8459	0.34	99.77	6.9718	0.34	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.9062	0.36	97.78	6.9956	0.34	262.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.8321	0.35	95.92	7.0102	0.35	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.7986	0.40	94.14	6.9810	0.36	265.98
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.8296	0.43	92.34	6.9766	0.47	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.8214	0.38	90.72	6.9876	0.37	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.7973	0.41	89.04	6.9505	0.39	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.7711	0.44	87.41	6.9311	0.40	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.8124	0.41	85.83	6.9251	0.41	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.8475	0.42	84.22	N/A	N/A	N/A
22	7.0461	0.34	155.35	7.0230	0.33	204.67	68	6.9078	0.45	82.63	7.0447	0.47	277.50
24	7.0240	0.33	143.86	7.0112	0.32	216.26	70	6.9170	0.47	81.09	6.9221	0.48	279.04
26	7.0072	0.32	136.18	7.0220	0.34	224.11	72	6.9197	0.51	79.52	6.8343	0.53	280.65
28	6.9937	0.32	130.29	7.0307	0.31	229.76	74	6.9025	0.57	77.91	6.7652	0.61	282.23
30	7.0039	0.32	125.33	7.0122	0.33	234.70	76	6.8637	0.64	76.34	6.7188	0.69	283.80
32	6.9570	0.32	121.20	7.0172	0.31	238.74	78	6.8474	N/A	74.72	6.6601	N/A	285.42
34	6.9768	0.31	117.52	7.0472	0.31	242.52	80	6.8152	N/A	73.10	N/A	N/A	N/A
36	6.9551	0.33	114.40	6.9625	0.33	245.81	82	6.7805	N/A	71.47	6.6962	N/A	288.70
38	6.9288	0.35	111.36	7.0127	0.32	248.71	84	6.8626	N/A	69.78	6.3298	N/A	290.40
40	6.9192	0.37	108.75	6.9863	0.32	251.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.8954	0.32	106.32	6.9530	0.34	253.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.9054	0.36	103.98	6.9720	0.37	256.11	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

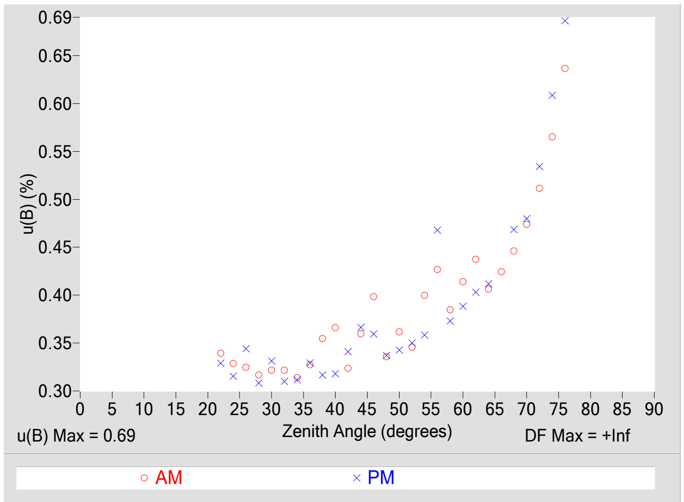


Figure 4. Residuals from Spline Interpolation

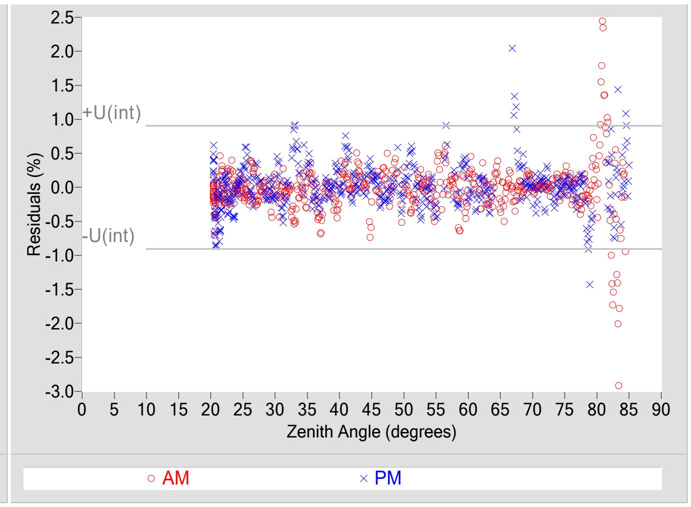


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.45
Combined Standard Uncertainty, u(c) (%)	±0.82
Effective degrees of freedom, DF(c)	10889
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

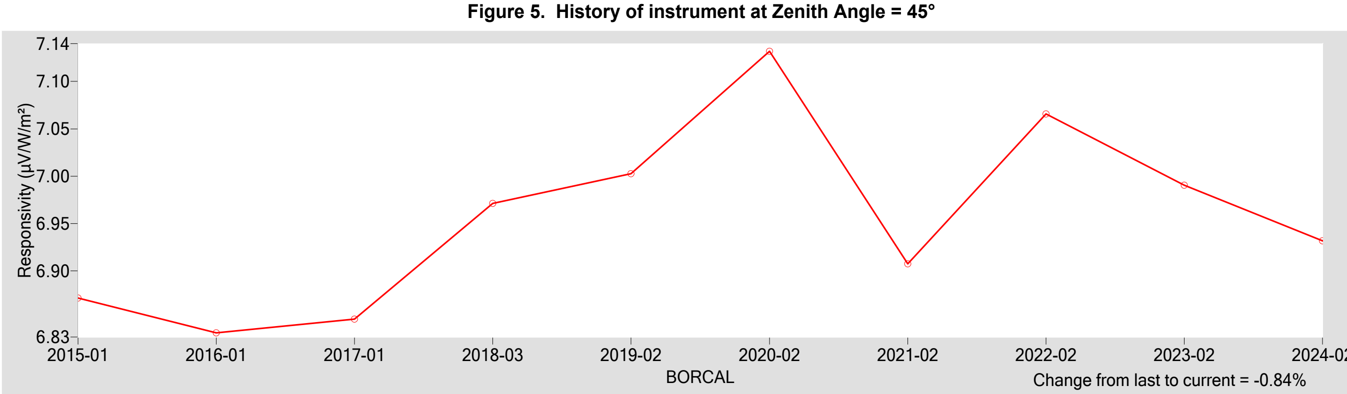
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
6.9315	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.92
Offset Uncertainty, U(off) (%)	+1.7 / -1.9
Expanded Uncertainty, U (%)	+2.6 / -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.

