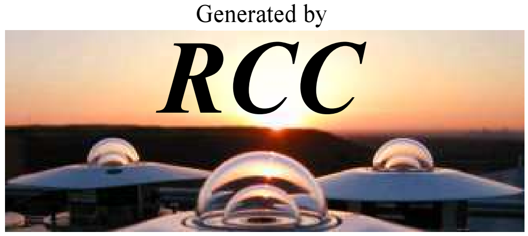
Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2019-02

Generated by



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
05/03/2019

Report Date
May 6, 2019

NREL

NOTICE

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

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

This report includes these sections:

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

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

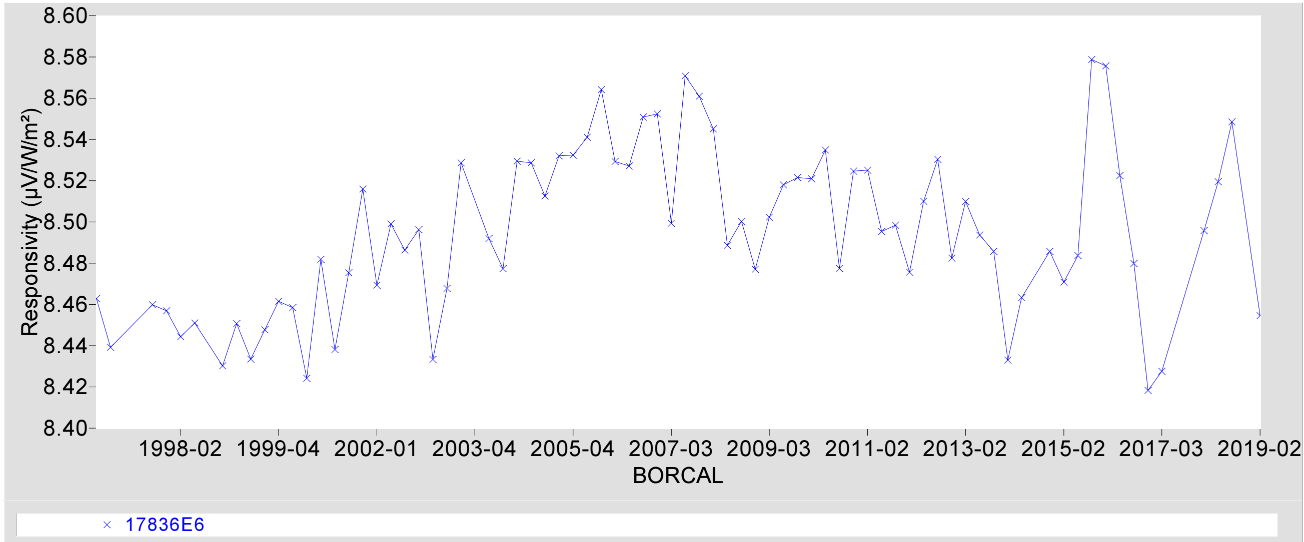
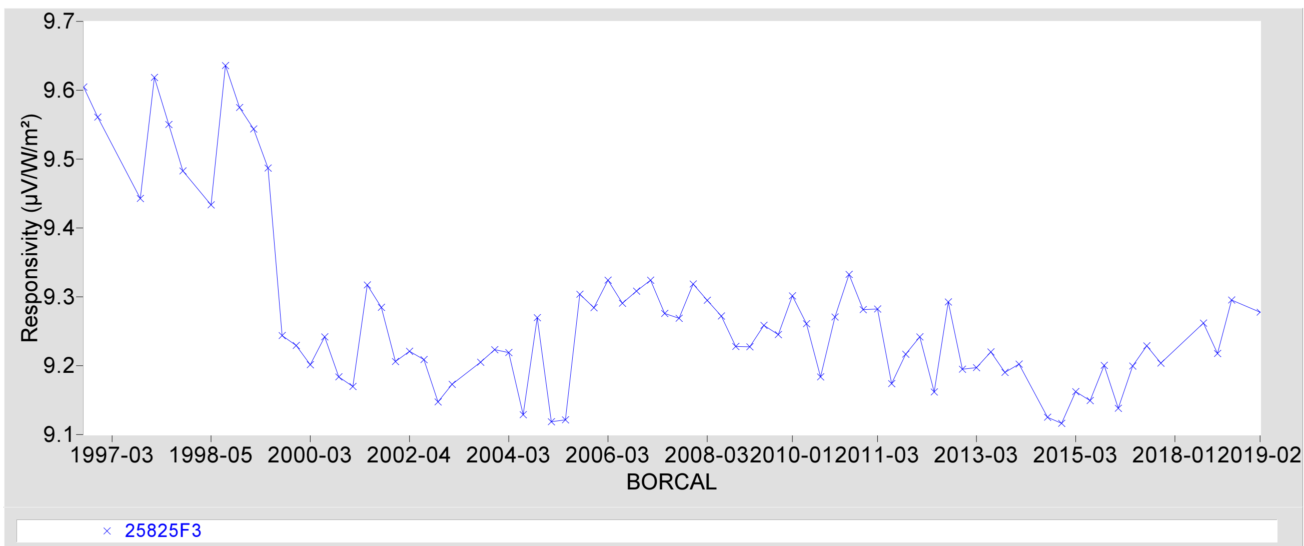


Figure 2. Eppley PSP Control Instrument History



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
010047 Kipp & Zonen CM22	9.7805	102.24	+1.8 / -1.4	0.087000	A1-2
014261 Kipp & Zonen CM3	22.202	45.041	+2.9 / -2.8	0.40000	A1-5
015189 Kipp & Zonen CM6B	10.980	91.072	+2.3 / -2.1	0.30000	A1-8
0212-2 Yankee TSP-700	3003.2	0.33298	+2.2 / -2.3	0	A1-11
080009 Kipp & Zonen CHP1	7.9357	126.01	+1.2 / -0.76	0	A1-14
080017 Kipp & Zonen CMP22	10.547	94.818	+1.5 / -1.6	0.087000	A1-17
100174 Kipp & Zonen CMP22	9.8283	101.75	+2.1 / -1.5	0.087000	A1-20
1171 Apogee SP-510	53.551	18.674	+2.8 / -5.0	2.5000	A1-23
140043 Kipp & Zonen CMP22	9.0682	110.28	+2.3 / -1.4	0.087000	A1-26
140108 Kipp & Zonen CHP1	8.0759	123.82	+0.84 / -0.89	0	A1-29
140712 Kipp & Zonen CMP11	9.1157	109.70	+1.5 / -2.3	0.20500	A1-32
151027 Kipp & Zonen SP-LITE2	69.571	14.374	+3.6 / -2.4	0	A1-35
170535 Kipp & Zonen CMP22	9.5974	104.20	+2.0 / -2.4	0.087000	A1-38
2529 Hukseflux SR25	9.3822	106.59	+2.4 / -1.4	0.043000	A1-41
2543 Hukseflux SR25	9.5401	104.82	+2.1 / -1.4	0.043000	A1-44
28402F3 Eppley PSP	6.9865	143.13	+2.4 / -2.2	0.64000	A1-47
31137E6 Eppley NIP	8.4944	117.73	+1.4 / -1.5	0	A1-50
32331 Eppley 8-48	8.9438	111.81	+4.5 / -2.4	0	A1-53
34718 Eppley 8-48	9.3855	106.55	+3.7 / -2.1	0	A1-56
37831F3 Eppley GPP	8.4828	117.89	+2.2 / -2.9	0.15000	A1-59
37839F3 Eppley SPP	8.6758	115.26	+1.8 / -2.2	0.30000	A1-62
37882E6 Eppley sNIP	8.4047	118.98	+0.71 / -1.1	0	A1-65
40337 Apogee SP-110	184.41	5.4226	+2.5 / -2.4	0	A1-68
9206 Hukseflux DR02	11.019	90.754	+1.6 / -0.88	0	A1-71
A360 Delta-T SPN1	1027.5	0.97320	+8.3 / -3.8	0	A1-74
F14077R EKO MS-802	7.0776	141.29	+2.3 / -2.1	0.18000	A1-77
PY100360 Licor LI200R	10.882	91.897	+1.6 / -1.7	0	A1-80
PY102022 Licor LI200R	10.652	93.879	+1.5 / -1.8	0	A1-83
PY28257 Licor LI200	13.817	72.373	+2.1 / -2.9	0	A1-86
PYHR101 Licor LI201SB	6.7215	148.78	+4.7 / -1.9	0	A1-89
S13071483 EKO MS-602	7.0025	142.81	+2.0 / -4.1	0.30000	A1-92
S13135063 EKO ML-01	40.604	24.628	+2.3 / -1.3	0	A1-95
S13144.085R EKO MS-410	9.3100	107.41	+2.1 / -1.5	0.20000	A1-98
S17096005 EKO MS-80	10.646	93.929	+2.4 / -1.3	0.043000	A1-101
S18015.22 EKO MS-57	6.6849	149.59	+0.88 / -0.87	0	A1-104

[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 A1-107.

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 (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CM22	**Serial Number:**	010047
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CGR4, S/N 140021	04/02/2019	04/02/2023

† 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: RCC

____ ____________________

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

010047 Kipp & Zonen CM22

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

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

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

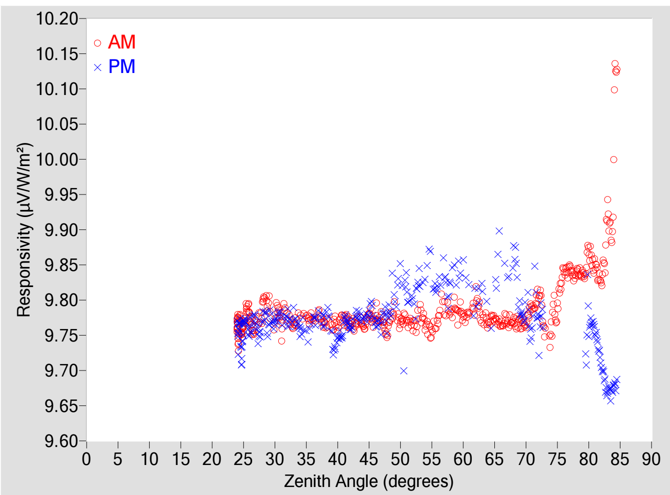


Figure 2. Responsivity vs Local Standard Time

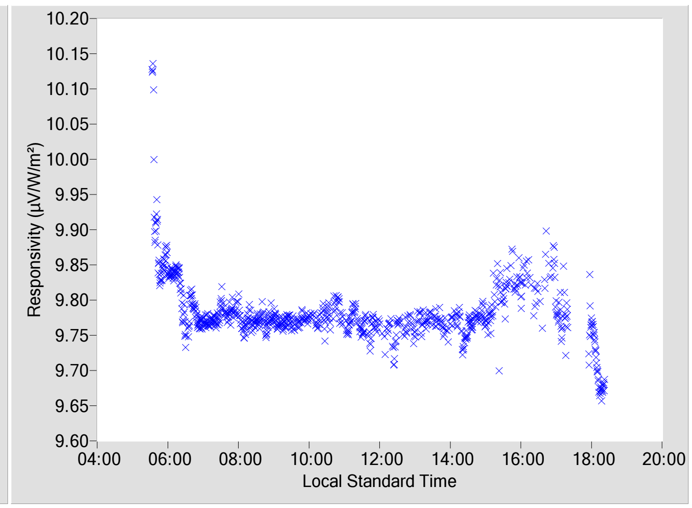


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.7783	0.34	108.16	9.7673	0.38	251.95
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7580	0.35	105.90	9.7751	0.39	254.15
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7689	0.36	103.75	9.8361	0.44	256.52
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7653	0.37	101.62	9.8009	0.44	258.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7659	0.38	99.69	9.8393	0.47	260.51
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7758	0.38	97.74	9.8229	0.50	262.26
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7815	0.39	95.95	9.8317	0.51	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7772	0.41	94.21	9.8572	N/A	265.93
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7997	0.42	92.43	9.8038	0.51	267.64
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7654	0.43	90.79	9.7981	0.53	269.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7662	0.46	89.11	9.8982	N/A	270.80
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.7681	0.48	87.49	9.8603	N/A	272.71
24	9.7610	0.32	174.70	9.7565	0.32	187.00	70	9.7679	0.52	85.85	9.7930	N/A	274.28
26	9.7781	0.32	154.04	9.7591	0.32	206.09	72	9.8063	0.57	84.23	9.7647	N/A	275.91
28	9.7892	0.33	144.18	9.7742	0.33	215.96	74	9.7556	0.63	82.66	N/A	N/A	N/A
30	9.7743	0.34	137.18	9.7680	0.34	222.79	76	9.8396	0.69	81.05	N/A	N/A	N/A
32	9.7774	0.33	131.41	9.7728	0.34	228.40	78	9.8388	N/A	79.44	N/A	N/A	N/A
34	9.7803	0.33	127.26	9.7582	0.34	233.04	80	9.8695	N/A	77.79	9.7804	N/A	282.39
36	9.7754	0.33	123.03	9.7724	0.35	237.26	82	9.8324	N/A	76.13	9.7064	N/A	284.05
38	9.7661	0.33	119.43	9.7699	0.35	240.58	84	10.029	N/A	74.47	9.6782	N/A	285.73
40	9.7644	0.33	116.28	9.7450	0.36	243.96	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7666	0.34	113.30	9.7608	0.39	246.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7636	0.34	110.74	9.7737	0.39	249.50	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

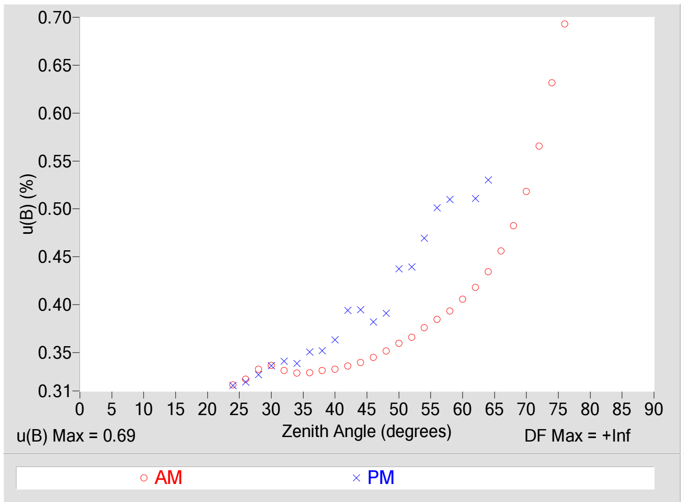


Figure 4. Residuals from Spline Interpolation

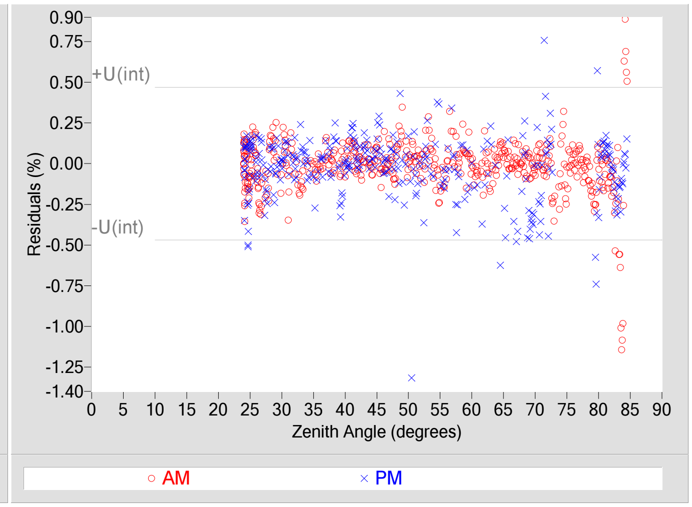


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.73
Effective degrees of freedom, DF(c)	66528
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

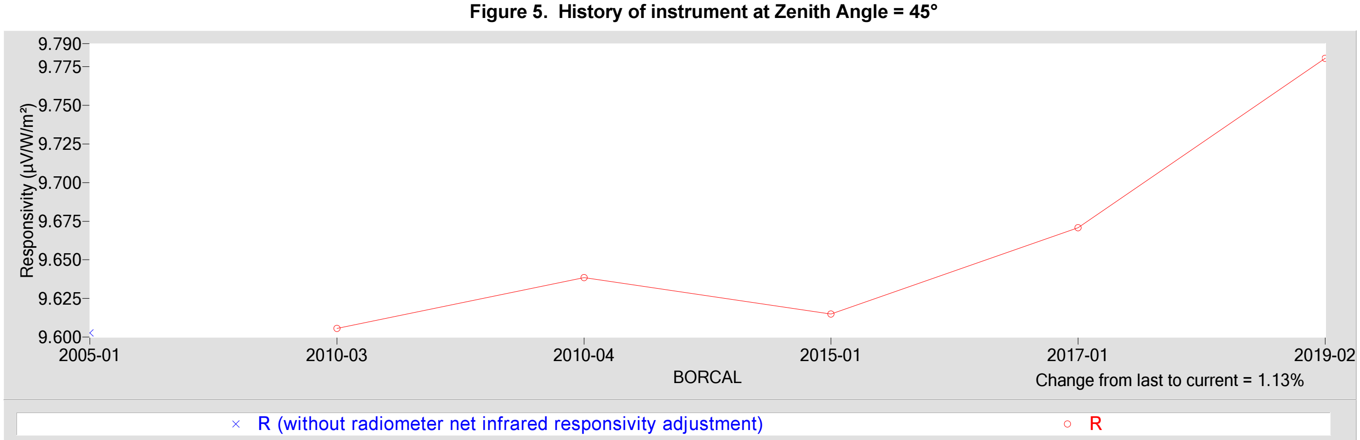
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.7805	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+0.78 / -0.36
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	**Manufacturer:**	Kipp & Zonen
Model:	CM3	**Serial Number:**	014261
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

______________________________ _______________

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

014261 Kipp & Zonen CM3

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

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

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

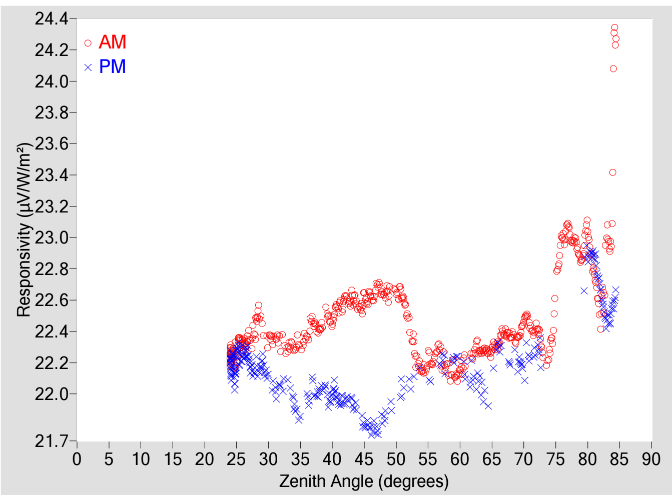


Figure 2. Responsivity vs Local Standard Time

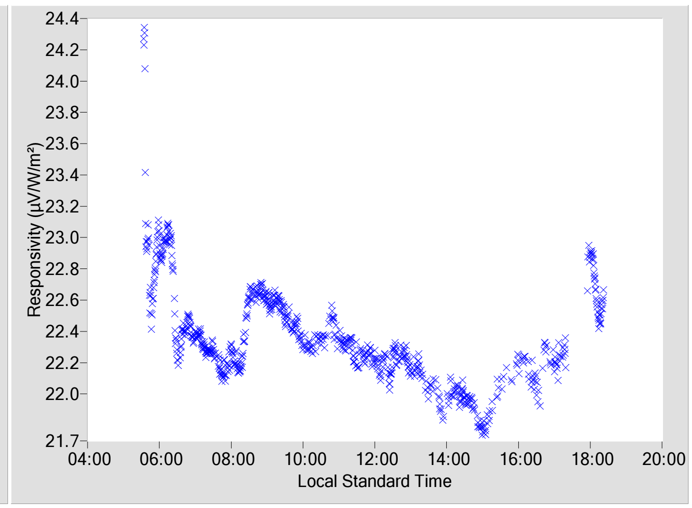


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	22.630	0.35	108.29	21.770	0.38	251.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	22.642	0.35	105.95	21.833	0.39	254.25
4	N/A	N/A	N/A	N/A	N/A	N/A	50	22.650	0.36	103.75	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	22.470	0.37	101.76	22.064	0.44	258.60
8	N/A	N/A	N/A	N/A	N/A	N/A	54	22.148	0.38	99.68	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	22.234	0.39	97.82	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	22.168	0.39	96.00	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	22.158	0.41	94.21	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	22.250	0.42	92.48	22.139	0.51	267.66
18	N/A	N/A	N/A	N/A	N/A	N/A	64	22.277	0.44	90.79	22.024	0.55	269.26
20	N/A	N/A	N/A	N/A	N/A	N/A	66	22.317	0.46	89.11	22.307	N/A	271.07
22	N/A	N/A	N/A	N/A	N/A	N/A	68	22.374	0.48	87.49	22.191	N/A	272.51
24	22.246	0.32	174.20	22.188	0.32	185.55	70	22.468	0.52	85.85	22.125	N/A	274.28
26	22.322	0.32	153.73	22.246	0.32	205.86	72	22.412	0.57	84.23	22.281	N/A	275.90
28	22.440	0.33	144.22	22.161	0.33	215.81	74	22.276	0.63	82.61	N/A	N/A	N/A
30	22.349	0.34	137.24	22.112	0.34	222.28	76	22.994	0.69	81.05	N/A	N/A	N/A
32	22.340	0.33	131.86	22.041	0.34	228.36	78	22.985	N/A	79.44	N/A	N/A	N/A
34	22.282	0.33	126.91	21.938	0.34	233.05	80	23.043	N/A	77.83	22.889	N/A	282.45
36	22.358	0.33	122.92	21.971	0.35	237.46	82	22.528	N/A	76.16	22.664	N/A	284.05
38	22.409	0.33	119.43	22.021	0.35	240.66	84	23.696	N/A	74.51	22.578	N/A	285.73
40	22.468	0.33	116.20	22.014	0.36	243.89	86	N/A	N/A	N/A	N/A	N/A	N/A
42	22.614	0.34	113.41	21.956	0.40	246.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	22.563	0.34	110.65	21.896	0.39	249.10	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