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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).

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument: Silicon Pyranometer
Manufacturer: EKO
Model: ML-01
Serial Number: S13135063
Calibration Date: 5/16/2024
Due Date: 5/16/2025
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/16

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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.

Calibration by: Afshin Andreas, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

S13135063 EKO ML-01

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

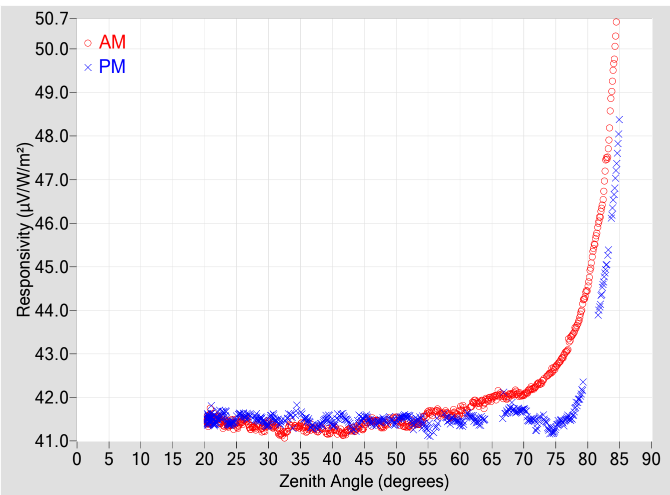


Figure 2. Responsivity vs Local Standard Time

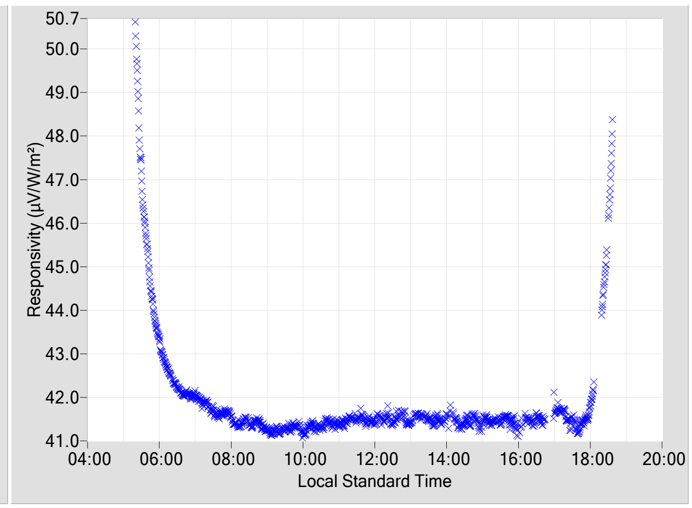


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	41.448	0.32	101.84	41.436	0.31	258.31
2	N/A	N/A	N/A	N/A	N/A	N/A	48	41.339	0.33	99.79	41.498	0.33	260.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	41.496	0.33	97.81	41.425	0.32	262.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	41.322	0.32	95.96	41.556	0.34	264.16
8	N/A	N/A	N/A	N/A	N/A	N/A	54	41.465	0.34	94.15	41.432	0.35	265.99
10	N/A	N/A	N/A	N/A	N/A	N/A	56	41.651	0.44	92.39	41.280	0.38	267.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	41.624	0.36	90.73	41.500	0.36	269.39
14	N/A	N/A	N/A	N/A	N/A	N/A	60	41.668	0.34	89.05	41.411	0.35	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	41.857	0.35	87.42	41.532	0.36	272.71
18	N/A	N/A	N/A	N/A	N/A	N/A	64	41.900	0.37	85.79	41.492	0.36	274.16
20	N/A	N/A	N/A	N/A	N/A	N/A	66	42.064	0.38	84.23	N/A	N/A	N/A
22	41.530	0.31	155.25	41.521	0.31	204.60	68	42.067	0.40	82.64	41.761	0.43	277.46
24	41.383	0.31	144.04	41.392	0.29	216.10	70	42.062	0.42	81.06	41.712	0.42	279.05
26	41.455	0.31	136.34	41.576	0.32	223.92	72	42.280	0.46	79.48	41.351	0.45	280.62
28	41.320	0.31	130.31	41.532	0.32	229.79	74	42.535	0.50	77.92	41.267	0.50	282.19
30	41.406	0.33	125.35	41.404	0.31	234.72	76	42.897	0.56	76.35	41.429	0.56	283.81
32	41.156	0.31	121.21	41.414	0.33	238.67	78	43.547	N/A	74.73	41.749	N/A	285.43
34	41.349	0.34	117.29	41.471	0.32	242.36	80	44.547	N/A	73.11	N/A	N/A	N/A
36	41.280	0.31	114.34	41.495	0.31	245.75	82	46.227	N/A	71.43	44.242	N/A	288.71
38	41.260	0.32	111.52	41.357	0.31	248.64	84	49.548	N/A	69.74	46.506	N/A	290.41
40	41.297	0.30	108.76	41.380	0.30	251.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	41.177	0.32	106.26	41.513	0.32	253.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	41.312	0.33	103.99	41.399	0.37	256.12	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