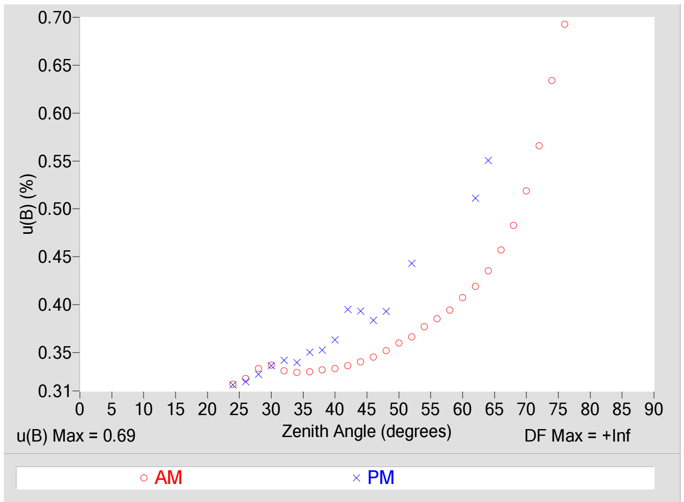


Figure 4. Residuals from Spline Interpolation

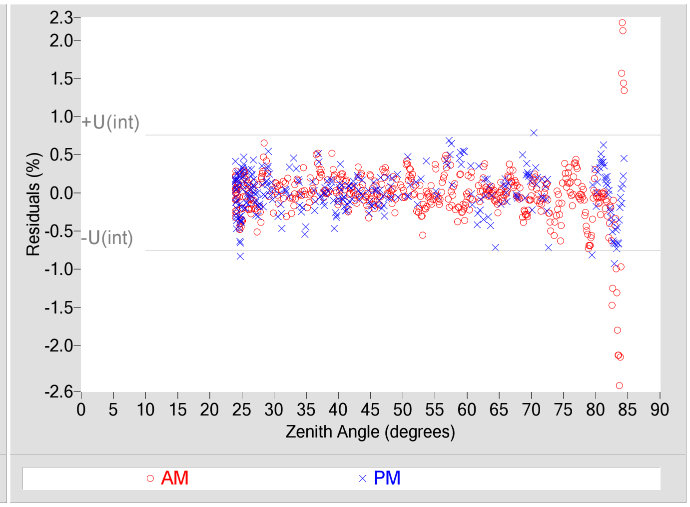


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.38
Combined Standard Uncertainty, u(c) (%)	±0.79
Effective degrees of freedom, DF(c)	12397
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

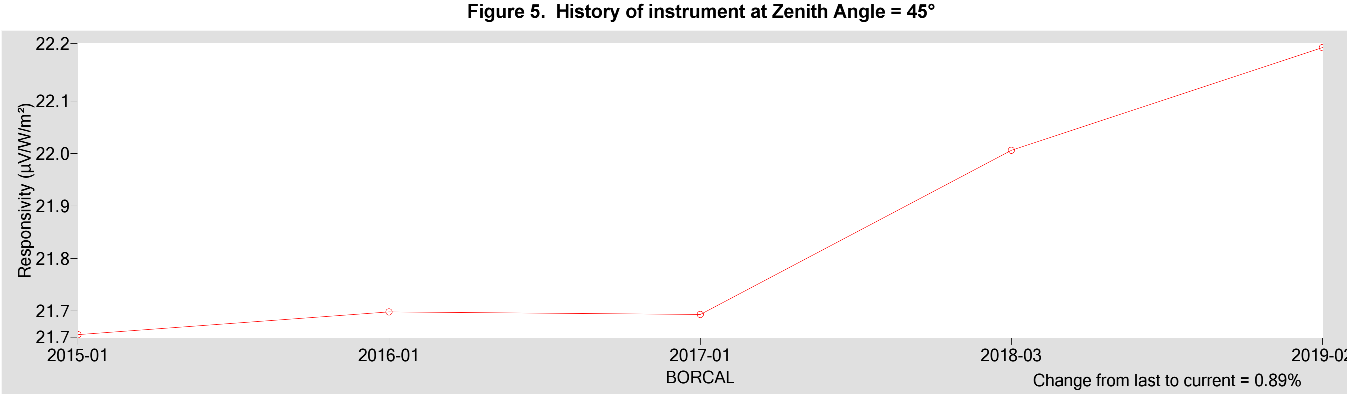
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
22.202	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+2.0 / -1.9
Expanded Uncertainty, U (%)	+2.9 / -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:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM6B	**Serial Number:**	015189
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

______________________________ ____________

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

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

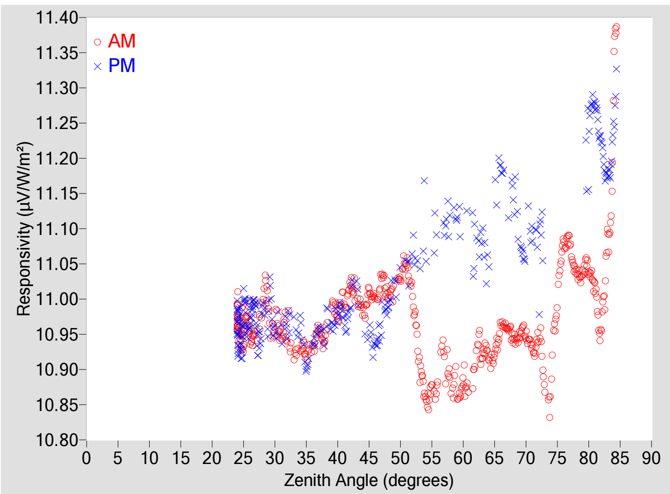


Figure 2. Responsivity vs Local Standard Time

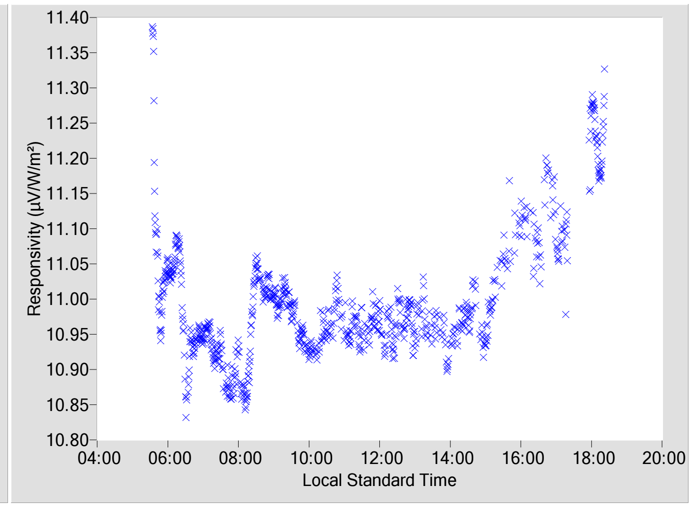


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	11.004	0.35	108.44	10.937	0.39	251.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.007	0.36	106.02	10.987	0.40	254.16
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.028	0.36	103.81	11.045	0.44	256.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.998	0.37	101.71	11.068	0.45	258.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.858	0.38	99.69	11.111	0.48	260.35
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.880	0.39	97.94	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.882	0.40	95.98	11.119	0.51	264.04
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.880	0.41	94.21	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.917	0.43	92.48	11.096	0.52	267.64
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.920	0.44	90.78	11.054	0.56	269.36
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.962	0.46	89.13	11.185	N/A	271.07
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.945	0.49	87.49	11.153	N/A	272.68
24	10.968	0.32	174.39	10.960	0.32	185.12	70	10.945	0.53	85.81	11.055	N/A	274.10
26	10.958	0.33	153.74	10.971	0.32	206.20	72	10.944	0.58	84.26	11.053	N/A	275.94
28	10.996	0.34	144.07	10.972	0.33	215.58	74	10.875	0.64	82.66	N/A	N/A	N/A
30	10.961	0.34	137.48	10.953	0.34	222.75	76	11.076	0.71	81.05	N/A	N/A	N/A
32	10.953	0.33	131.94	10.963	0.35	228.30	78	11.038	N/A	79.39	N/A	N/A	N/A
34	10.927	0.33	126.60	10.959	0.34	233.26	80	11.040	N/A	77.79	11.239	N/A	282.44
36	10.930	0.33	122.88	10.939	0.35	237.40	82	10.964	N/A	76.18	11.221	N/A	284.06
38	10.944	0.33	119.52	10.955	0.36	240.54	84	11.290	N/A	74.52	11.253	N/A	285.73
40	10.976	0.34	116.18	10.977	0.37	243.78	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.019	0.34	113.38	11.000	0.40	246.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.985	0.34	110.64	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

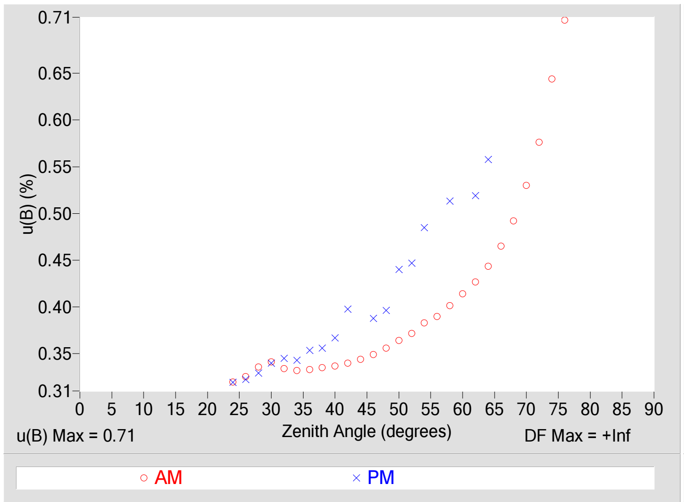


Figure 4. Residuals from Spline Interpolation

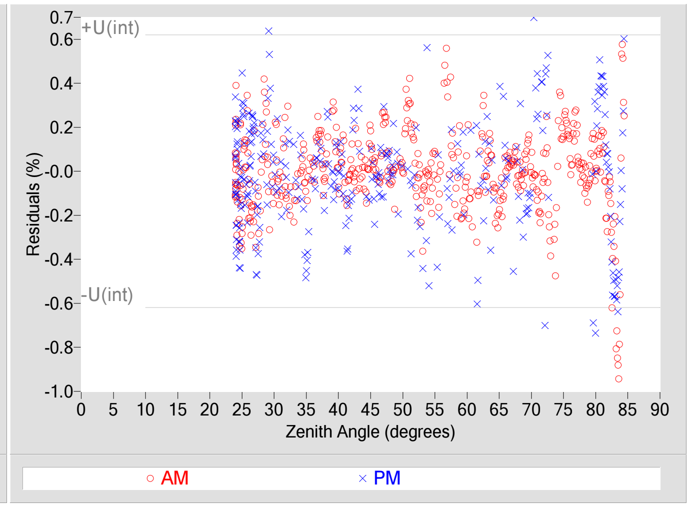


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.71
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	26147
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

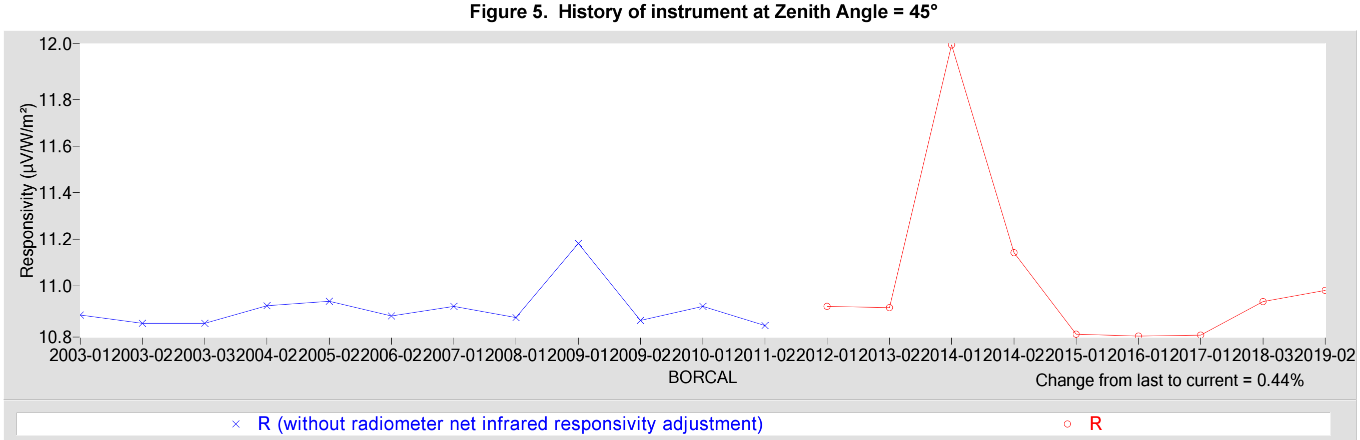
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.980	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.3 / -1.1
Expanded Uncertainty, U (%)	+2.3 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Yankee
Model:	TSP-700	**Serial Number:**	0212-2
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

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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

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

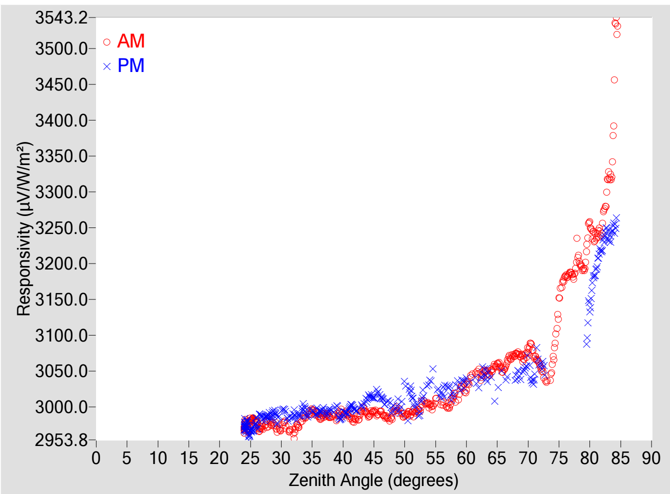


Figure 2. Responsivity vs Local Standard Time

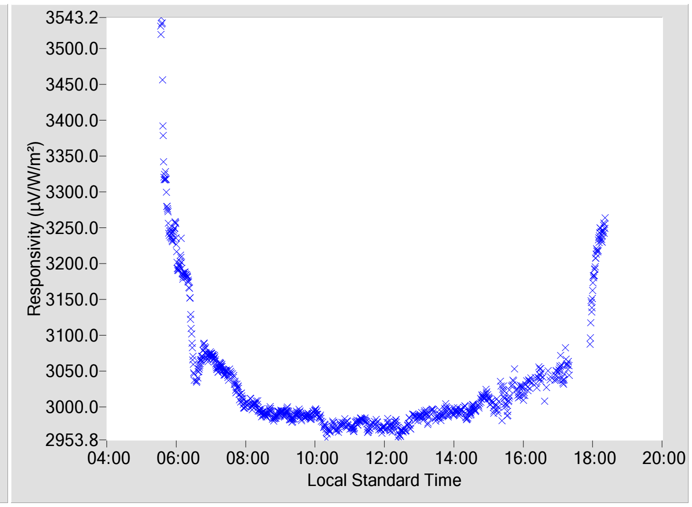


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	2993.6	0.34	108.12	3013.5	0.38	252.04
2	N/A	N/A	N/A	N/A	N/A	N/A	48	2987.3	0.35	105.93	2996.4	0.39	254.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	2987.6	0.36	103.74	3032.1	0.43	256.46
6	N/A	N/A	N/A	N/A	N/A	N/A	52	2994.4	0.36	101.65	2996.9	0.44	258.58
8	N/A	N/A	N/A	N/A	N/A	N/A	54	3003.1	0.37	99.74	3034.6	0.47	260.48
10	N/A	N/A	N/A	N/A	N/A	N/A	56	3004.5	0.38	97.71	3019.3	0.50	262.40
12	N/A	N/A	N/A	N/A	N/A	N/A	58	3014.2	0.39	95.95	3022.2	0.51	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	3027.3	0.40	94.16	3038.3	N/A	265.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	3048.6	0.41	92.45	3026.4	0.51	267.64
18	N/A	N/A	N/A	N/A	N/A	N/A	64	3048.9	0.43	90.76	3041.4	0.54	269.40
20	N/A	N/A	N/A	N/A	N/A	N/A	66	3051.6	0.45	89.11	3050.4	N/A	270.80
22	N/A	N/A	N/A	N/A	N/A	N/A	68	3073.0	0.48	87.49	3039.8	N/A	272.71
24	2972.6	0.31	175.39	2972.6	0.31	185.93	70	3079.6	0.51	85.85	3062.0	N/A	274.28
26	2978.0	0.32	154.28	2976.4	0.32	205.69	72	3054.9	0.56	84.23	3057.2	N/A	275.93
28	2977.5	0.33	144.13	2987.7	0.32	215.63	74	3061.8	0.62	82.65	N/A	N/A	N/A
30	2969.5	0.34	137.46	2995.9	0.34	223.46	76	3180.7	0.68	81.05	N/A	N/A	N/A
32	2963.8	0.33	131.53	2988.3	0.34	228.51	78	3208.7	N/A	79.43	N/A	N/A	N/A
34	2985.0	0.33	127.25	2992.5	0.34	233.04	80	3252.7	N/A	77.78	3143.0	N/A	282.39
36	2986.6	0.33	122.91	2993.2	0.35	237.11	82	3256.8	N/A	76.10	3224.5	N/A	284.05
38	2985.4	0.33	119.67	2995.4	0.35	240.46	84	3473.2	N/A	74.46	3251.2	N/A	285.72
40	2990.6	0.33	116.22	2989.6	0.36	244.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	2981.5	0.33	113.44	2995.5	0.39	246.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	2989.4	0.34	110.74	3012.4	0.39	249.50	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

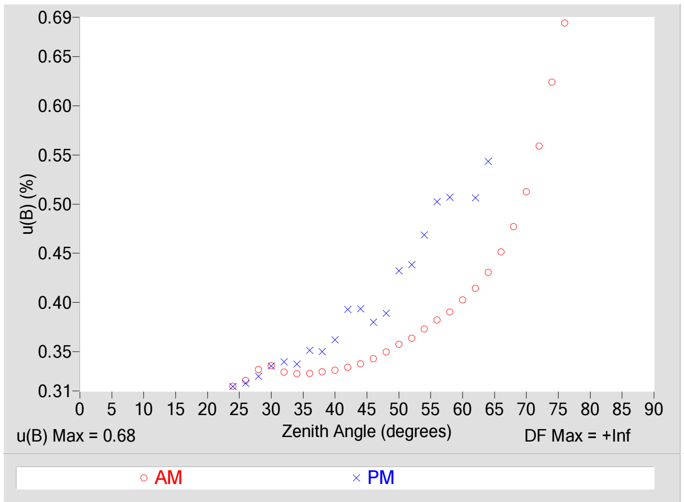


Figure 4. Residuals from Spline Interpolation

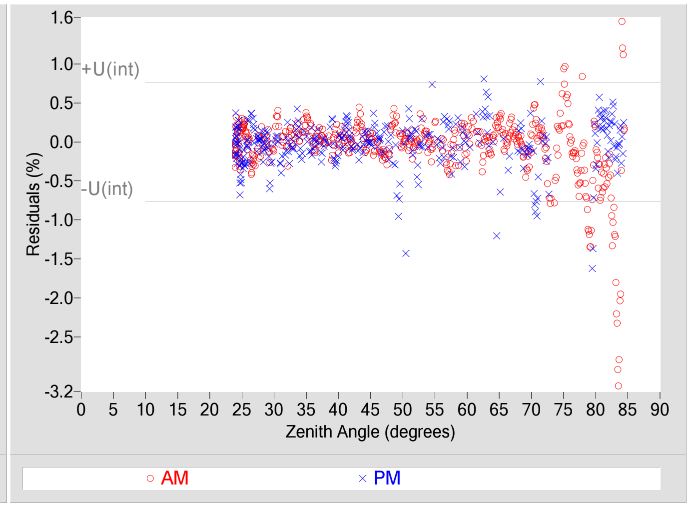


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.68
Type-A Interpolating Function, u(int) (%)	±0.38
Combined Standard Uncertainty, u(c) (%)	±0.78
Effective degrees of freedom, DF(c)	12552
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

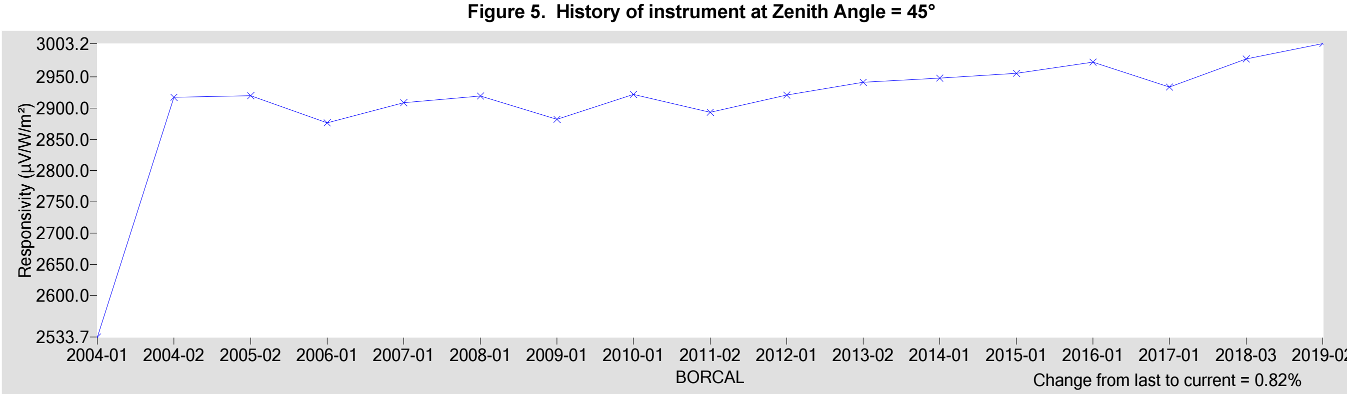
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
3003.2	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.2 / -1.3
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 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:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	080009
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

_______________________________________ ____________________

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

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

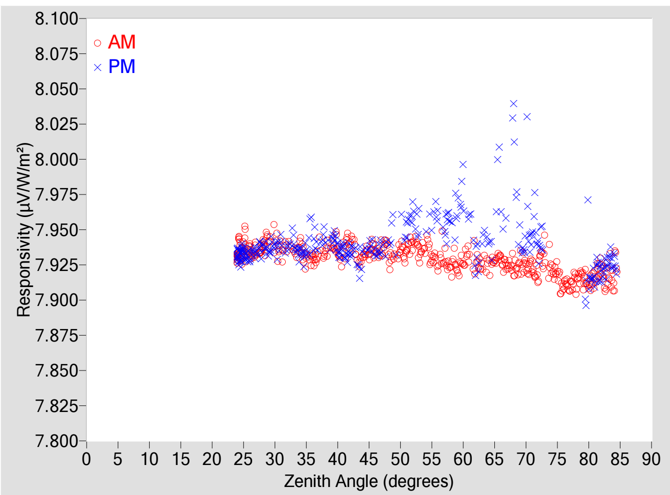


Figure 2. Responsivity vs Local Standard Time

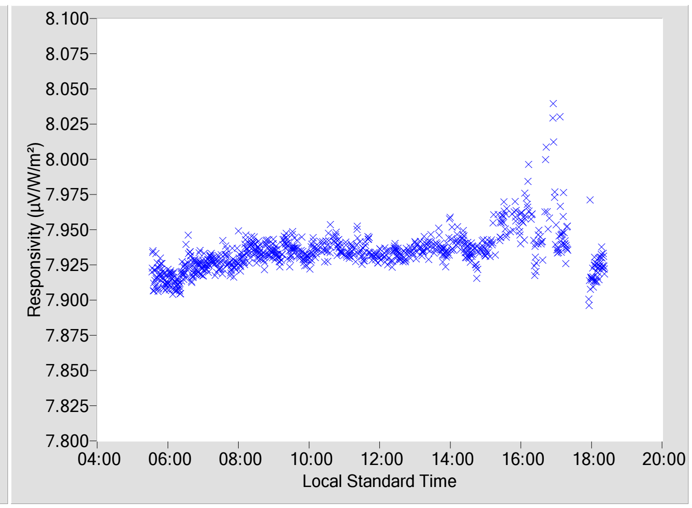


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9334	0.28	108.27	7.9331	0.28	251.93
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9337	0.28	105.88	7.9410	0.29	254.21
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9372	0.28	103.73	7.9609	0.30	256.55
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9393	0.28	101.79	7.9620	0.29	258.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9381	0.28	99.77	7.9486	0.30	260.54
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9231	0.28	97.82	7.9595	0.30	262.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9227	0.28	95.93	7.9556	0.30	264.14
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9254	0.29	94.15	7.9813	N/A	265.88
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9300	0.29	92.49	7.9301	0.30	267.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9252	0.29	90.77	7.9420	0.30	269.35
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9288	0.29	89.10	7.9627	N/A	271.06
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.9236	0.29	87.47	8.0270	N/A	272.67
24	7.9338	0.28	174.40	7.9317	0.28	185.29	70	7.9233	0.29	85.88	7.9690	N/A	274.32
26	7.9350	0.28	153.95	7.9314	0.28	205.72	72	7.9206	0.30	84.26	7.9368	N/A	275.94
28	7.9377	0.28	144.37	7.9359	0.28	215.69	74	7.9254	0.30	82.64	N/A	N/A	N/A
30	7.9430	0.28	137.22	7.9390	0.28	223.11	76	7.9103	0.30	81.04	N/A	N/A	N/A
32	7.9383	0.28	131.86	7.9378	0.28	228.47	78	7.9128	N/A	79.42	N/A	N/A	N/A
34	7.9379	0.28	126.98	7.9337	0.28	233.02	80	7.9112	N/A	77.77	7.9139	N/A	282.51
36	7.9288	0.28	122.98	7.9460	0.28	237.23	82	7.9219	N/A	76.16	7.9200	N/A	284.04
38	7.9327	0.28	119.44	7.9465	0.28	240.44	84	7.9192	N/A	74.45	7.9262	N/A	285.76
40	7.9388	0.28	116.30	7.9356	0.28	243.86	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9406	0.28	113.46	7.9350	0.28	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9306	0.28	110.66	7.9298	0.28	249.41	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

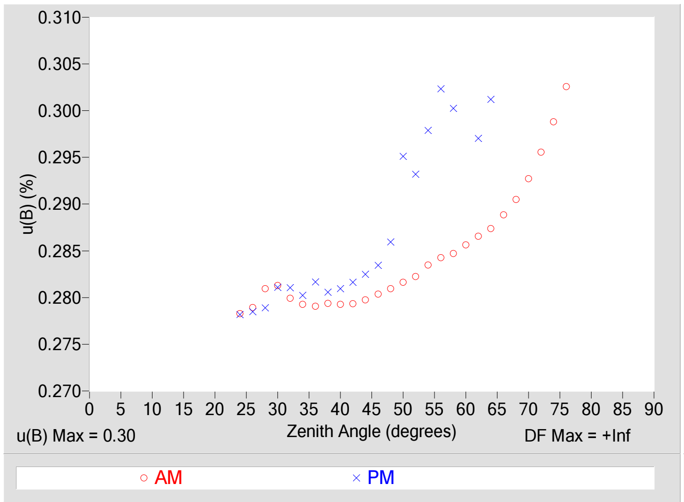


Figure 4. Residuals from Spline Interpolation

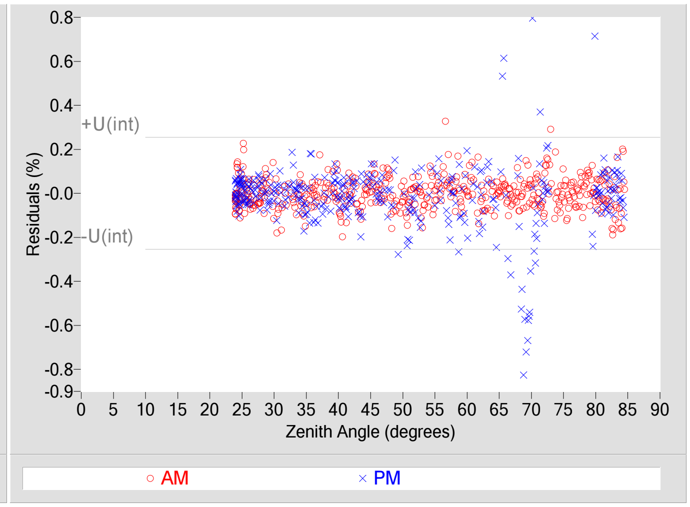


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.33
Effective degrees of freedom, DF(c)	30753
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.64
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

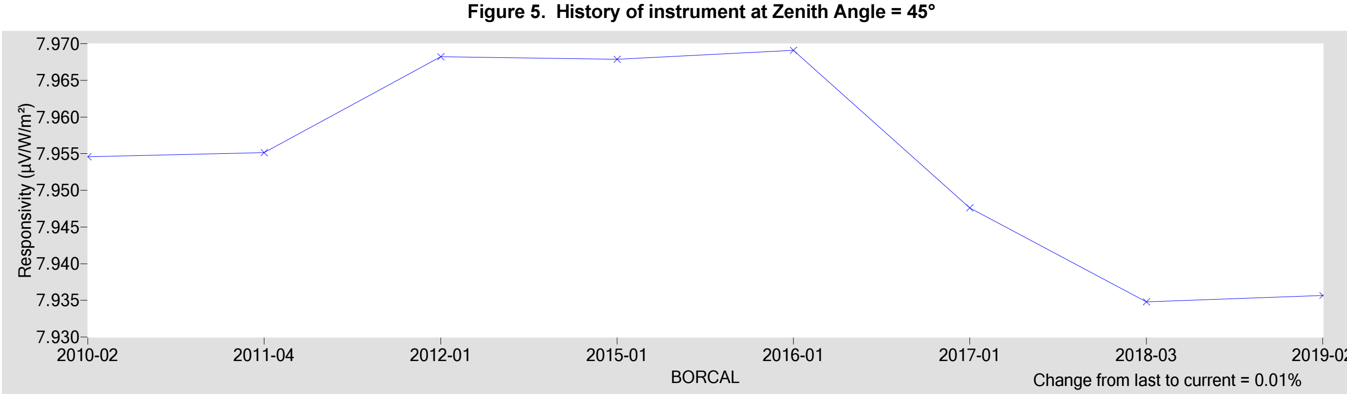
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9357	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.58 / -0.16
Expanded Uncertainty, U (%)	+1.2 / -0.76
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	080017
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CGR4, S/N 140021	04/02/2019	04/02/2023

† 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: RCC

_______________________________ _______________

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

080017 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),
= $Win - Wout$ = $Win - \sigma * Tc^4$
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

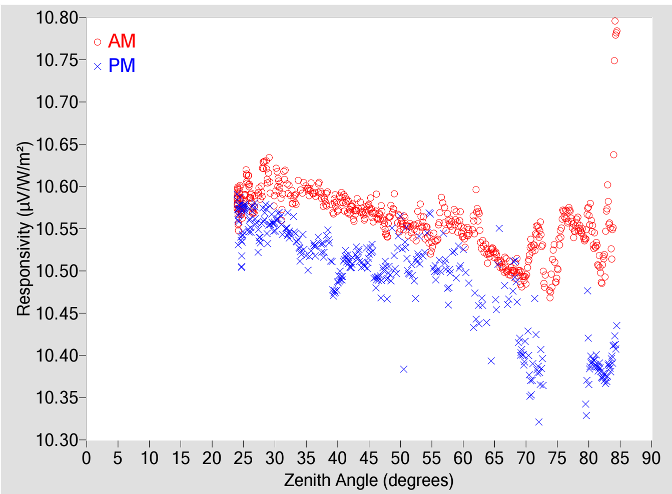


Figure 2. Responsivity vs Local Standard Time

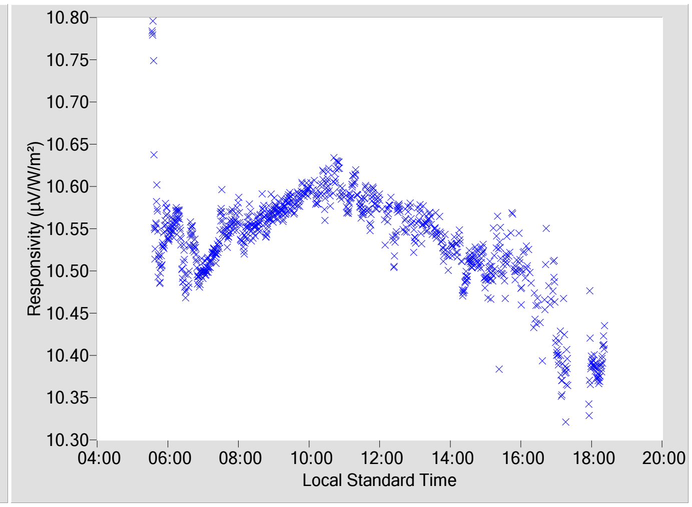


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.572	0.34	108.16	10.489	0.38	251.95
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.551	0.35	105.90	10.490	0.39	254.15
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.556	0.36	103.75	10.546	0.44	256.52
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.548	0.37	101.62	10.497	0.44	258.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.548	0.38	99.69	10.534	0.47	260.51
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.551	0.38	97.74	10.504	0.50	262.26
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.555	0.39	95.95	10.507	0.51	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.543	0.41	94.21	10.525	N/A	265.93
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.571	0.42	92.43	10.458	0.51	267.64
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.517	0.43	90.79	10.439	0.53	269.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.507	0.46	89.11	10.550	N/A	270.80
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.498	0.48	87.49	10.493	N/A	272.71
24	10.578	0.32	174.57	10.569	0.32	187.00	70	10.494	0.52	85.85	10.413	N/A	274.28
26	10.596	0.32	154.04	10.556	0.32	206.09	72	10.549	0.56	84.23	10.369	N/A	275.91
28	10.612	0.33	144.18	10.563	0.33	215.96	74	10.485	0.63	82.66	N/A	N/A	N/A
30	10.596	0.34	137.18	10.555	0.34	222.79	76	10.566	0.69	81.05	N/A	N/A	N/A
32	10.599	0.33	131.41	10.549	0.34	228.40	78	10.555	N/A	79.44	N/A	N/A	N/A
34	10.601	0.33	127.26	10.524	0.34	233.04	80	10.569	N/A	77.79	10.407	N/A	282.39
36	10.596	0.33	123.03	10.529	0.35	237.26	82	10.500	N/A	76.13	10.377	N/A	284.05
38	10.583	0.33	119.43	10.527	0.35	240.58	84	10.677	N/A	74.47	10.410	N/A	285.73
40	10.578	0.33	116.28	10.487	0.36	243.96	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.573	0.34	113.30	10.507	0.39	246.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.568	0.34	110.74	10.507	0.39	249.50	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

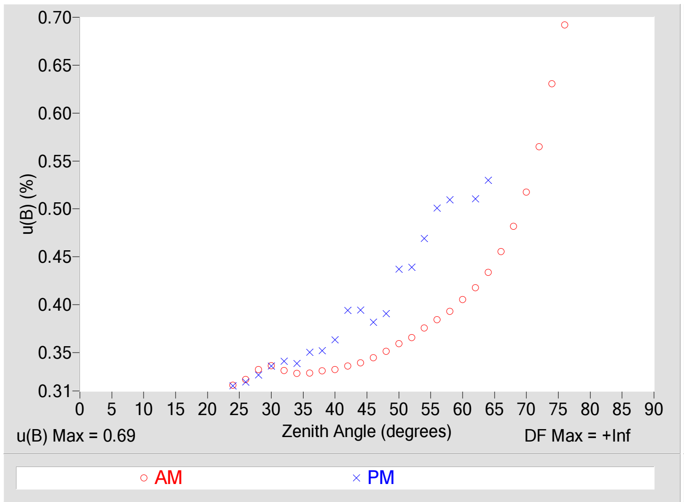


Figure 4. Residuals from Spline Interpolation

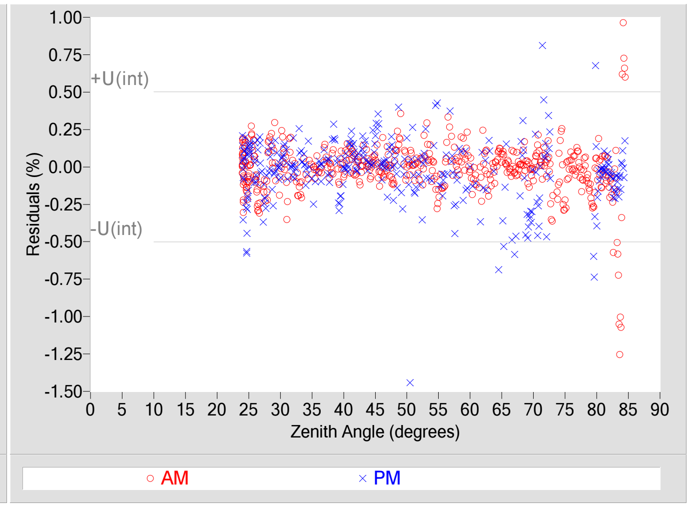


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.74
Effective degrees of freedom, DF(c)	52439
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

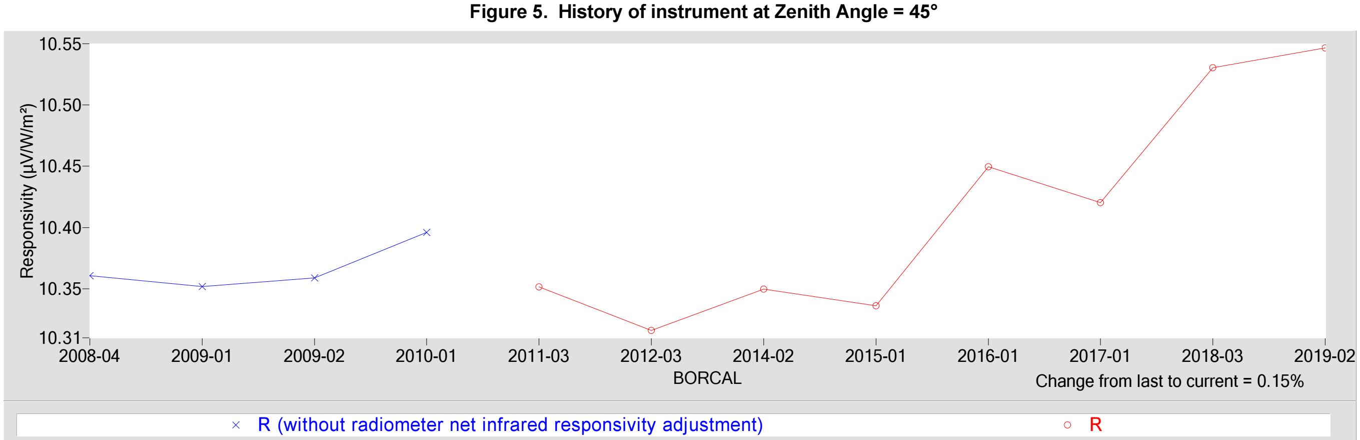
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.547	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+0.52 / -0.57
Expanded Uncertainty, U (%)	+1.5 / -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: Pyranometer