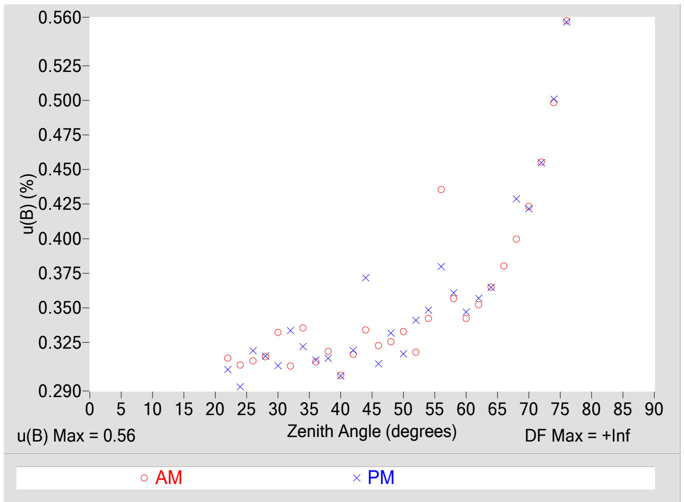


Figure 4. Residuals from Spline Interpolation

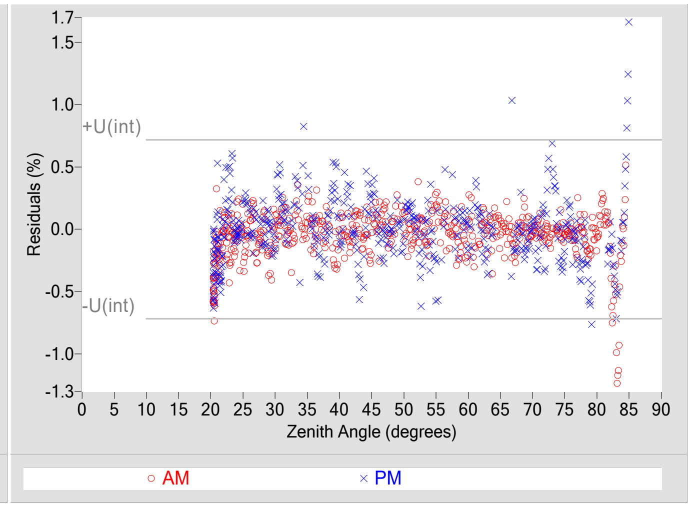


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.56
Type-A Interpolating Function, u(int) (%)	±0.36
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	11605
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

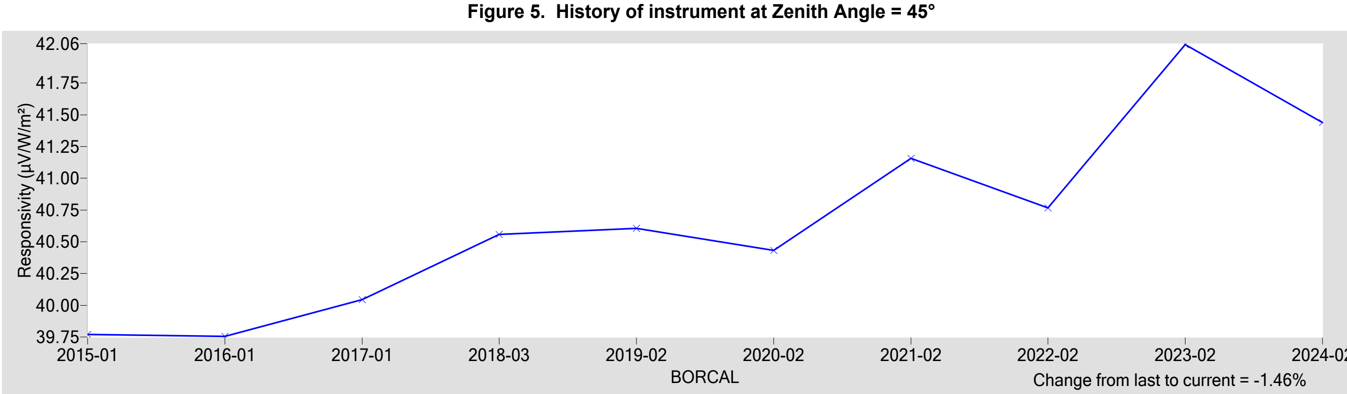
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
41.438	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+0.55 / -0.68
Expanded Uncertainty, U (%)	+1.4 / -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:**	EKO
Model:	MS-410	**Serial Number:**	S13144.085R
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

____________________ 05/21/2024

Ibrahim Reda, 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

S13144.085R EKO MS-410

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 - 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