Manufacturer: Kipp & Zonen

Model: CMP22

Serial Number: 100174

Calibration Date: 5/3/2019

Due Date: 5/3/2020

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/3

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

________________________________ 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:

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

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

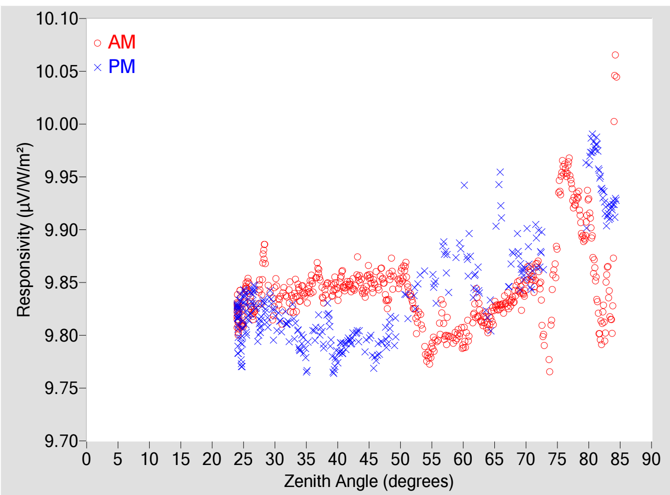


Figure 2. Responsivity vs Local Standard Time

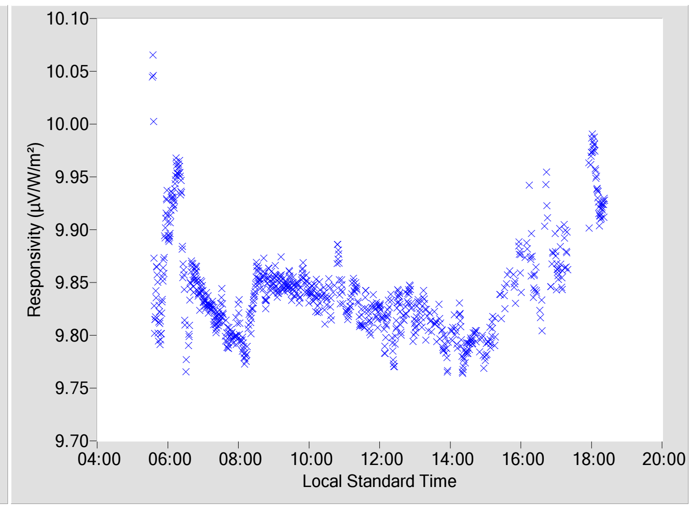


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	9.8526	0.34	108.34	9.7747	0.38	251.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8361	0.35	105.95	9.7981	0.39	254.21
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8557	0.36	103.74	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8303	0.37	101.75	9.8414	0.44	258.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7817	0.38	99.63	9.8610	0.47	260.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8002	0.38	97.78	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7992	0.39	96.09	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7959	0.41	94.20	9.9422	N/A	266.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8275	0.42	92.45	9.8525	0.51	267.59
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.8088	0.43	90.79	9.8250	0.55	269.45
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.8276	0.46	89.10	9.9295	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.8351	0.48	87.49	9.8782	N/A	272.60
24	9.8193	0.32	174.60	9.8146	0.32	185.66	70	9.8498	0.52	85.85	9.8824	N/A	274.28
26	9.8353	0.32	153.77	9.8248	0.32	206.06	72	9.8593	0.56	84.27	9.8759	N/A	275.91
28	9.8598	0.33	144.08	9.8222	0.33	215.43	74	9.8082	0.63	82.63	N/A	N/A	N/A
30	9.8377	0.34	137.37	9.8127	0.34	222.58	76	9.9586	0.69	81.04	N/A	N/A	N/A
32	9.8390	0.33	131.78	9.8087	0.34	228.46	78	9.9281	N/A	79.43	N/A	N/A	N/A
34	9.8399	0.33	127.08	9.7898	0.34	233.16	80	9.9225	N/A	77.83	9.9682	N/A	282.52
36	9.8476	0.33	123.17	9.8044	0.35	237.42	82	9.8059	N/A	76.17	9.9406	N/A	284.05
38	9.8399	0.33	119.47	9.8036	0.35	240.73	84	9.9362	N/A	74.51	9.9226	N/A	285.72
40	9.8402	0.33	116.28	9.7809	0.36	243.88	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8472	0.34	113.44	9.7945	0.39	246.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8438	0.34	110.71	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

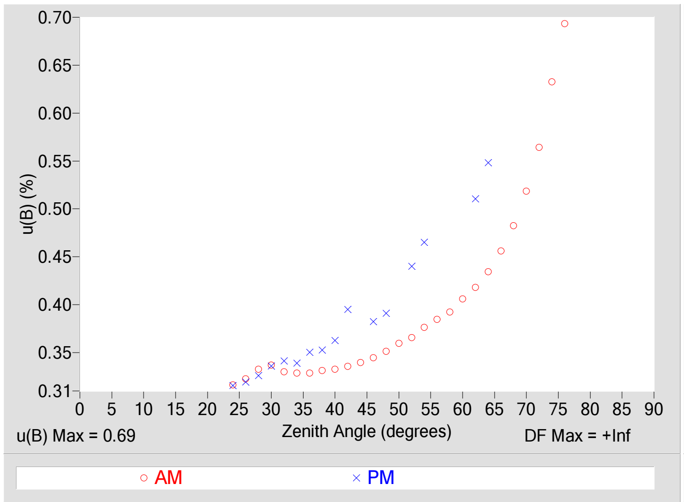


Figure 4. Residuals from Spline Interpolation

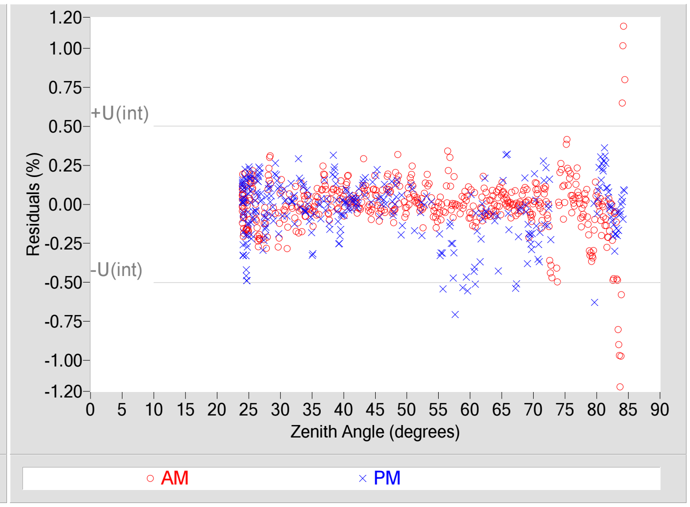


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.74
Effective degrees of freedom, DF(c)	50869
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

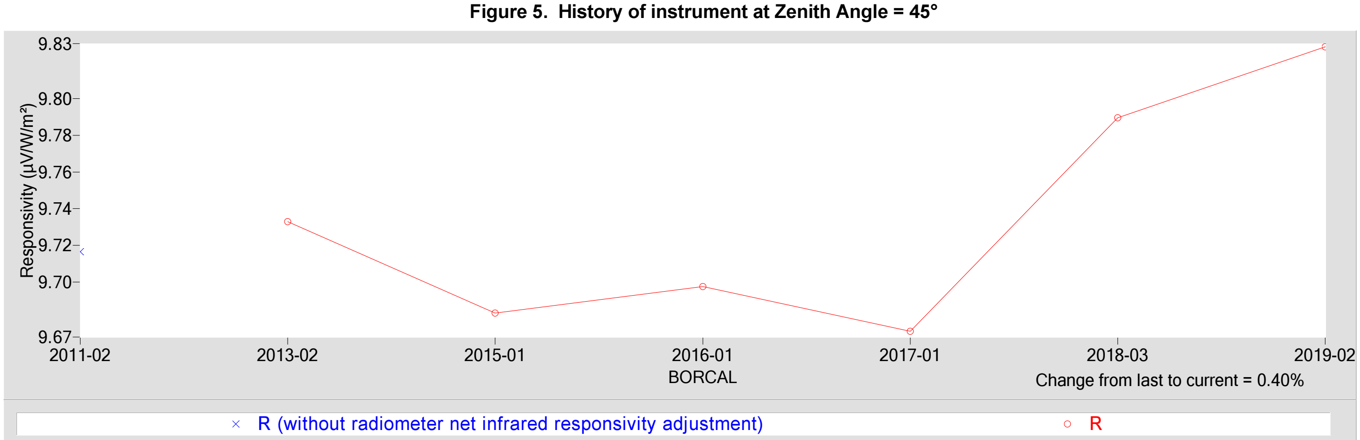
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.8283	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+1.2 / -0.55
Expanded Uncertainty, U (%)	+2.1 / -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:	Thermopile Pyranometer	**Manufacturer:**	Apogee
Model:	SP-510	**Serial Number:**	1171
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

______________________________ _______________

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

1171 Apogee SP-510

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

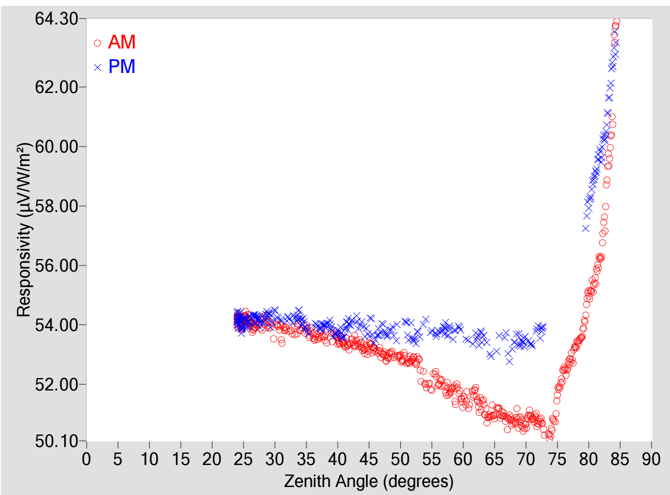


Figure 2. Responsivity vs Local Standard Time

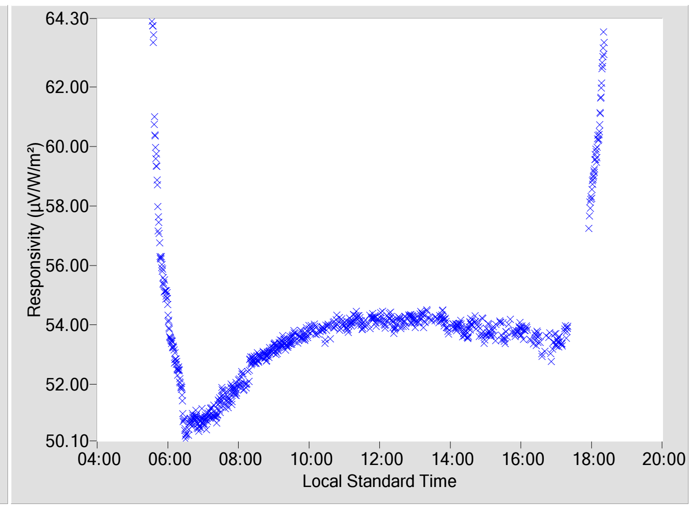


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	53.172	0.36	108.30	53.509	0.40	251.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	52.937	0.37	105.92	53.630	0.41	254.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	52.898	0.37	103.76	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	52.833	0.38	101.67	53.509	0.46	258.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	51.969	0.40	99.70	54.192	0.50	260.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	52.080	0.41	97.77	53.753	0.53	262.34
12	N/A	N/A	N/A	N/A	N/A	N/A	58	51.781	0.43	95.96	53.901	0.53	264.01
14	N/A	N/A	N/A	N/A	N/A	N/A	60	51.450	0.44	94.22	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	51.720	0.46	92.47	53.599	0.54	267.75
18	N/A	N/A	N/A	N/A	N/A	N/A	64	50.877	0.48	90.80	53.218	0.56	269.37
20	N/A	N/A	N/A	N/A	N/A	N/A	66	51.005	0.50	89.12	53.641	N/A	270.81
22	N/A	N/A	N/A	N/A	N/A	N/A	68	50.718	0.53	87.53	53.340	N/A	272.73
24	54.183	0.33	175.30	54.157	0.33	185.06	70	50.641	0.57	85.87	53.433	N/A	274.16
26	54.112	0.33	154.13	54.144	0.33	205.45	72	50.707	0.61	84.24	53.798	N/A	275.91
28	53.978	0.34	144.74	54.159	0.34	216.35	74	50.426	0.69	82.67	N/A	N/A	N/A
30	53.770	0.35	137.11	54.490	0.35	222.79	76	52.440	0.76	81.02	N/A	N/A	N/A
32	53.851	0.34	131.79	54.227	0.35	228.43	78	53.316	N/A	79.45	N/A	N/A	N/A
34	53.815	0.34	126.91	54.240	0.35	233.17	80	55.013	N/A	77.80	58.052	N/A	282.37
36	53.676	0.34	122.81	N/A	N/A	N/A	82	56.471	N/A	76.14	59.845	N/A	284.02
38	53.549	0.34	119.43	53.983	0.37	240.70	84	62.605	N/A	74.47	63.130	N/A	285.70
40	53.475	0.35	116.20	53.721	0.38	243.84	86	N/A	N/A	N/A	N/A	N/A	N/A
42	53.390	0.35	113.31	54.043	0.41	246.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	53.232	0.35	110.76	54.019	0.41	249.39	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

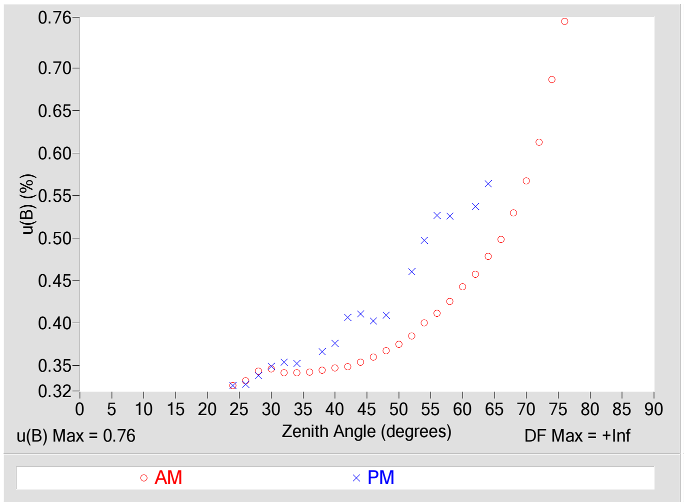


Figure 4. Residuals from Spline Interpolation

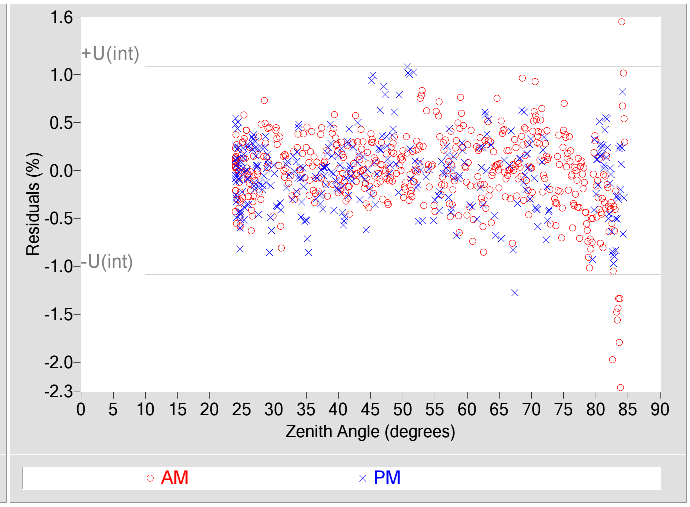


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.76
Type-A Interpolating Function, u(int) (%)	±0.54
Combined Standard Uncertainty, u(c) (%)	±0.93
Effective degrees of freedom, DF(c)	5659
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.8
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

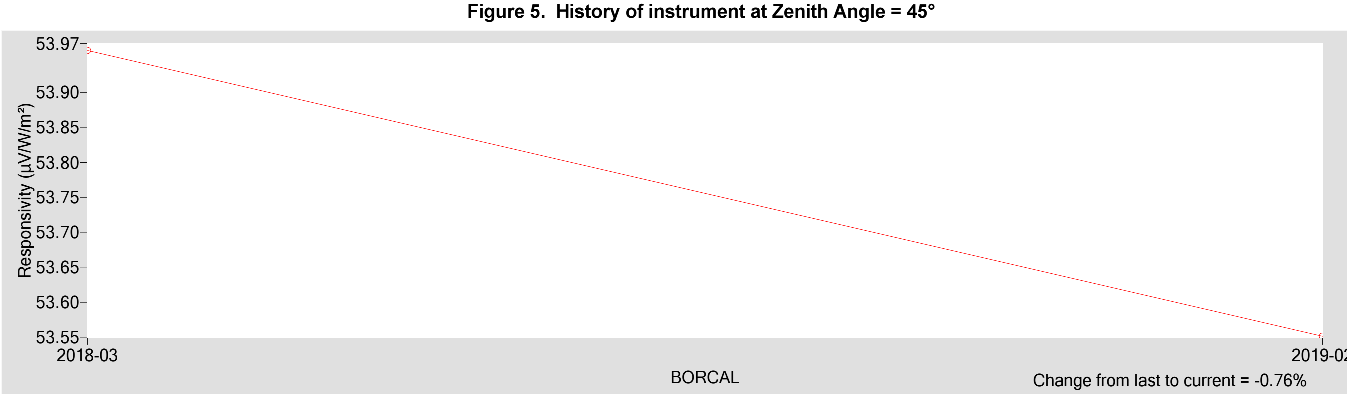
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
53.551	2.5000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.8 / -3.9
Expanded Uncertainty, U (%)	+2.8 / -5.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	140043
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

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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:

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

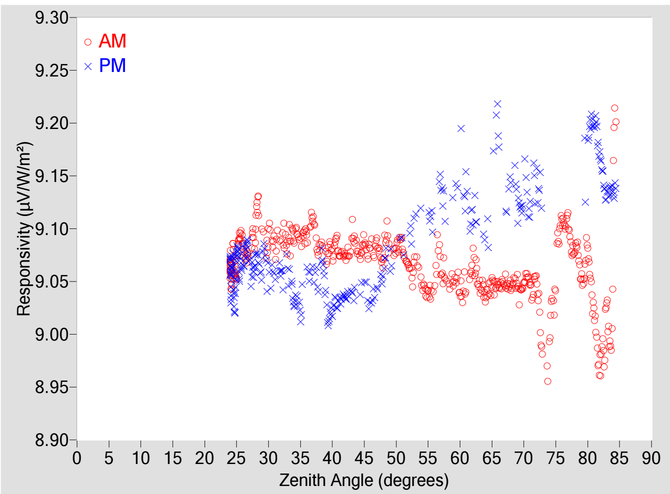


Figure 2. Responsivity vs Local Standard Time

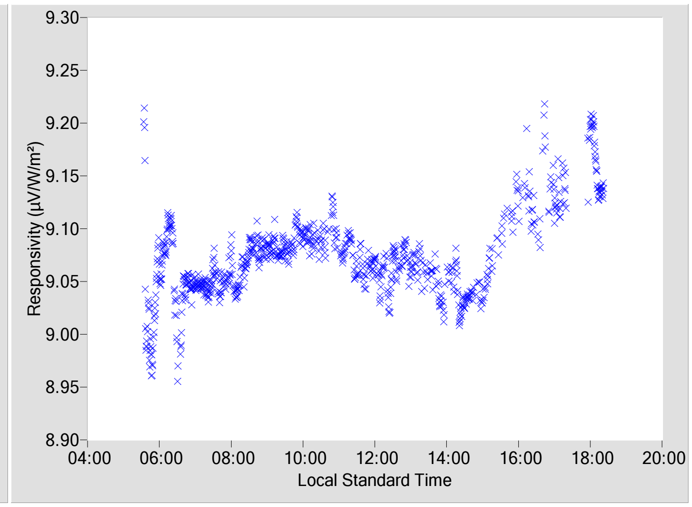


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.0846	0.35	108.34	9.0283	0.38	251.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0732	0.35	105.95	9.0594	0.39	254.21
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0832	0.36	103.74	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0650	0.37	101.75	9.0993	0.44	258.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0474	0.38	99.63	9.1193	0.47	260.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0505	0.39	97.78	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0507	0.39	96.09	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0433	0.41	94.20	9.1948	N/A	266.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0651	0.42	92.45	9.1132	0.51	267.59
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0365	0.44	90.79	9.0994	0.55	269.45
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0464	0.46	89.10	9.1945	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.0462	0.48	87.49	9.1463	N/A	272.60
24	9.0606	0.32	174.60	9.0587	0.32	185.66	70	9.0487	0.52	85.85	9.1442	N/A	274.28
26	9.0846	0.32	153.77	9.0691	0.32	206.06	72	9.0466	0.57	84.27	9.1351	N/A	275.91
28	9.1059	0.33	144.08	9.0693	0.33	215.43	74	8.9907	0.63	82.63	N/A	N/A	N/A
30	9.0920	0.34	137.37	9.0557	0.34	222.58	76	9.1073	0.69	81.04	N/A	N/A	N/A
32	9.0912	0.33	131.78	9.0563	0.34	228.46	78	9.0799	N/A	79.43	N/A	N/A	N/A
34	9.0943	0.33	127.08	9.0310	0.34	233.16	80	9.0779	N/A	77.83	9.1888	N/A	282.52
36	9.0927	0.33	123.17	9.0613	0.35	237.42	82	8.9739	N/A	76.17	9.1635	N/A	284.05
38	9.0810	0.33	119.47	9.0546	0.35	240.73	84	9.1013	N/A	74.51	9.1362	N/A	285.72
40	9.0758	0.33	116.28	9.0231	0.36	243.88	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0738	0.34	113.44	9.0350	0.40	246.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0794	0.34	110.71	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

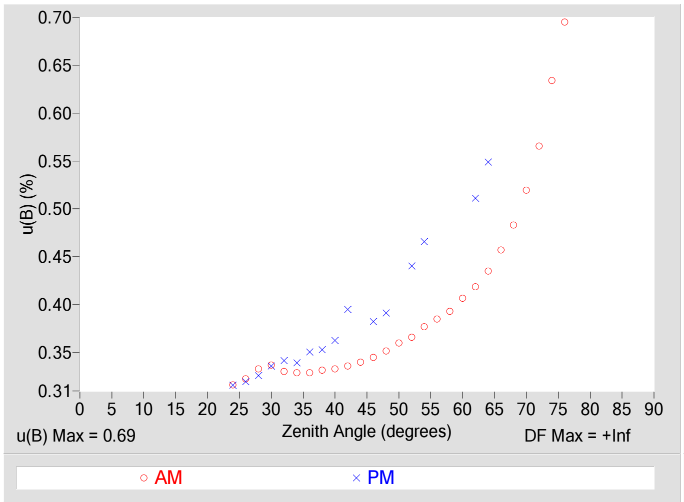


Figure 4. Residuals from Spline Interpolation

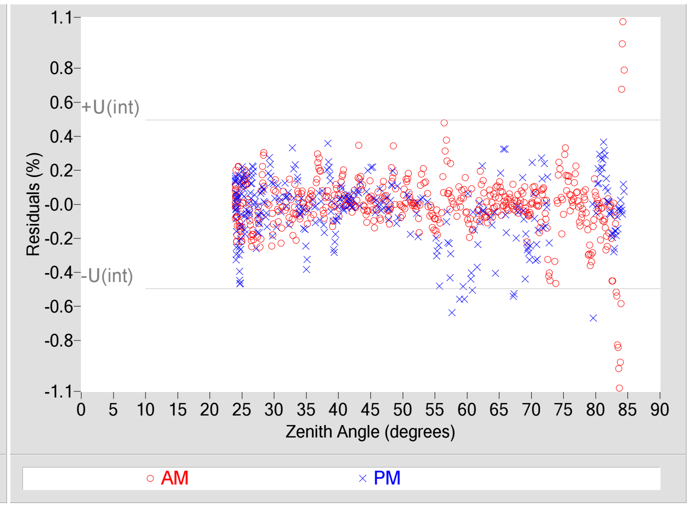


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.74
Effective degrees of freedom, DF(c)	53737
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