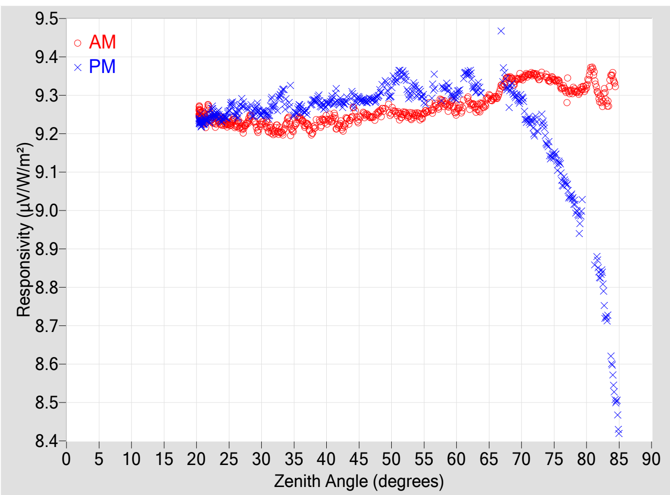


Figure 2. Responsivity vs Local Standard Time

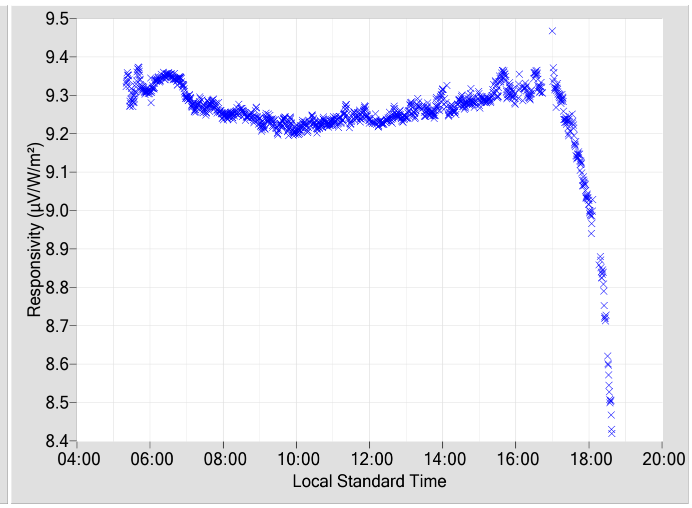


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.2487	0.38	101.83	9.2847	0.35	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2552	0.32	99.77	9.3019	0.32	260.33
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2568	0.35	97.78	9.3199	0.33	262.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2539	0.33	95.92	9.3502	0.33	264.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2492	0.38	94.14	9.3077	0.34	265.98
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2678	0.41	92.34	9.2928	0.45	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2814	0.36	90.72	9.3189	0.35	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2577	0.39	89.04	9.3010	0.36	271.08
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2794	0.41	87.41	9.3587	0.37	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2748	0.38	85.83	9.3056	0.38	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2936	0.39	84.22	N/A	N/A	N/A
22	9.2568	0.33	155.35	9.2405	0.32	204.67	68	9.3461	0.42	82.63	9.3098	0.44	277.50
24	9.2324	0.32	143.86	9.2400	0.31	216.26	70	9.3456	0.44	81.09	9.2927	0.44	279.04
26	9.2256	0.32	136.18	9.2502	0.34	224.11	72	9.3551	0.47	79.52	9.2200	0.48	280.65
28	9.2351	0.31	130.29	9.2648	0.30	229.76	74	9.3447	0.52	77.91	9.1676	0.54	282.23
30	9.2259	0.31	125.33	9.2520	0.32	234.70	76	9.3253	0.59	76.34	9.1027	0.60	283.80
32	9.2082	0.31	121.20	9.2704	0.30	238.74	78	9.3127	N/A	74.72	9.0243	N/A	285.42
34	9.2348	0.30	117.52	9.2861	0.30	242.52	80	9.3254	N/A	73.10	N/A	N/A	N/A
36	9.2388	0.32	114.40	9.2682	0.32	245.81	82	9.2942	N/A	71.47	8.8346	N/A	288.70
38	9.2116	0.34	111.36	9.2847	0.31	248.71	84	9.3484	N/A	69.78	8.5772	N/A	290.40
40	9.2351	0.35	108.75	9.2759	0.31	251.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2243	0.31	106.32	9.2833	0.33	253.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2530	0.35	103.98	9.2895	0.35	256.11	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

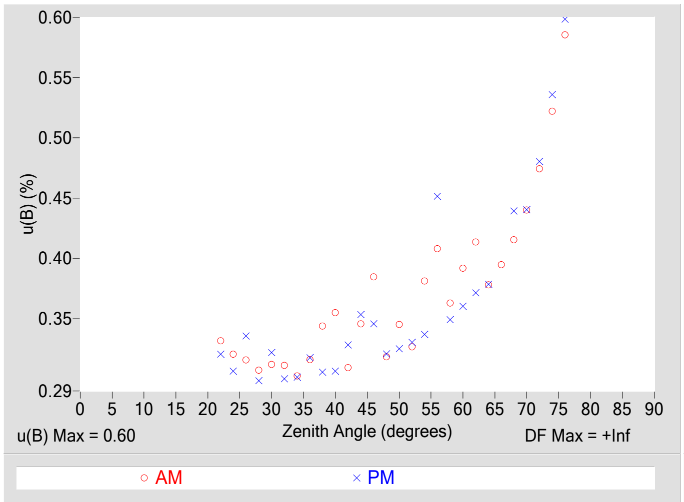


Figure 4. Residuals from Spline Interpolation

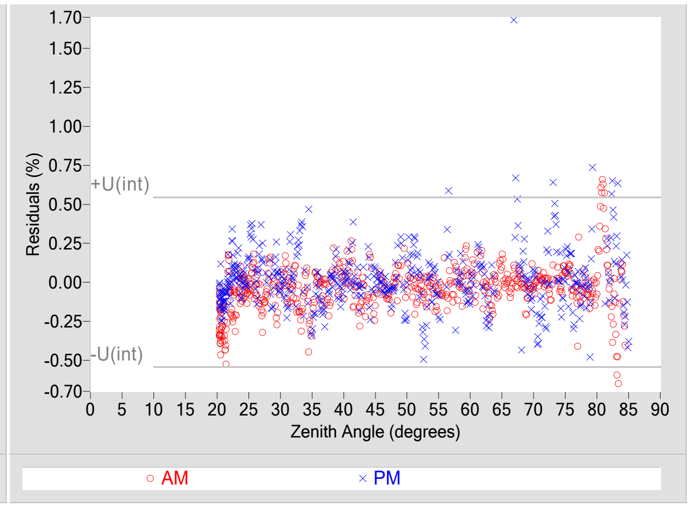


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	34110
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

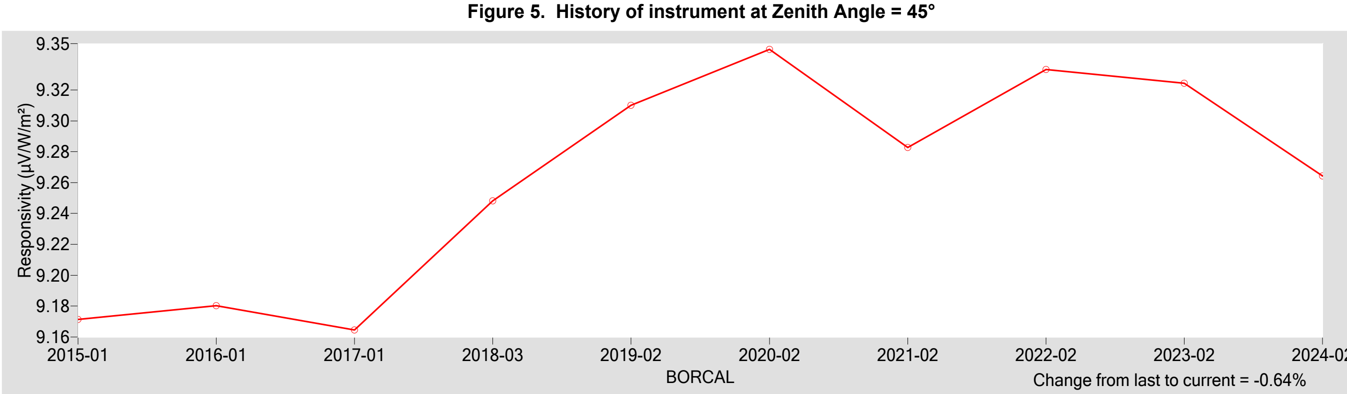
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.2644	0.20000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+0.93 / -0.61
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 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:**	EKO
Model:	MS-80	**Serial Number:**	S17096005
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager — Date: 05/21/2024

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

S17096005 EKO MS-80

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

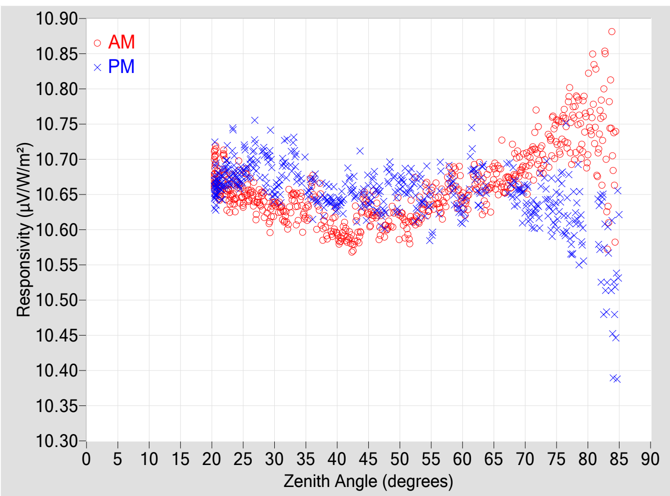


Figure 2. Responsivity vs Local Standard Time

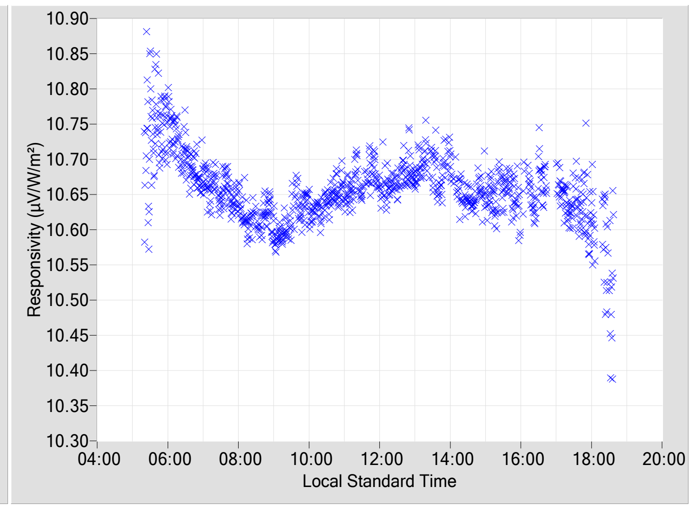


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	10.633	0.35	101.82	10.655	0.33	258.29
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.605	0.33	99.77	10.665	0.37	260.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.613	0.34	97.81	10.660	0.34	262.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.618	0.34	95.96	10.671	0.36	264.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.648	0.33	94.13	10.647	0.35	265.93
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.645	0.35	92.40	10.622	0.45	267.89
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.669	0.36	90.72	10.675	0.34	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.642	0.39	89.03	10.624	0.35	271.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.669	0.36	87.40	10.681	0.39	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.662	0.37	85.82	10.652	0.37	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.680	0.41	84.22	N/A	N/A	N/A
22	10.690	0.31	155.61	10.677	0.35	204.96	68	10.680	0.40	82.67	10.658	0.43	277.49
24	10.659	0.30	143.88	10.671	0.31	216.21	70	10.689	0.43	81.09	10.646	0.43	279.08
26	10.652	0.33	136.17	10.688	0.32	223.97	72	10.723	0.46	79.51	10.624	0.53	280.65
28	10.643	0.32	130.39	10.713	0.30	230.25	74	10.716	0.51	77.91	10.629	0.51	282.22
30	10.634	0.31	125.42	10.653	0.30	234.65	76	10.755	0.57	76.34	10.640	0.57	283.80
32	10.613	0.30	121.30	10.697	0.30	238.64	78	10.753	N/A	74.72	10.615	N/A	285.42
34	10.639	0.34	117.43	10.676	0.30	242.51	80	10.731	N/A	73.10	N/A	N/A	N/A
36	10.662	0.31	114.39	10.652	0.30	245.75	82	10.738	N/A	71.46	10.611	N/A	288.74
38	10.609	0.32	111.49	10.641	0.30	248.69	84	10.736	N/A	69.77	10.496	N/A	290.39
40	10.590	0.35	108.64	10.635	0.30	251.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.589	0.30	106.30	10.664	0.33	253.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.628	0.34	103.97	10.646	0.39	256.10	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

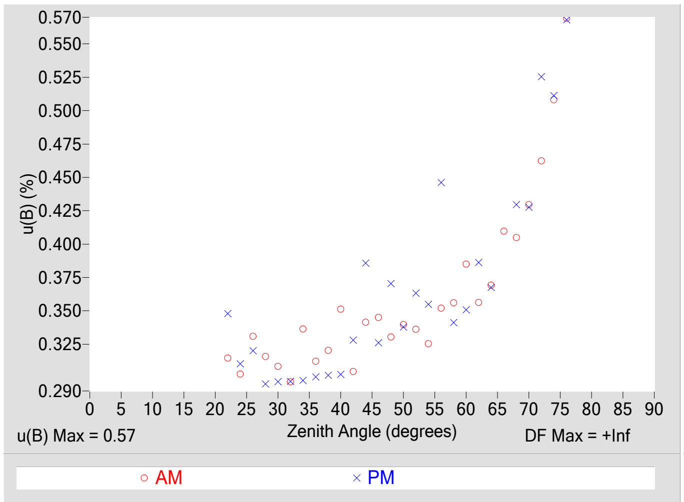


Figure 4. Residuals from Spline Interpolation

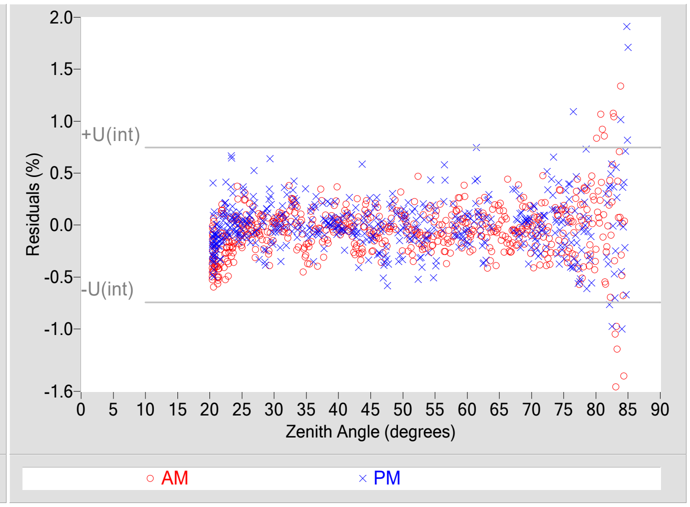


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.37
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	10898
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