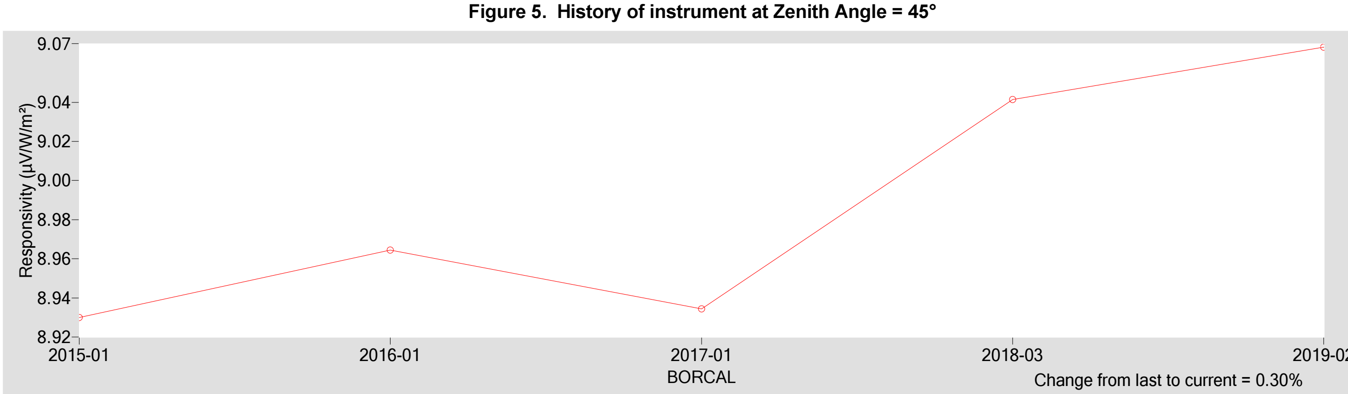
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.0682	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+1.4 / -0.50
Expanded Uncertainty, U (%)	+2.3 / -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:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	140108
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

______________________________ ______________

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

140108 Kipp & Zonen CHP1

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

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

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

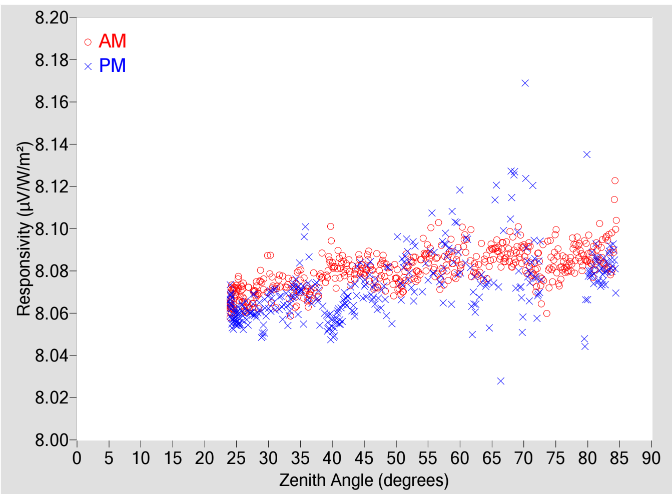


Figure 2. Responsivity vs Local Standard Time

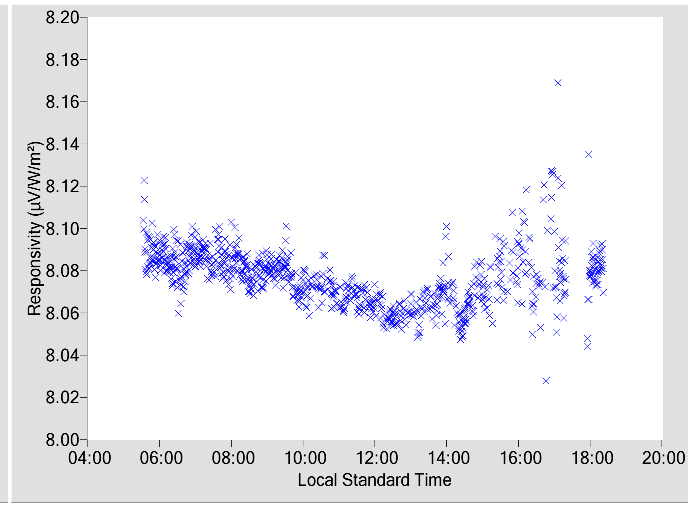


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0800	0.28	108.27	8.0744	0.28	251.93
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0812	0.28	105.88	8.0701	0.29	254.21
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0774	0.28	103.73	8.0962	0.30	256.55
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0798	0.28	101.79	8.0821	0.29	258.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0861	0.28	99.77	8.0702	0.30	260.54
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0799	0.28	97.82	8.0822	0.30	262.18
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0824	0.28	95.93	8.0901	0.30	264.14
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0814	0.29	94.15	8.0955	N/A	265.88
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0849	0.29	92.49	8.0649	0.30	267.72
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0834	0.29	90.77	8.0743	0.30	269.35
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0895	0.29	89.10	8.0724	N/A	271.06
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.0886	0.29	87.47	8.1155	N/A	272.67
24	8.0655	0.28	174.40	8.0639	0.28	185.29	70	8.0875	0.29	85.88	8.1004	N/A	274.32
26	8.0679	0.28	153.95	8.0595	0.28	205.72	72	8.0785	0.30	84.26	8.0697	N/A	275.94
28	8.0697	0.28	144.37	8.0612	0.28	215.69	74	8.0848	0.30	82.64	N/A	N/A	N/A
30	8.0786	0.28	137.22	8.0677	0.28	223.11	76	8.0820	0.30	81.04	N/A	N/A	N/A
32	8.0760	0.28	131.86	8.0639	0.28	228.47	78	8.0880	N/A	79.42	N/A	N/A	N/A
34	8.0698	0.28	126.98	8.0719	0.28	233.02	80	8.0887	N/A	77.77	8.0876	N/A	282.47
36	8.0690	0.28	122.98	8.0804	0.28	237.23	82	8.0900	N/A	76.16	8.0781	N/A	284.04
38	8.0734	0.28	119.44	8.0635	0.28	240.44	84	8.0990	N/A	74.45	8.0852	N/A	285.76
40	8.0874	0.28	116.30	8.0519	0.28	243.86	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0809	0.28	113.46	8.0661	0.28	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0835	0.28	110.66	8.0758	0.28	249.41	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

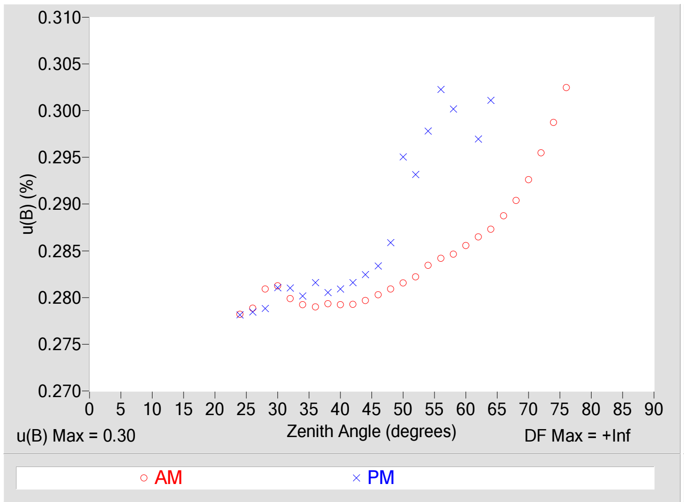


Figure 4. Residuals from Spline Interpolation

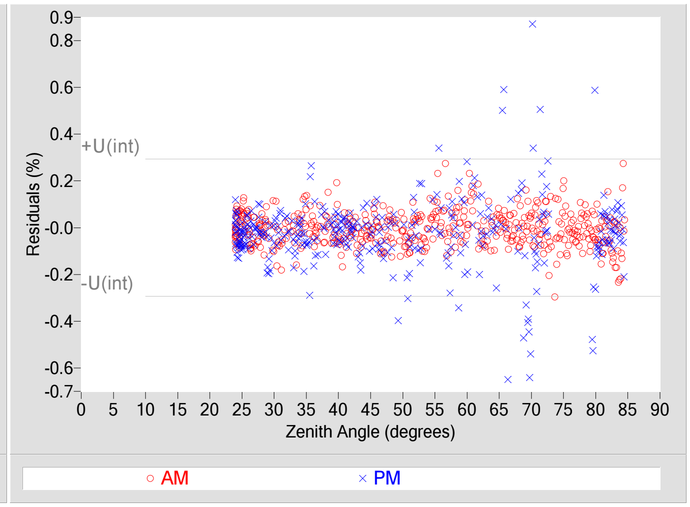


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.34
Effective degrees of freedom, DF(c)	19237
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.66
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

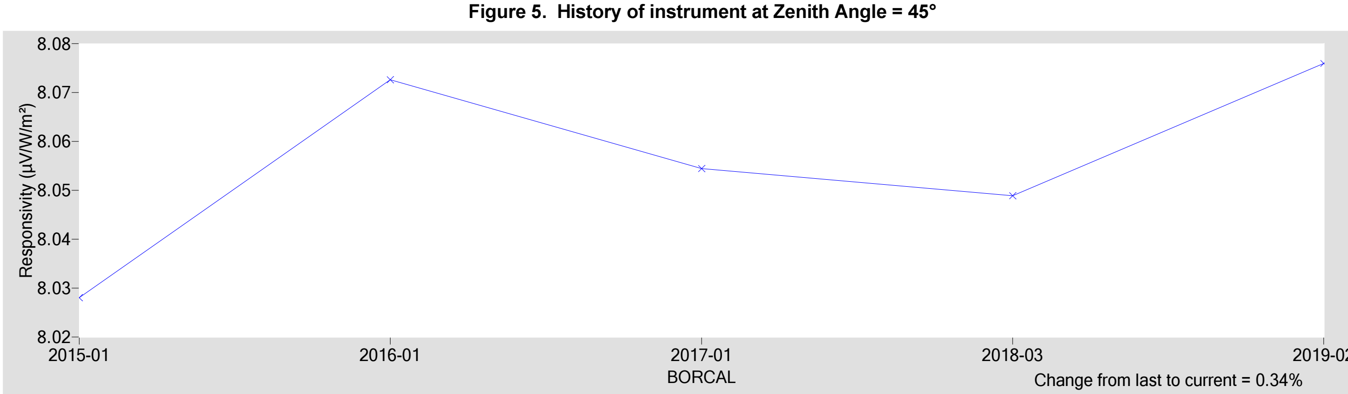
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0759	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.25 / -0.30
Expanded Uncertainty, U (%)	+0.84 / -0.89
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP11	**Serial Number:**	140712
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

________________________________ ______________

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:

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

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

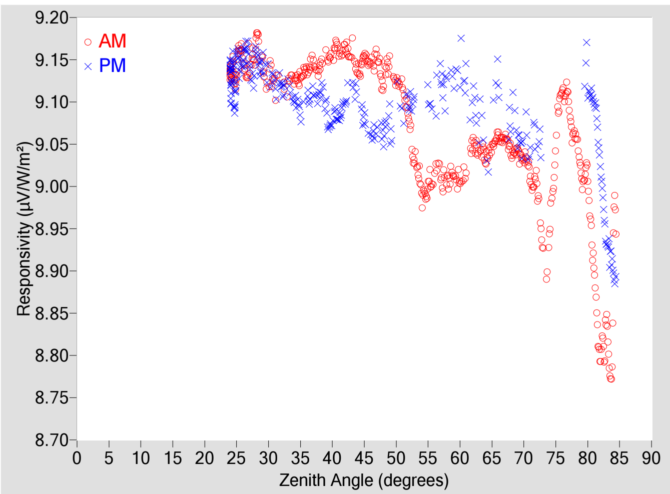


Figure 2. Responsivity vs Local Standard Time

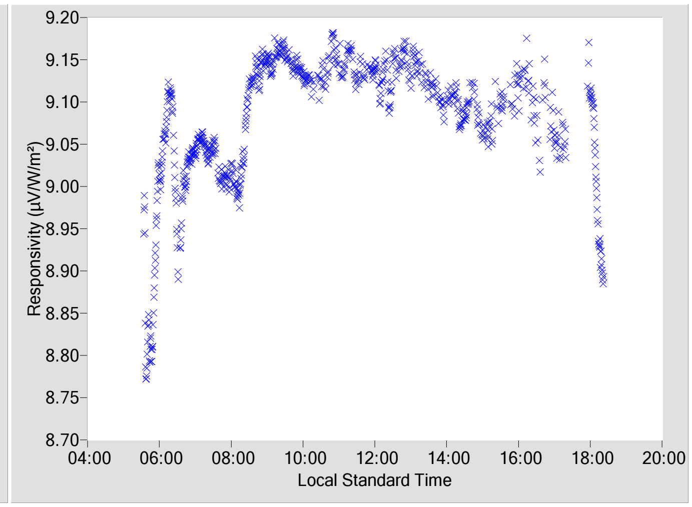


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.1476	0.35	108.31	9.0580	0.39	252.02
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1229	0.35	105.99	9.0610	0.40	254.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1244	0.36	103.74	9.1242	0.44	256.51
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0797	0.37	101.69	9.0995	0.44	258.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9930	0.38	99.68	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0149	0.39	97.78	9.0832	N/A	262.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0061	0.40	95.94	9.1293	0.51	263.98
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0080	0.41	94.23	9.1464	N/A	266.02
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0491	0.42	92.45	9.1090	0.51	267.67
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0343	0.44	90.78	9.0307	N/A	269.53
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0595	0.46	89.14	9.1252	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.0422	0.49	87.48	9.0853	N/A	272.63
24	9.1351	0.32	175.08	9.1296	0.32	185.09	70	9.0334	0.53	85.84	9.0534	N/A	274.14
26	9.1515	0.32	154.05	9.1485	0.32	205.96	72	9.0025	0.57	84.26	9.0458	N/A	275.90
28	9.1678	0.34	144.11	9.1540	0.33	215.79	74	8.9502	0.64	82.61	N/A	N/A	N/A
30	9.1324	0.34	137.05	9.1284	0.34	222.72	76	9.1111	0.70	81.04	N/A	N/A	N/A
32	N/A	N/A	N/A	9.1182	0.34	228.55	78	9.0606	N/A	79.43	N/A	N/A	N/A
34	9.1263	0.33	126.67	9.1012	0.34	233.22	80	9.0099	N/A	77.82	9.1291	N/A	282.39
36	9.1368	0.33	122.99	9.1073	0.35	237.50	82	8.8054	N/A	76.17	9.0202	N/A	284.05
38	9.1392	0.33	119.50	9.1092	0.36	240.73	84	8.8845	N/A	74.50	8.8989	N/A	285.72
40	9.1569	0.34	116.16	9.0782	0.37	243.88	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1656	0.34	113.29	9.0997	0.40	246.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1374	0.34	110.67	9.1116	0.40	249.09	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

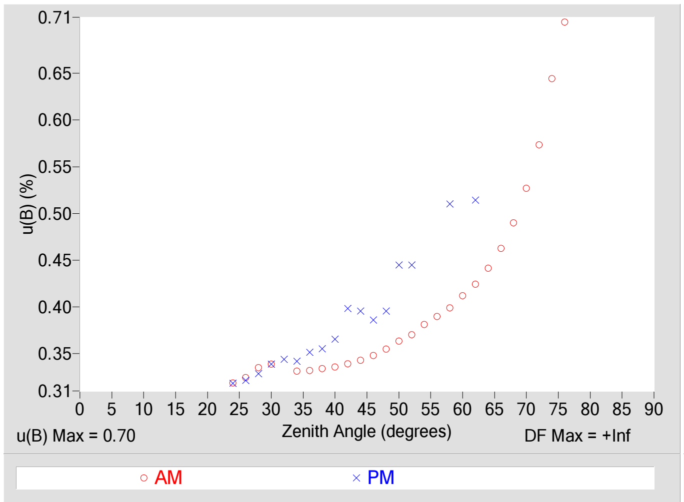


Figure 4. Residuals from Spline Interpolation

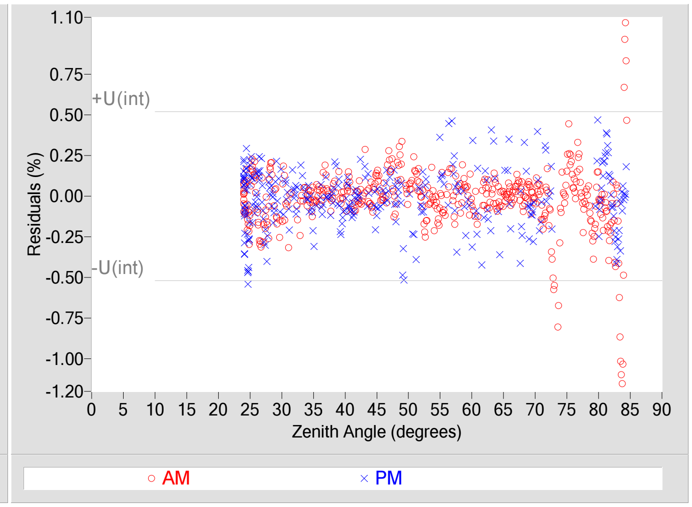


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.70
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	46379
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 62°

‡ 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

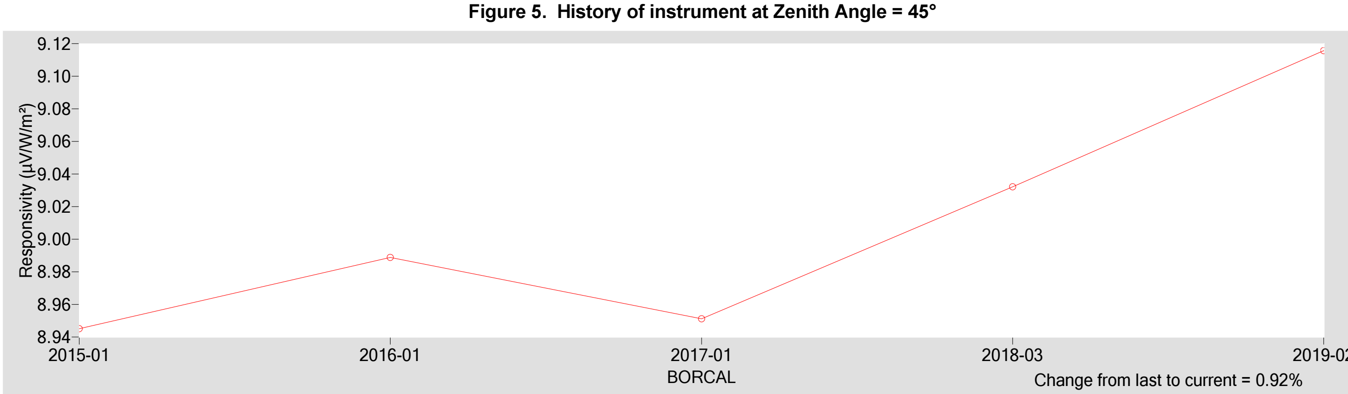
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.1157	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+0.55 / -1.3
Expanded Uncertainty, U (%)	+1.5 / -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 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:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

______________________________ ____________

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

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* [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

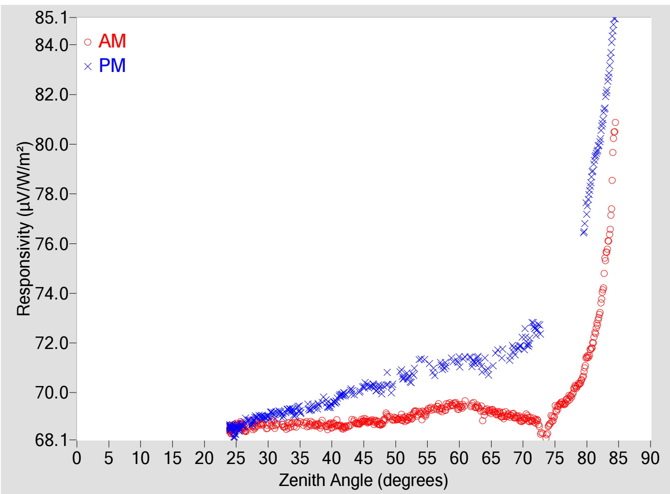


Figure 2. Responsivity vs Local Standard Time

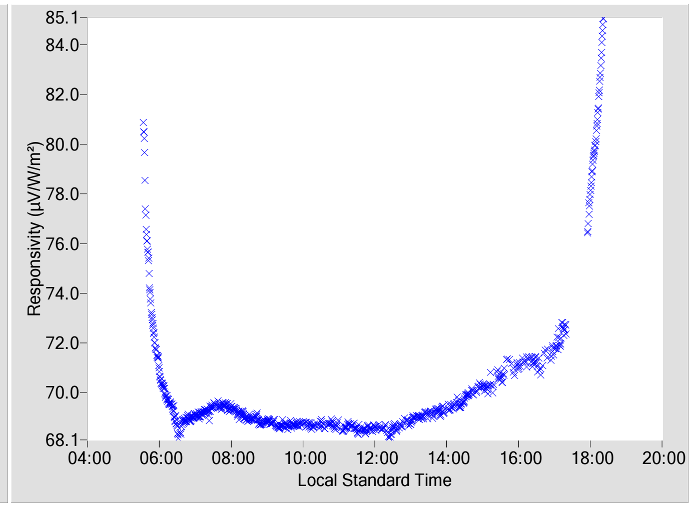


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	68.844	0.34	108.30	70.244	0.38	251.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	68.833	0.35	105.89	70.118	0.39	254.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	68.947	0.36	103.73	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	68.960	0.36	101.69	70.602	0.44	258.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	69.152	0.37	99.71	71.356	0.47	260.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	69.356	0.38	97.77	70.831	0.50	262.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	69.424	0.39	95.98	71.146	0.50	264.03
14	N/A	N/A	N/A	N/A	N/A	N/A	60	69.423	0.40	94.20	71.231	N/A	265.88
16	N/A	N/A	N/A	N/A	N/A	N/A	62	69.525	0.41	92.47	71.238	0.51	267.67
18	N/A	N/A	N/A	N/A	N/A	N/A	64	69.219	0.43	90.82	71.144	0.55	269.48
20	N/A	N/A	N/A	N/A	N/A	N/A	66	69.174	0.45	89.10	71.718	N/A	271.06
22	N/A	N/A	N/A	N/A	N/A	N/A	68	69.085	0.48	87.50	71.391	N/A	272.62
24	68.524	0.32	174.16	68.594	0.31	184.92	70	68.915	0.51	85.84	72.180	N/A	274.39
26	68.617	0.32	153.92	68.693	0.32	205.84	72	68.855	0.56	84.26	72.534	N/A	275.90
28	68.647	0.33	144.26	68.970	0.33	215.75	74	68.581	0.62	82.65	N/A	N/A	N/A
30	68.644	0.34	137.44	69.027	0.33	222.89	76	69.570	0.68	81.04	N/A	N/A	N/A
32	68.725	0.33	131.07	69.149	0.34	228.51	78	70.131	N/A	79.42	N/A	N/A	N/A
34	68.744	0.33	126.92	69.199	0.34	233.09	80	71.375	N/A	77.78	77.534	N/A	282.42
36	68.741	0.33	122.90	69.538	0.35	237.57	82	73.285	N/A	76.12	80.155	N/A	284.04
38	68.705	0.33	119.44	69.476	0.35	240.40	84	78.911	N/A	74.46	84.434	N/A	285.76
40	68.699	0.33	116.31	69.534	0.36	243.80	86	N/A	N/A	N/A	N/A	N/A	N/A
42	68.608	0.33	113.36	69.936	0.39	246.68	88	N/A	N/A	N/A	N/A	N/A	N/A
44	68.763	0.34	110.73	70.016	0.39	249.81	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

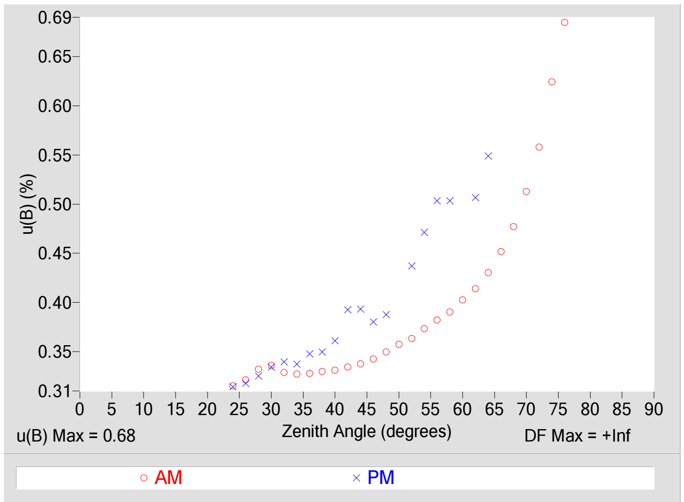


Figure 4. Residuals from Spline Interpolation

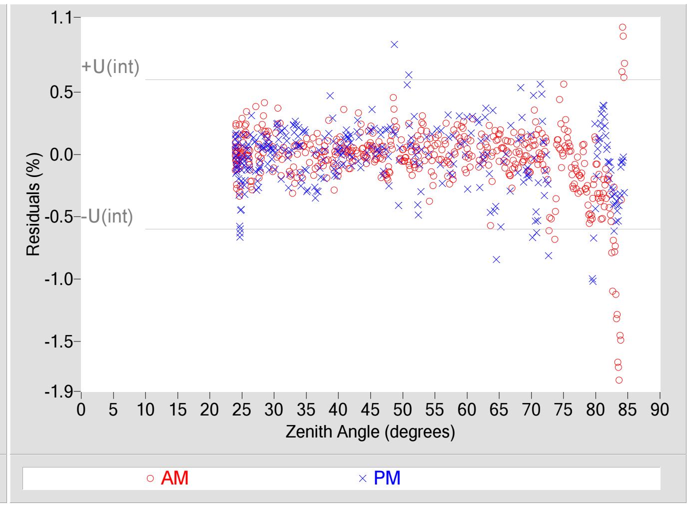


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.68
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	25796
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

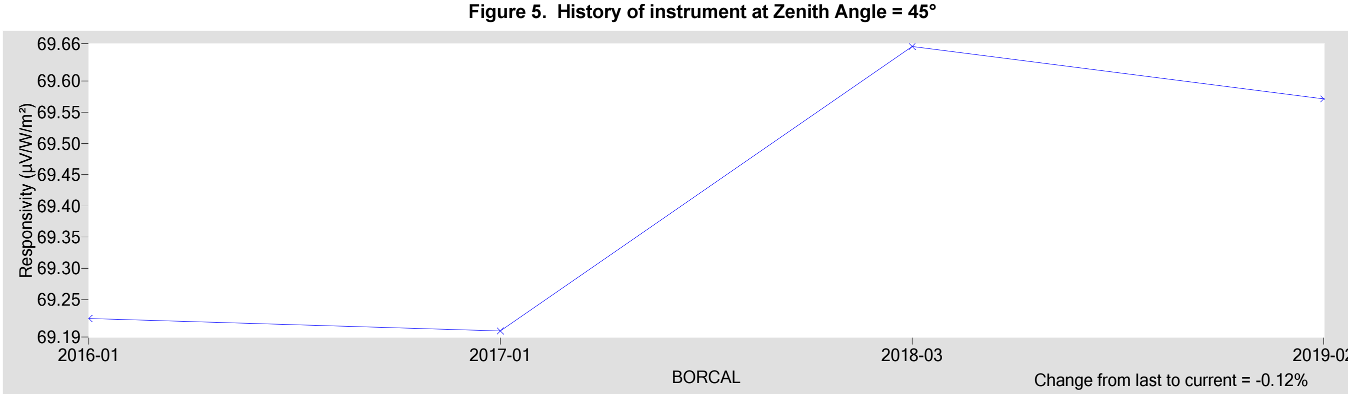
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
69.571	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+2.6 / -1.4
Expanded Uncertainty, U (%)	+3.6 / -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:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	170535
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

________________________________ ________________

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

170535 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

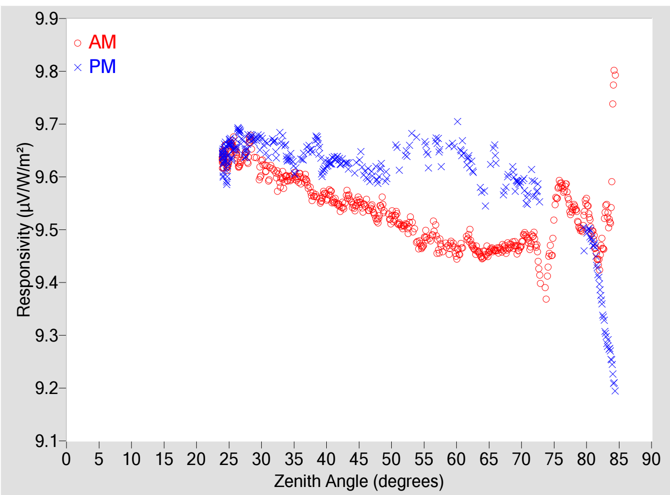


Figure 2. Responsivity vs Local Standard Time

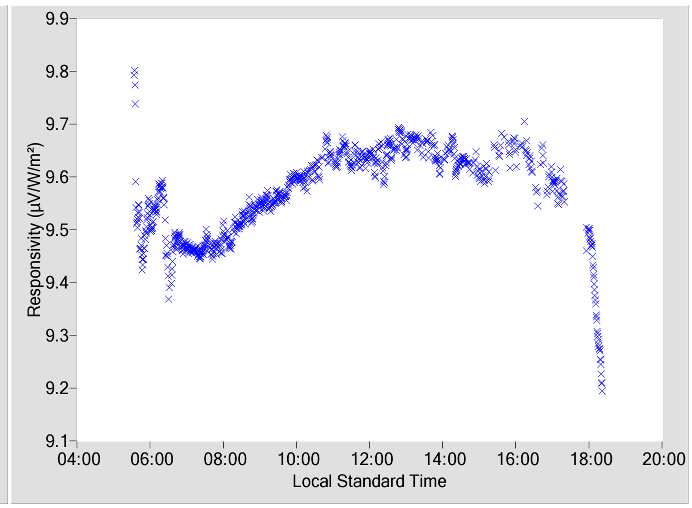


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.5498	0.34	108.34	9.6044	0.38	251.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.5238	0.35	105.95	9.5999	0.39	254.21
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.5240	0.36	103.74	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.5070	0.37	101.75	9.6452	0.44	258.65
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4740	0.38	99.63	9.6749	0.47	260.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4841	0.38	97.78	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4581	0.39	96.09	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.4569	0.41	94.20	9.7047	N/A	266.07
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.4840	0.42	92.45	9.6309	0.51	267.59
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.4493	0.43	90.79	9.5722	0.55	269.45
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.4621	0.46	89.10	9.6425	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.4676	0.48	87.49	9.6024	N/A	272.60
24	9.6339	0.32	174.60	9.6360	0.32	185.66	70	9.4747	0.52	85.85	9.5918	N/A	274.28
26	9.6467	0.32	153.77	9.6617	0.32	206.06	72	9.4817	0.56	84.27	9.5727	N/A	275.91
28	9.6526	0.33	144.08	9.6654	0.33	215.43	74	9.4148	0.63	82.63	N/A	N/A	N/A
30	9.6177	0.34	137.37	9.6671	0.34	222.58	76	9.5856	0.69	81.04	N/A	N/A	N/A
32	9.6115	0.33	131.78	9.6587	0.34	228.46	78	9.5413	N/A	79.43	N/A	N/A	N/A
34	9.5981	0.33	127.08	9.6339	0.34	233.16	80	9.5481	N/A	77.83	9.4978	N/A	282.52
36	9.5979	0.33	123.17	9.6336	0.35	237.42	82	9.4445	N/A	76.17	9.3914	N/A	284.05
38	9.5628	0.33	119.47	9.6576	0.35	240.73	84	9.6598	N/A	74.51	9.2330	N/A	285.72
40	9.5625	0.33	116.28	9.6233	0.36	243.88	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5444	0.34	113.44	9.6276	0.40	246.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.5471	0.34	110.71	N/A	N/A	N/A	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

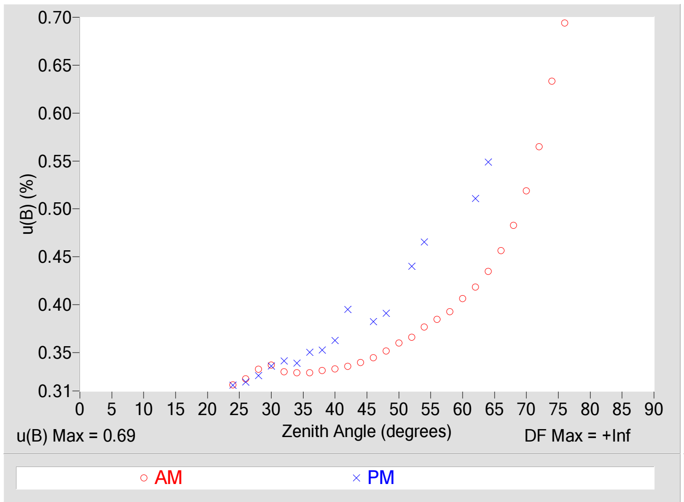


Figure 4. Residuals from Spline Interpolation

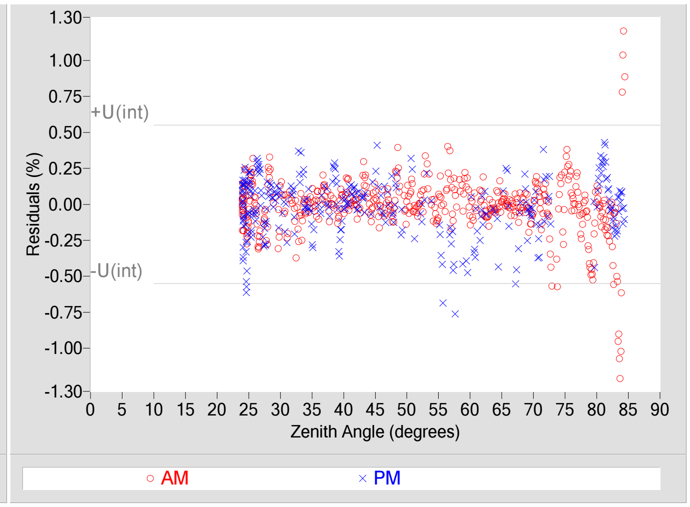


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	36639
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

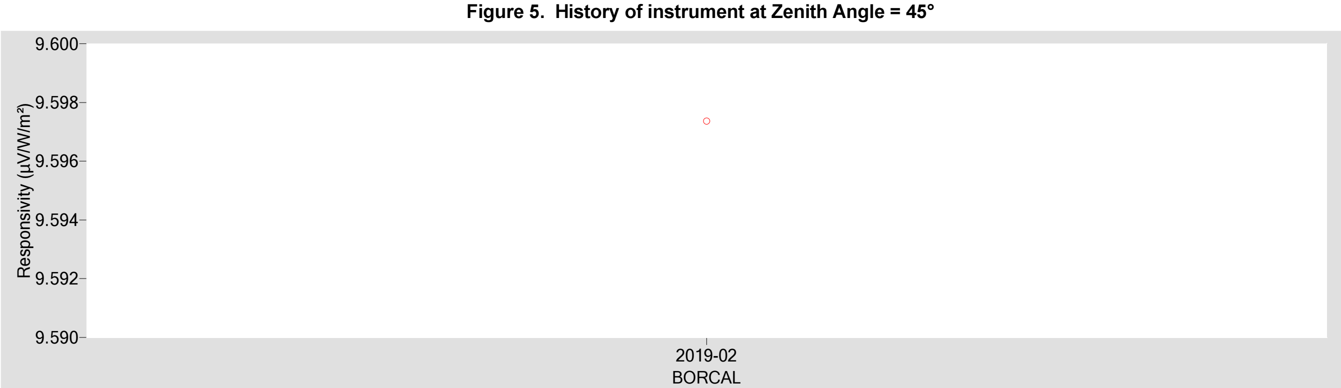
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.5974	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+1.1 / -1.5
Expanded Uncertainty, U (%)	+2.0 / -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

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument: Pyranometer
Manufacturer: Hukseflux
Model: SR25
Serial Number: 2529
Calibration Date: 5/3/2019
Due Date: 5/3/2020
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/3

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

_______________________________ _______________
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

2529 Hukseflux SR25

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

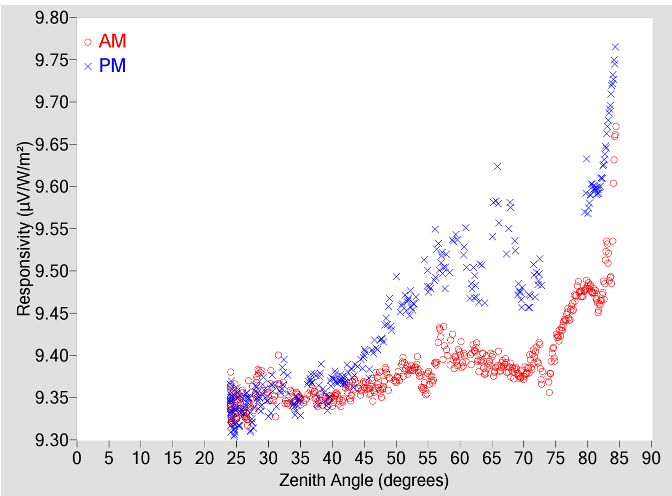


Figure 2. Responsivity vs Local Standard Time

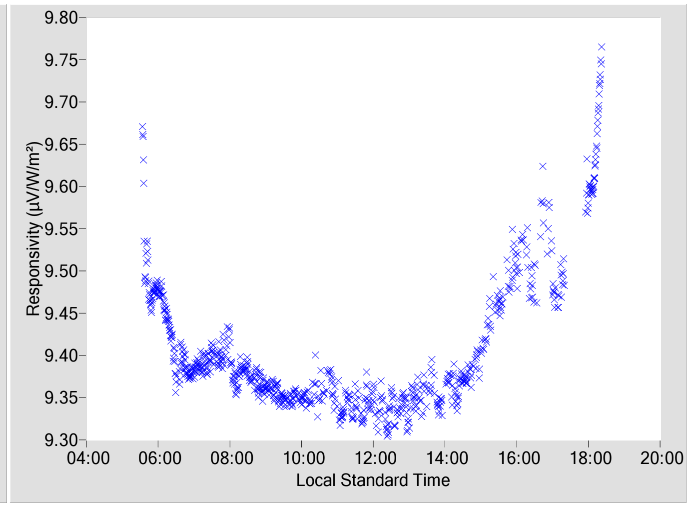


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.3629	0.34	108.24	9.3951	0.38	251.90
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.3647	0.35	105.94	9.4237	0.39	254.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3717	0.36	103.68	9.4934	0.43	256.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3825	0.37	101.72	9.4641	0.44	258.42
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3679	0.38	99.68	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3819	0.38	97.81	9.5103	0.51	262.44
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4035	0.39	96.04	9.5120	0.50	263.98
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.4027	0.41	94.17	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.4026	0.42	92.49	9.4840	0.51	267.68
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.3843	0.43	90.78	9.4623	0.55	269.25
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.3904	0.46	89.05	9.5868	N/A	271.01
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.3839	0.48	87.48	9.5780	N/A	272.59
24	9.3379	0.32	174.14	9.3432	0.32	185.41	70	9.3772	0.52	85.82	9.4798	N/A	274.13
26	9.3403	0.32	153.65	9.3364	0.32	205.79	72	9.3993	0.56	84.27	9.4849	N/A	275.96
28	9.3624	0.33	144.15	9.3546	0.33	216.06	74	9.3715	0.63	82.65	N/A	N/A	N/A
30	9.3562	0.34	137.21	9.3401	0.34	222.49	76	9.4319	0.69	81.04	N/A	N/A	N/A
32	9.3601	0.33	132.01	9.3649	0.34	228.56	78	9.4661	N/A	79.42	N/A	N/A	N/A
34	9.3440	0.33	126.86	9.3399	0.34	233.18	80	9.4828	N/A	77.82	9.5787	N/A	282.42
36	9.3498	0.33	123.10	9.3677	0.35	237.49	82	9.4627	N/A	76.16	9.6035	N/A	284.04
38	9.3497	0.33	119.38	9.3699	0.35	240.67	84	9.5829	N/A	74.48	9.7326	N/A	285.71
40	9.3465	0.33	116.25	9.3705	0.36	243.81	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3625	0.34	113.36	9.3731	0.39	246.78	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3609	0.34	110.65	9.3871	0.39	249.35	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