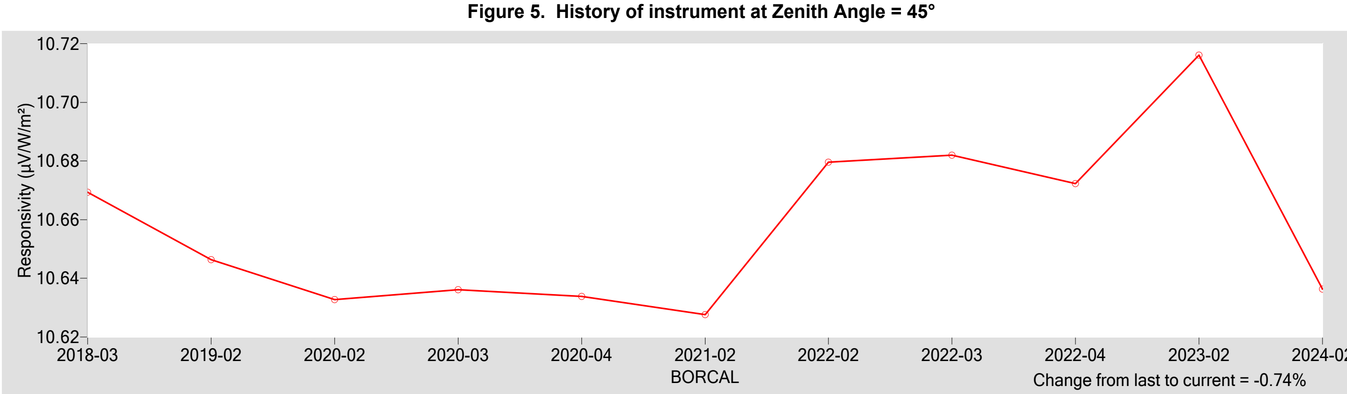
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.636	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+0.57 / -0.44
Expanded Uncertainty, U (%)	+1.4 / -1.3
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:**	EKO
Model:	MS-57	**Serial Number:**	S18015.22
Calibration Date:	5/16/2024	**Due Date:**	5/16/2025
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/16		

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	09/28/2023	09/28/2024
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/14/2024	04/14/2025
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/14/2024	04/14/2025
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, RCC, and Shawn L. Jaker

Ibrahim Reda, Technical Manager

05/21/2024
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

S18015.22 EKO MS-57

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

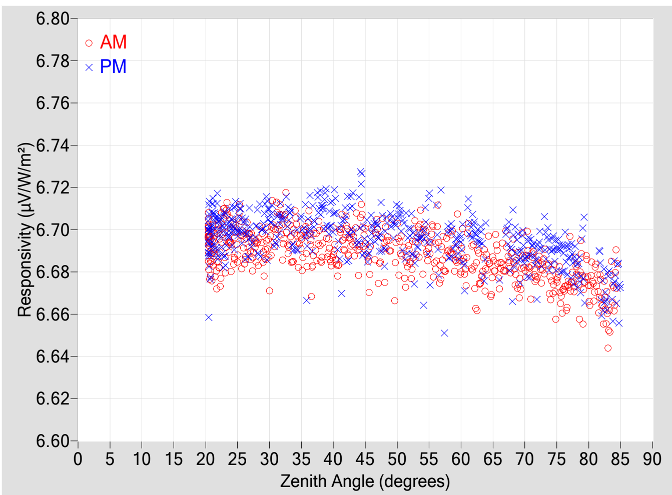


Figure 2. Responsivity vs Local Standard Time

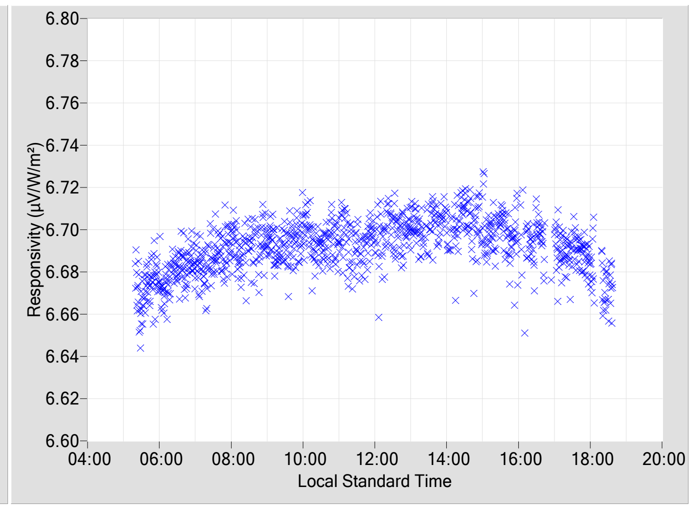


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	6.6906	0.31	102.00	6.7005	0.32	258.30
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.6930	0.30	99.77	6.6909	0.31	260.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.6912	0.32	97.80	6.7067	0.30	262.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.6857	0.29	95.97	6.7015	0.31	264.18
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.6952	0.31	94.14	6.6901	0.30	266.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.6872	0.31	92.41	6.7046	0.30	267.90
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.6936	0.33	90.77	6.6934	0.30	269.43
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.6873	0.30	89.04	6.6962	0.30	271.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.6806	0.30	87.41	6.7009	0.30	272.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.6813	0.31	85.83	6.6945	0.30	274.15
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.6799	0.30	84.22	6.6762	N/A	275.90
22	6.6889	0.31	155.24	6.7002	0.31	204.69	68	6.6876	0.30	82.63	6.6900	0.32	277.50
24	6.6956	0.31	144.12	6.7011	0.31	216.07	70	6.6837	0.31	81.09	6.6874	0.31	279.08
26	6.6930	0.30	136.32	6.7004	0.33	223.85	72	6.6811	0.31	79.52	6.6909	0.31	280.67
28	6.6903	0.29	130.36	6.6978	0.31	229.84	74	6.6758	0.31	77.91	6.6882	0.31	282.23
30	6.6882	0.32	125.47	6.7064	0.30	234.70	76	6.6694	0.32	76.35	6.6868	0.32	283.80
32	6.6969	0.29	121.19	6.7071	0.29	238.74	78	6.6811	N/A	74.73	6.6832	N/A	285.42
34	6.7002	0.30	117.61	6.6937	0.31	242.69	80	6.6735	N/A	73.10	N/A	N/A	N/A
36	6.6965	0.31	114.32	6.6923	0.32	245.65	82	6.6677	N/A	71.42	6.6729	N/A	288.70
38	6.6921	0.31	111.43	6.7109	0.29	248.63	84	6.6737	N/A	69.73	6.6741	N/A	290.40
40	6.6903	0.32	108.78	6.7081	0.30	251.32	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.6973	0.30	106.25	6.7035	0.32	253.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.6917	0.29	103.98	6.7042	0.31	256.11	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

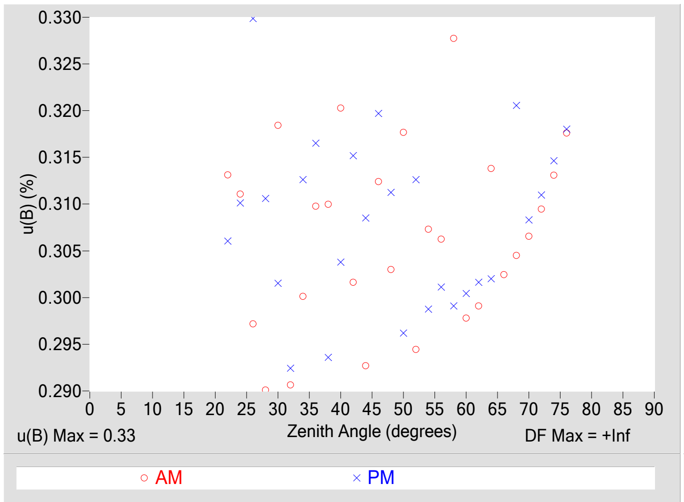


Figure 4. Residuals from Spline Interpolation

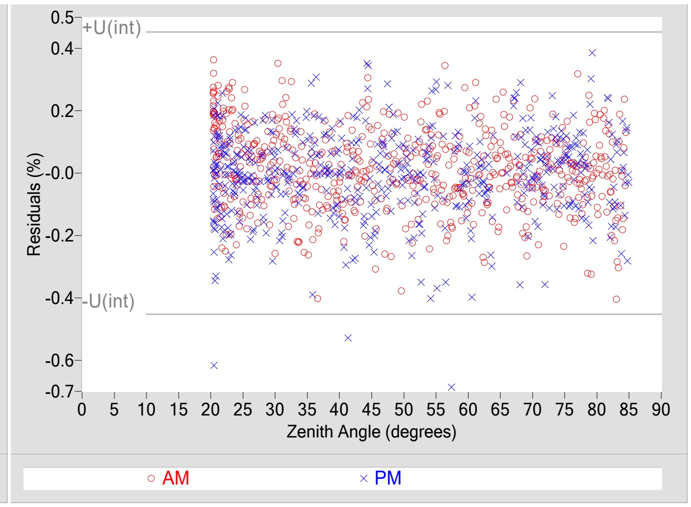


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	9766
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	22° to 76°
PM Valid zenith angle range	22° to 76°

‡ 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

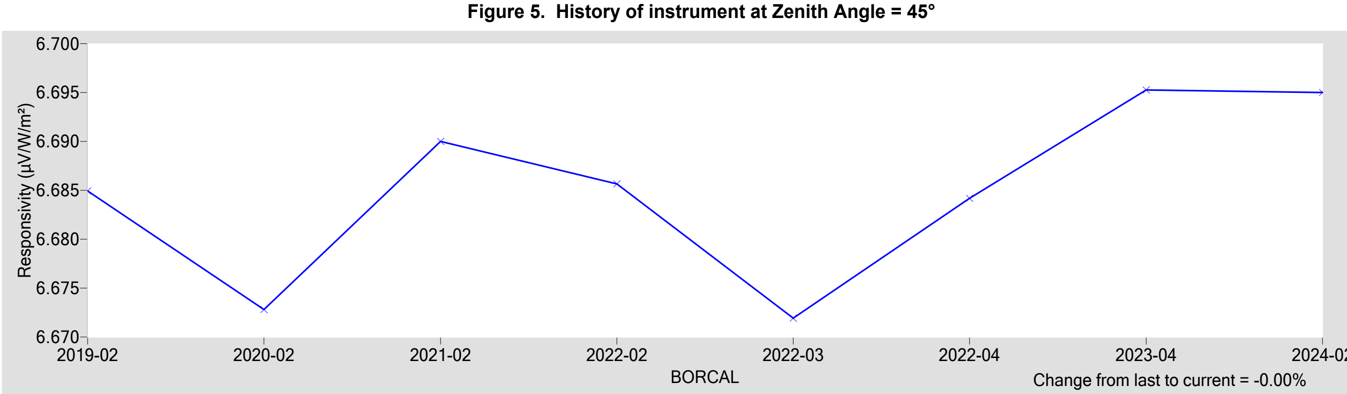
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
6.6950	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.24 / -0.14
Expanded Uncertainty, U (%)	+0.88 / -0.78
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).