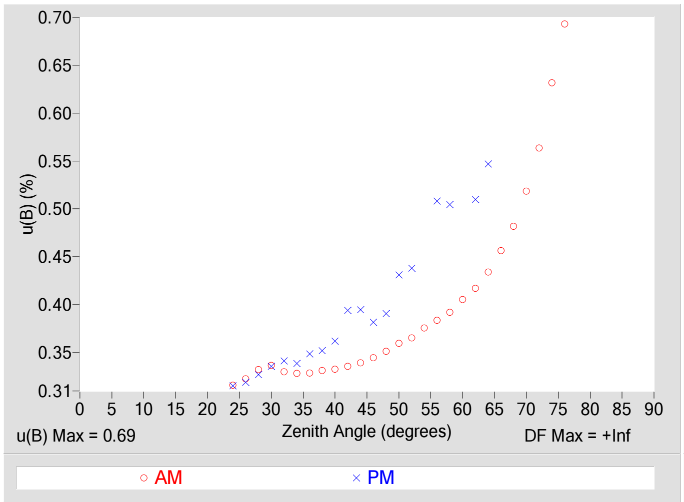


Figure 4. Residuals from Spline Interpolation

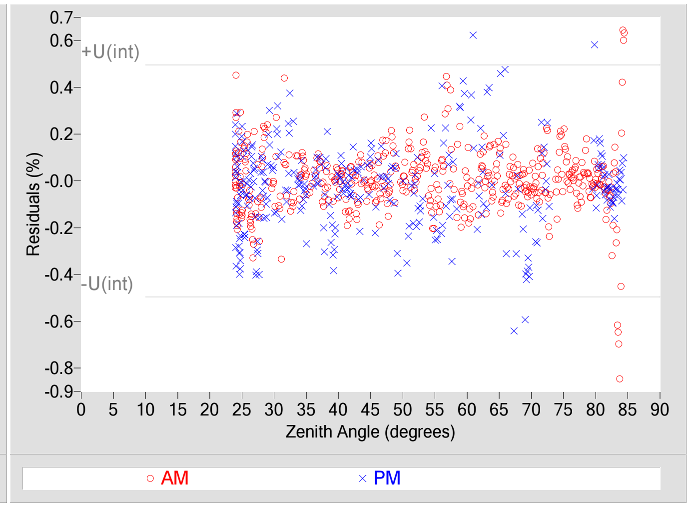


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.74
Effective degrees of freedom, DF(c)	50382
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

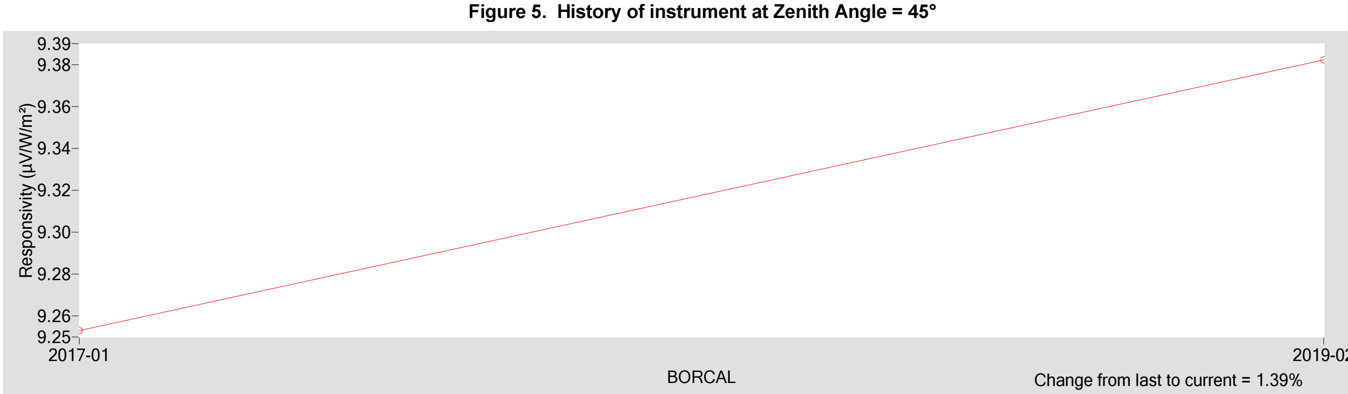
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3822	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+1.4 / -0.45
Expanded Uncertainty, U (%)	+2.4 / -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

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Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Hukseflux
Model:	SR25	**Serial Number:**	2543
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

______________________________ ____________

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

2543 Hukseflux SR25

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

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

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

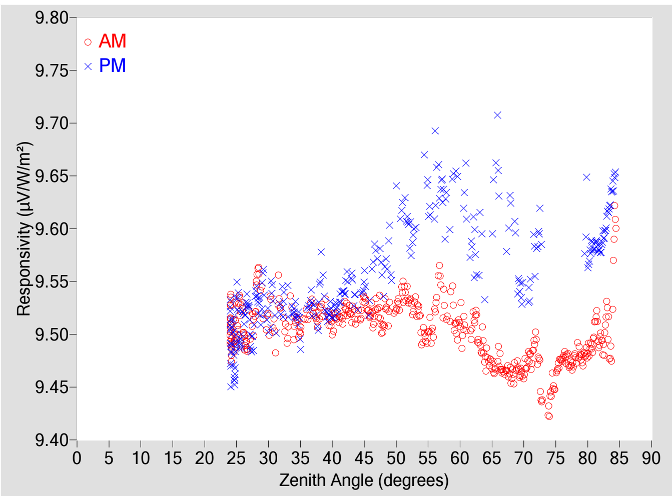


Figure 2. Responsivity vs Local Standard Time

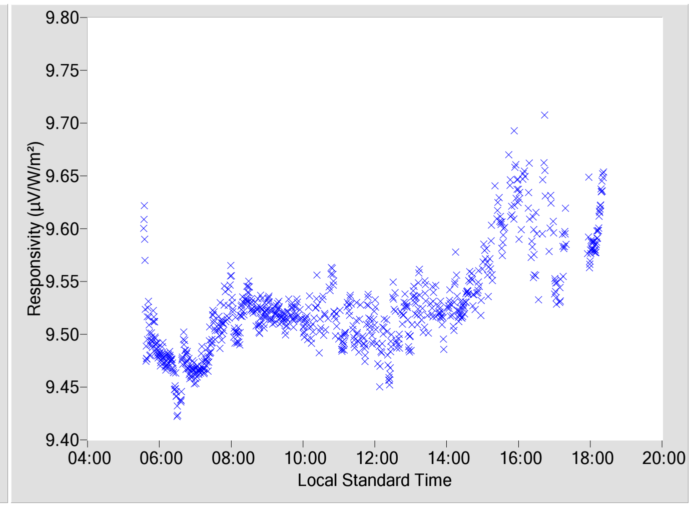


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.5203	0.34	108.24	9.5470	0.38	251.90
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.5103	0.35	105.94	9.5520	0.39	254.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.5253	0.36	103.68	9.6405	0.43	256.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.5350	0.37	101.72	9.6019	0.44	258.42
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.5016	0.38	99.68	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.5156	0.38	97.81	9.6413	0.51	262.44
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5156	0.39	96.04	9.6312	0.50	263.98
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5098	0.41	94.17	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.5087	0.42	92.49	9.5840	0.51	267.68
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.4775	0.43	90.78	9.5327	0.55	269.25
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.4785	0.46	89.05	9.6645	N/A	271.01
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.4621	0.48	87.48	9.6278	N/A	272.59
24	9.5036	0.32	174.17	9.4980	0.32	185.41	70	9.4648	0.52	85.82	9.5487	N/A	274.13
26	9.5062	0.32	153.65	9.5074	0.32	205.79	72	9.4875	0.56	84.27	9.5791	N/A	275.96
28	9.5356	0.33	144.15	9.5331	0.33	216.06	74	9.4329	0.63	82.65	N/A	N/A	N/A
30	9.5182	0.34	137.21	9.5133	0.34	222.49	76	9.4766	0.69	81.04	N/A	N/A	N/A
32	9.5250	0.33	132.01	9.5268	0.34	228.56	78	9.4762	N/A	79.42	N/A	N/A	N/A
34	9.5078	0.33	126.86	9.5210	0.34	233.18	80	9.4831	N/A	77.82	9.5727	N/A	282.42
36	9.5171	0.33	123.10	9.5259	0.35	237.49	82	9.4941	N/A	76.16	9.5812	N/A	284.04
38	9.5214	0.33	119.38	9.5418	0.35	240.67	84	9.5560	N/A	74.48	9.6420	N/A	285.71
40	9.5085	0.33	116.25	9.5208	0.36	243.81	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5254	0.34	113.36	9.5455	0.39	246.78	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.5184	0.34	110.65	9.5232	0.39	249.35	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

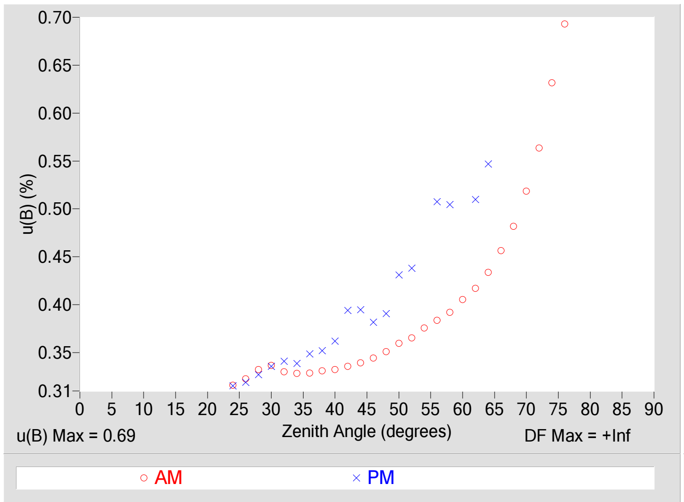


Figure 4. Residuals from Spline Interpolation

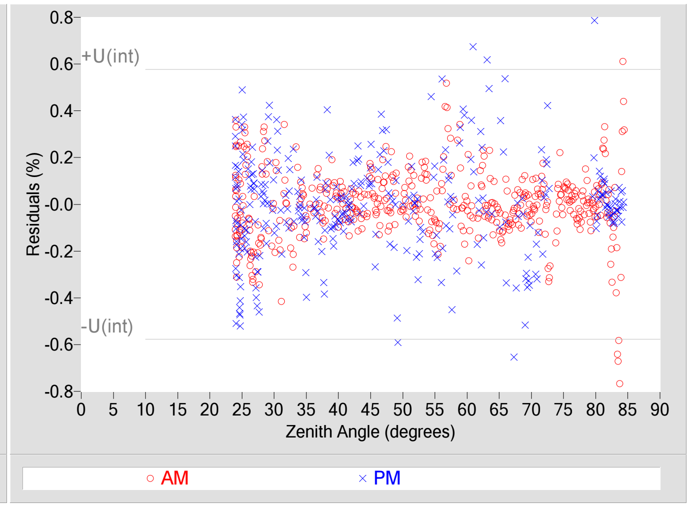


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	29791
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

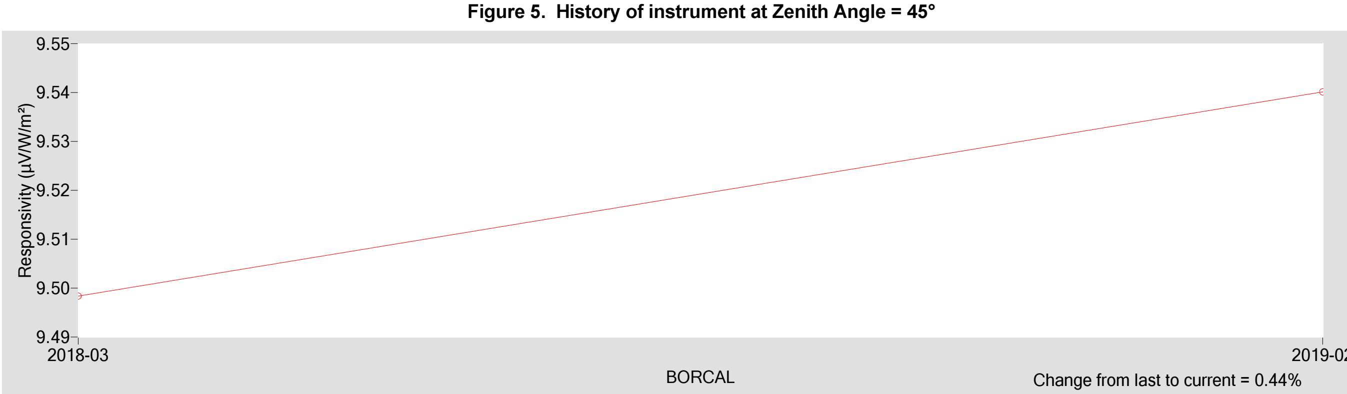
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.5401	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.1 / -0.40
Expanded Uncertainty, U (%)	+2.1 / -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:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	28402F3
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 37757F3	04/02/2019	04/02/2023

† 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: RCC

____ ____________________

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

28402F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

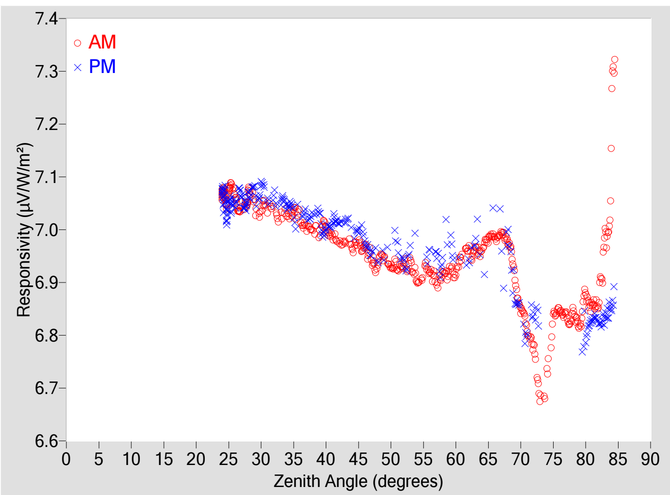


Figure 2. Responsivity vs Local Standard Time

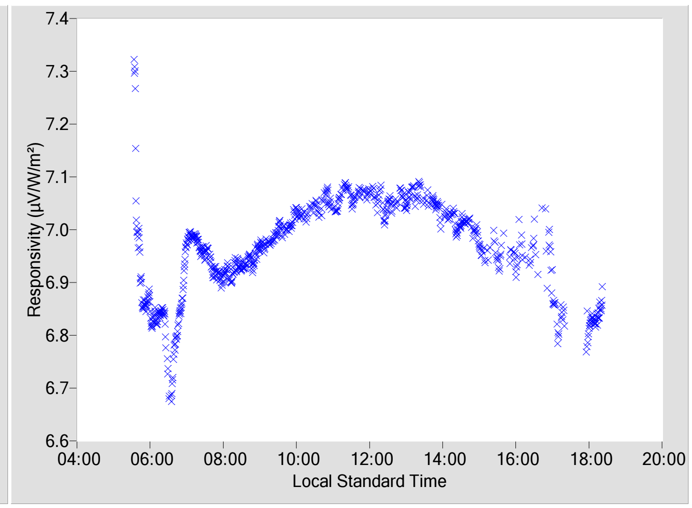


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	6.9681	0.36	108.27	6.9749	0.40	251.97
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.9387	0.37	105.85	6.9397	0.41	254.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.9303	0.38	103.76	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.9365	0.38	101.71	6.9387	0.46	258.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.9041	0.40	99.70	6.9932	0.49	260.15
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.9202	0.41	97.80	6.9618	0.53	262.26
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.9169	0.42	95.99	6.9369	0.53	264.00
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9190	0.43	94.22	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9621	0.45	92.49	6.9410	0.53	267.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9598	0.47	90.76	6.9529	0.56	269.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.9850	0.49	89.12	7.0412	N/A	270.81
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.9783	0.52	87.50	6.9836	N/A	272.67
24	7.0698	0.33	174.48	7.0638	0.32	185.80	70	6.8503	0.56	85.86	6.8620	N/A	274.11
26	7.0624	0.33	153.87	7.0499	0.33	205.88	72	6.7731	0.61	84.24	6.8353	N/A	275.88
28	7.0632	0.34	144.21	7.0612	0.34	215.89	74	6.7249	0.69	82.62	N/A	N/A	N/A
30	7.0350	0.35	137.27	7.0791	0.35	222.70	76	6.8473	0.76	81.01	N/A	N/A	N/A
32	7.0441	0.34	132.06	7.0600	0.35	228.48	78	6.8389	N/A	79.45	N/A	N/A	N/A
34	7.0300	0.34	127.04	7.0443	0.35	233.22	80	6.8759	N/A	77.80	6.8081	N/A	282.42
36	7.0199	0.34	122.82	N/A	N/A	N/A	82	6.8719	N/A	76.14	6.8244	N/A	284.03
38	6.9979	0.34	119.53	7.0307	0.36	240.67	84	7.1837	N/A	74.48	6.8540	N/A	285.69
40	7.0059	0.35	116.31	6.9996	0.37	243.83	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.9764	0.35	113.18	7.0126	0.40	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.9656	0.35	110.72	7.0044	0.41	249.31	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

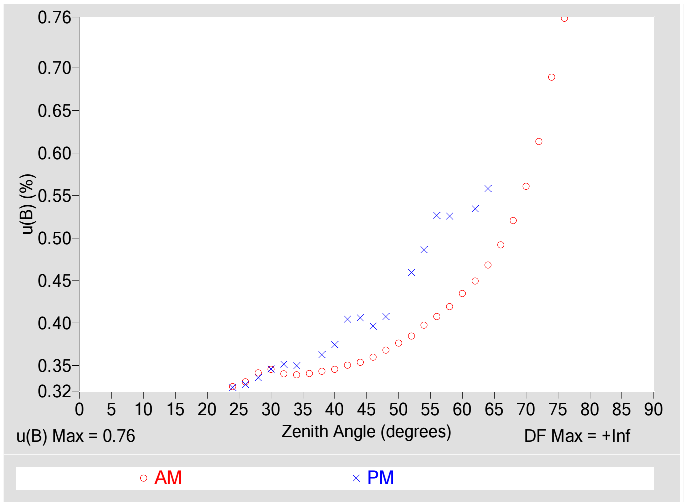


Figure 4. Residuals from Spline Interpolation

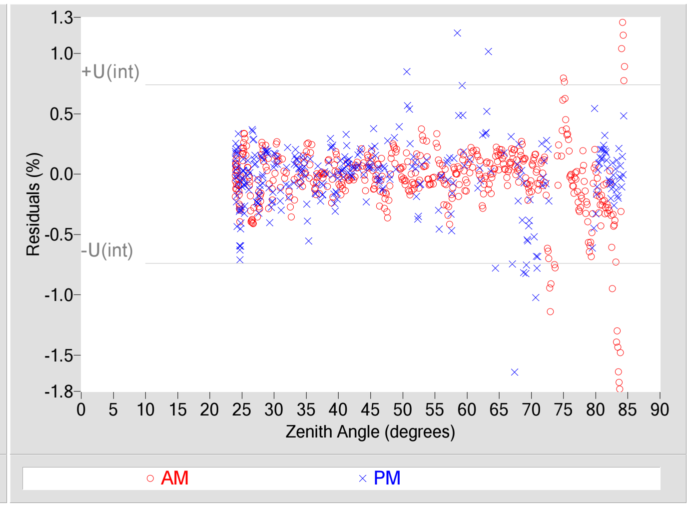


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.76
Type-A Interpolating Function, u(int) (%)	±0.37
Combined Standard Uncertainty, u(c) (%)	±0.84
Effective degrees of freedom, DF(c)	17905
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.7
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

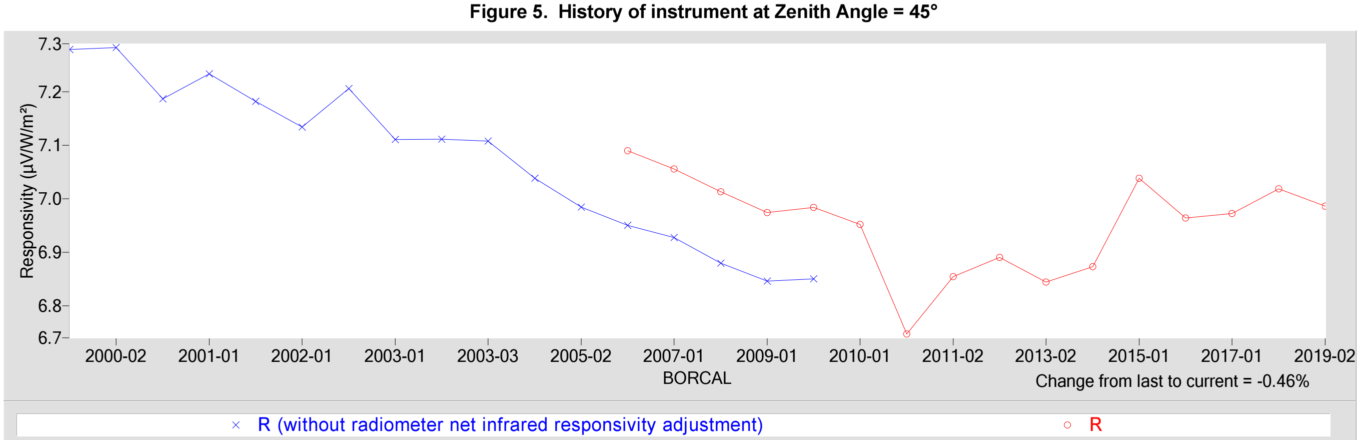
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
6.9865	0.64000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.3 / -1.2
Expanded Uncertainty, U (%)	+2.4 / -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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31137E6
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