Environmental and Sky Conditions for BORCAL-SW 2024-02

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

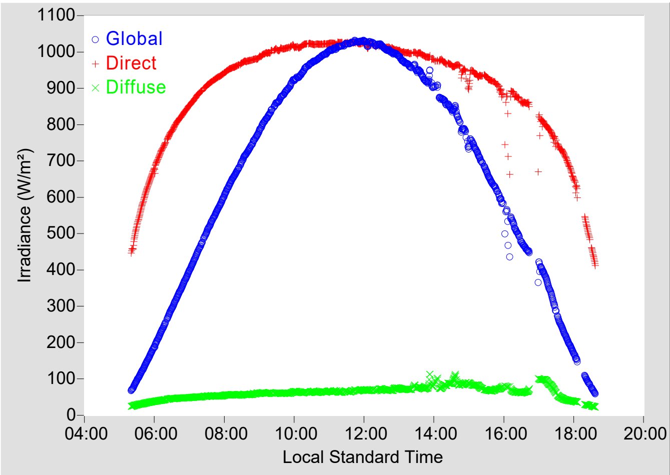
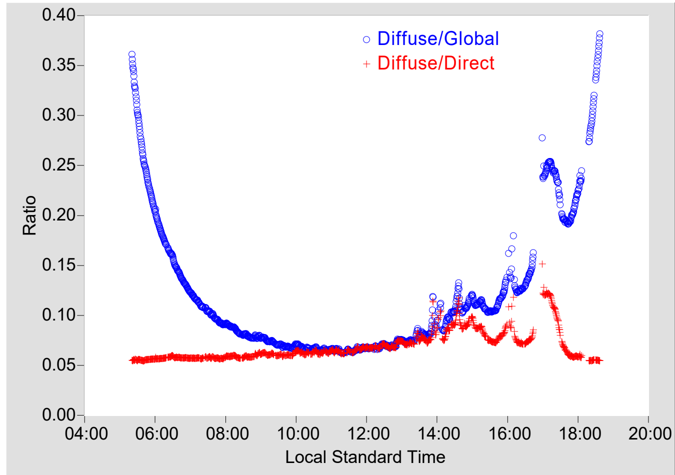


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

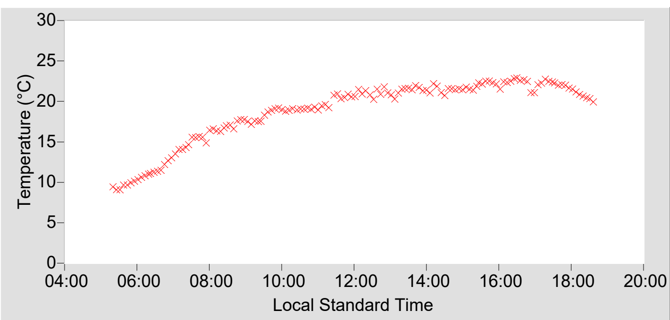


Figure 9. Humidity

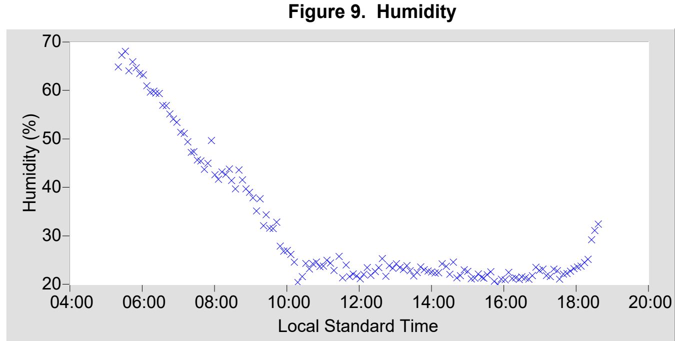


Figure 10. Pressure

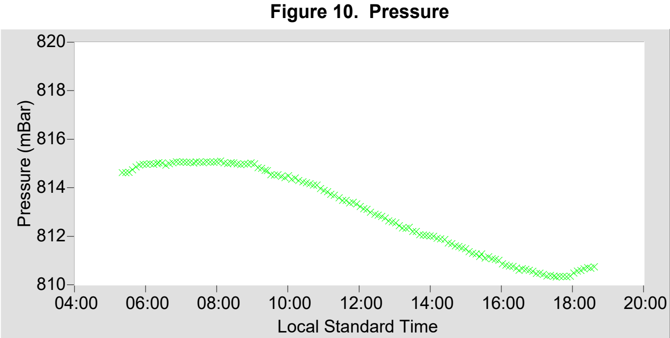


Figure 11. Effective Net Infrared

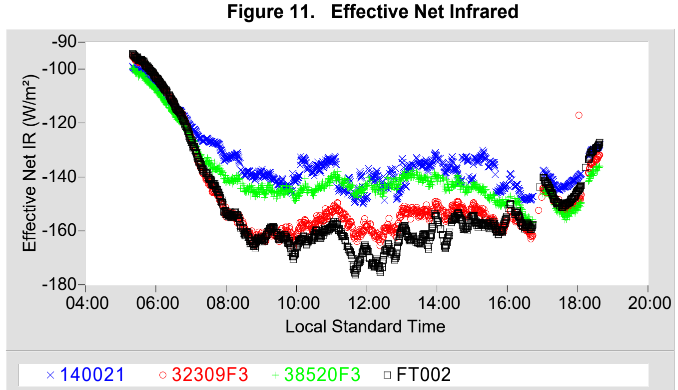


Figure 12. Estimated Broadband Aerosol Optical Depth

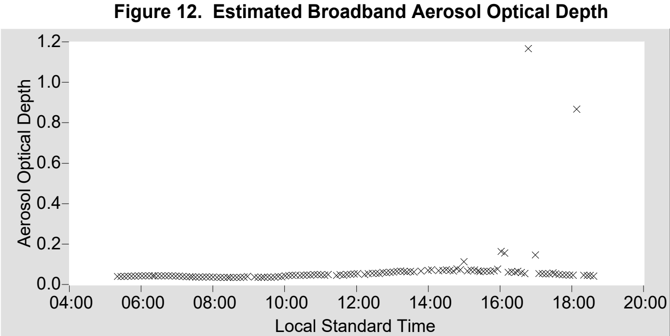


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	18.78	9.09	22.90
Humidity (%)	31.93	20.02	68.07
Pressure (mBar)	813.0	810.3	815.1
Est. Aerosol Optical Depth (BB)	0.068	0.034	1.167

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).

010284-DW-CM3 Kipp & Zonen CM3
Comments:
Retro-fitted from CNR1