______________________________ ____________

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

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

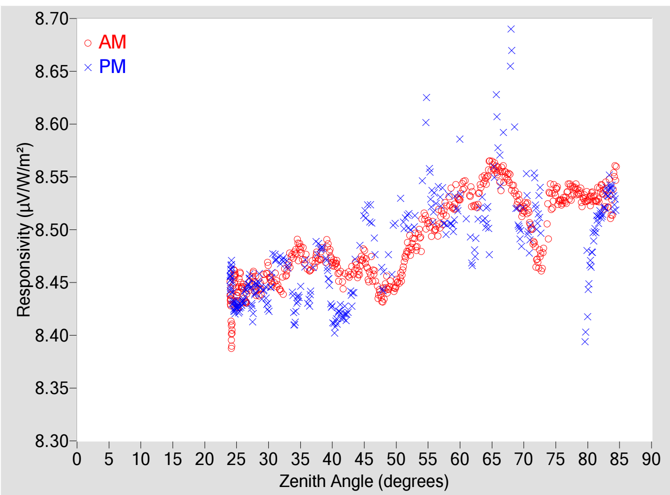


Figure 2. Responsivity vs Local Standard Time

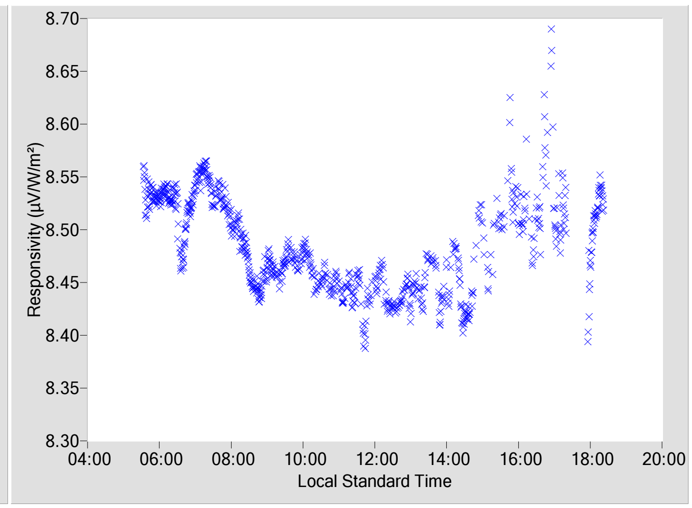


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4638	0.28	108.27	8.5125	0.28	251.87
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4369	0.28	105.93	8.4527	0.29	254.07
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4481	0.28	103.72	8.5060	0.29	256.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4839	0.28	101.68	8.5077	0.29	258.42
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4936	0.28	99.82	8.5463	0.30	260.53
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4998	0.28	97.72	8.5208	0.30	262.27
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5223	0.28	95.96	8.5110	0.30	264.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5299	0.29	94.24	8.5598	N/A	265.96
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5286	0.29	92.49	8.4718	0.30	267.68
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5479	0.29	90.77	8.5097	0.30	269.42
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5533	0.29	89.13	8.5850	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5441	0.29	87.52	8.6715	N/A	272.66
24	8.4190	0.28	173.36	8.4543	0.28	185.64	70	8.5185	0.29	85.88	8.5209	N/A	274.17
26	8.4441	0.28	154.55	8.4330	0.28	206.04	72	8.4722	0.30	84.25	8.5129	N/A	275.93
28	8.4461	0.28	144.51	8.4450	0.28	216.05	74	8.5248	0.30	82.64	N/A	N/A	N/A
30	8.4595	0.28	137.14	8.4309	0.28	222.92	76	8.5269	0.30	81.03	N/A	N/A	N/A
32	8.4445	0.28	131.70	8.4719	0.28	228.51	78	8.5382	N/A	79.42	N/A	N/A	N/A
34	8.4776	0.28	126.84	8.4221	0.28	233.07	80	8.5297	N/A	77.77	8.4513	N/A	282.46
36	8.4698	0.28	123.06	8.4509	0.28	237.04	82	8.5373	N/A	76.16	8.5141	N/A	284.03
38	8.4730	0.28	119.34	8.4837	0.28	240.75	84	8.5408	N/A	74.45	8.5302	N/A	285.75
40	8.4704	0.28	116.29	8.4214	0.28	243.82	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4512	0.28	113.55	8.4196	0.28	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4601	0.28	110.71	8.4851	0.28	249.79	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

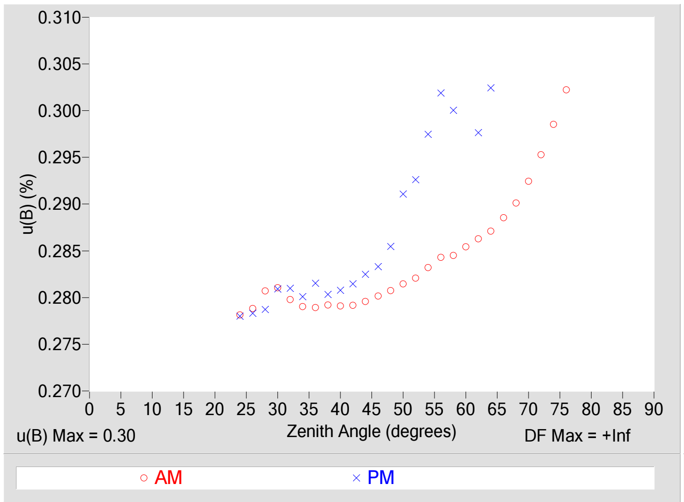


Figure 4. Residuals from Spline Interpolation

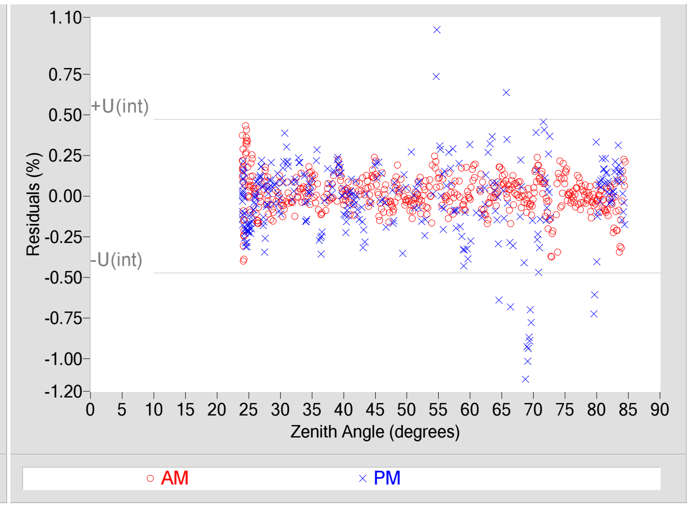


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	4667
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

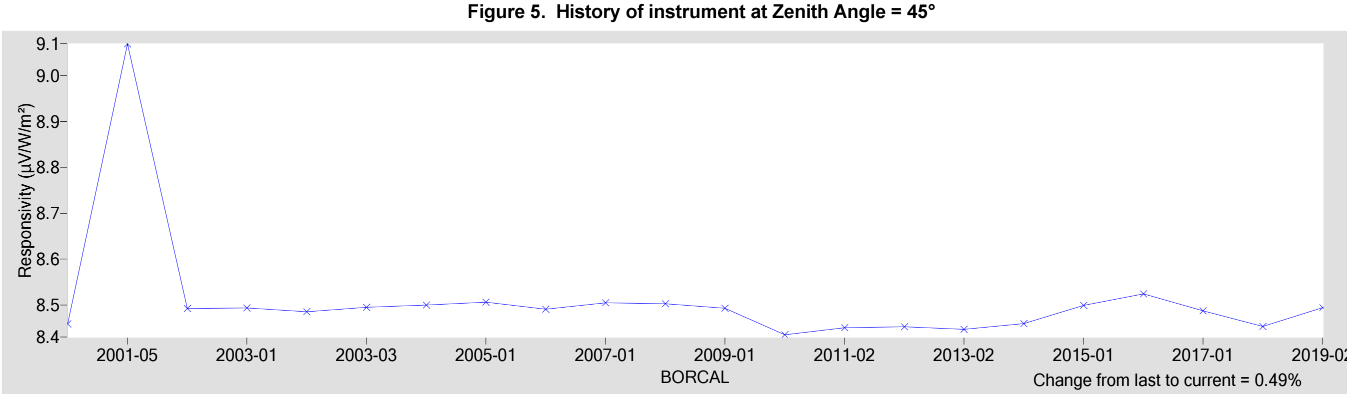
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4944	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.77 / -0.88
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

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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:**	32331
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

__________________________________ ____________

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

32331 Eppley 8-48

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

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

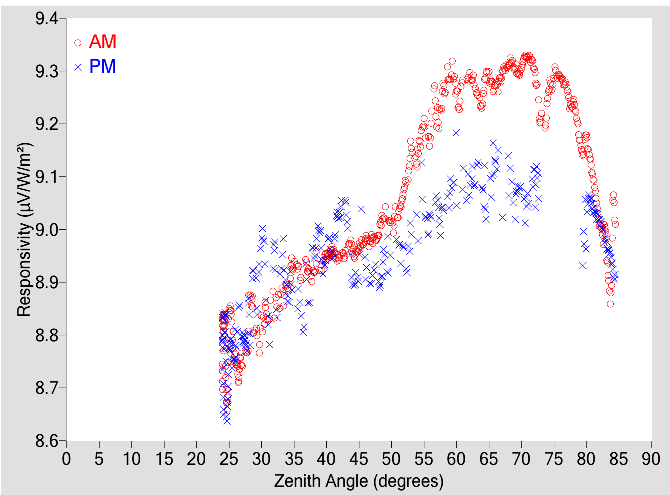


Figure 2. Responsivity vs Local Standard Time

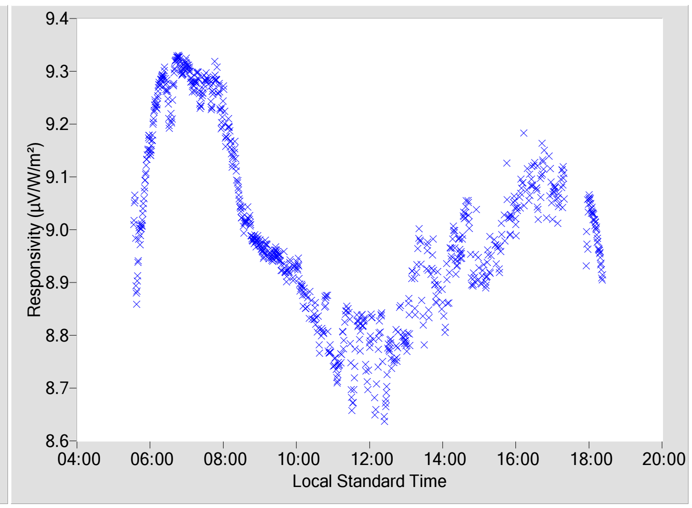


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.9793	0.34	108.27	8.9270	0.38	251.95
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9916	0.35	105.93	8.8950	0.39	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0098	0.36	103.73	8.9512	0.42	256.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0803	0.37	101.68	8.9532	0.44	258.42
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1409	0.38	99.71	9.0031	0.47	260.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1865	0.38	97.81	9.0175	0.50	262.22
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2594	0.39	95.97	9.0399	0.50	264.06
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2576	0.41	94.18	9.1140	N/A	265.95
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2872	0.42	92.46	9.0846	0.51	267.65
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2445	0.43	90.77	9.0688	0.55	269.42
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2722	0.45	89.15	9.1202	N/A	271.03
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.3123	0.48	87.47	9.1064	N/A	272.78
24	8.7995	0.32	174.09	8.7644	0.32	185.36	70	9.3050	0.52	85.88	9.0807	N/A	274.12
26	8.7505	0.32	153.68	8.7737	0.32	206.06	72	9.3003	0.56	84.25	9.0867	N/A	275.93
28	8.8102	0.33	144.46	8.8179	0.33	215.87	74	9.2369	0.63	82.64	N/A	N/A	N/A
30	8.8143	0.34	137.29	8.9824	0.34	223.09	76	9.2885	0.69	81.03	N/A	N/A	N/A
32	8.8619	0.33	131.64	8.9339	0.34	228.49	78	9.2355	N/A	79.41	N/A	N/A	N/A
34	8.8916	0.33	126.95	8.8824	0.34	233.00	80	9.1710	N/A	77.81	9.0321	N/A	282.45
36	8.9064	0.33	122.96	8.8492	0.35	237.12	82	9.0151	N/A	76.15	9.0170	N/A	284.08
38	8.9162	0.33	119.43	8.9563	0.35	240.70	84	8.9883	N/A	74.45	8.9256	N/A	285.75
40	8.9491	0.33	116.29	8.9506	0.36	243.78	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9474	0.34	113.48	9.0287	0.39	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9625	0.34	110.71	8.8990	0.40	249.49	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

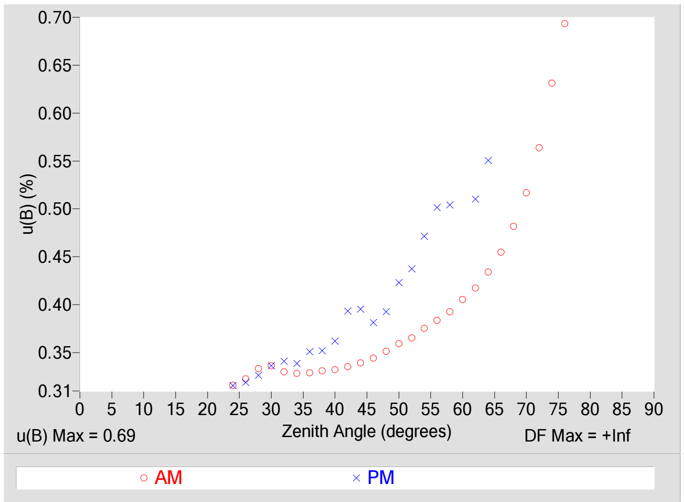


Figure 4. Residuals from Spline Interpolation

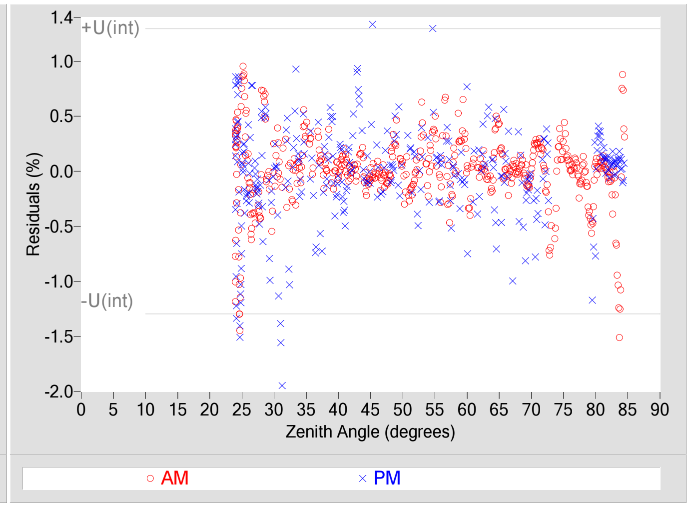


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.65
Combined Standard Uncertainty, u(c) (%)	±0.95
Effective degrees of freedom, DF(c)	3140
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.9
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

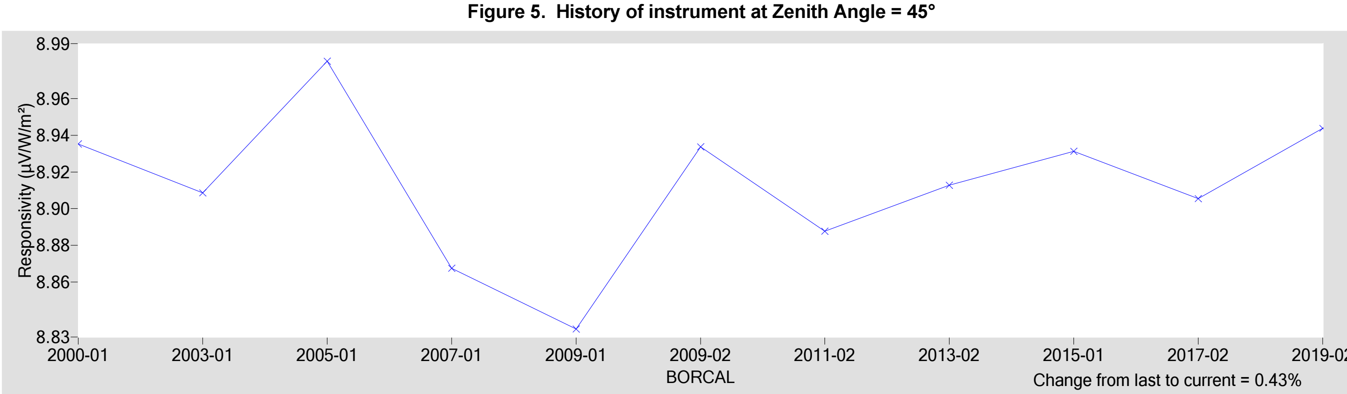
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.9438	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+3.5 / -1.4
Expanded Uncertainty, U (%)	+4.5 / -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:	Black and White Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	34718
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

______________________________ _______________

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

34718 Eppley 8-48

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

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

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

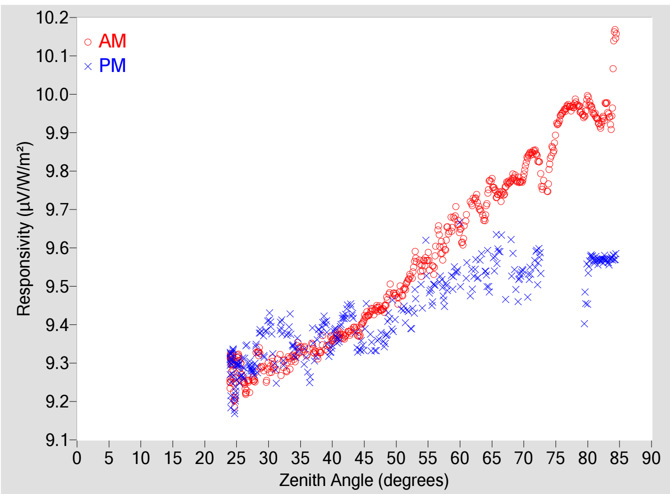


Figure 2. Responsivity vs Local Standard Time

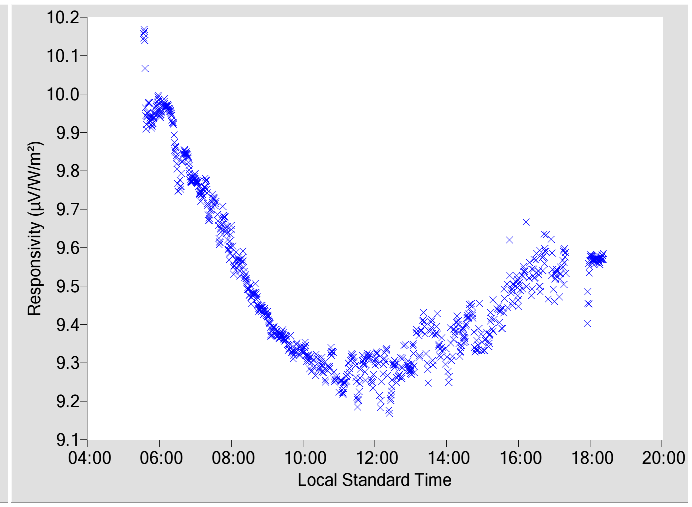


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	9.4326	0.34	108.27	9.3536	0.38	251.95
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4403	0.35	105.93	9.3499	0.39	254.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.4718	0.36	103.73	9.4132	0.42	256.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.5215	0.37	101.68	9.4209	0.44	258.42
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.5476	0.38	99.71	9.4743	0.47	260.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.5633	0.38	97.81	9.4931	0.50	262.22
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6337	0.39	95.97	9.4995	0.50	264.06
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.6424	0.41	94.18	9.5827	N/A	265.95
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7195	0.42	92.46	9.5211	0.51	267.65
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.6916	0.43	90.77	9.5267	0.55	269.42
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7391	0.45	89.15	9.5845	N/A	271.03
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.7769	0.48	87.47	9.5780	N/A	272.78
24	9.2933	0.32	174.09	9.2825	0.32	185.36	70	9.7900	0.52	85.88	9.5424	N/A	274.12
26	9.2542	0.32	153.68	9.2828	0.32	206.06	72	9.8416	0.56	84.25	9.5599	N/A	275.93
28	9.2823	0.33	144.46	9.3076	0.33	215.87	74	9.8012	0.63	82.64	N/A	N/A	N/A
30	9.2814	0.34	137.29	9.4147	0.34	223.09	76	9.9510	0.69	81.03	N/A	N/A	N/A
32	9.2989	0.33	131.64	9.3798	0.34	228.49	78	9.9743	N/A	79.41	N/A	N/A	N/A
34	9.3136	0.33	126.95	9.3344	0.34	233.00	80	9.9841	N/A	77.81	9.5328	N/A	282.45
36	9.3208	0.33	122.96	9.2959	0.35	237.12	82	9.9204	N/A	76.15	9.5691	N/A	284.08
38	9.3249	0.33	119.43	9.3823	0.35	240.70	84	10.074	N/A	74.45	9.5739	N/A	285.75
40	9.3643	0.33	116.29	9.3492	0.36	243.78	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3692	0.34	113.48	9.4239	0.39	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3784	0.34	110.71	9.3348	0.40	249.49	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

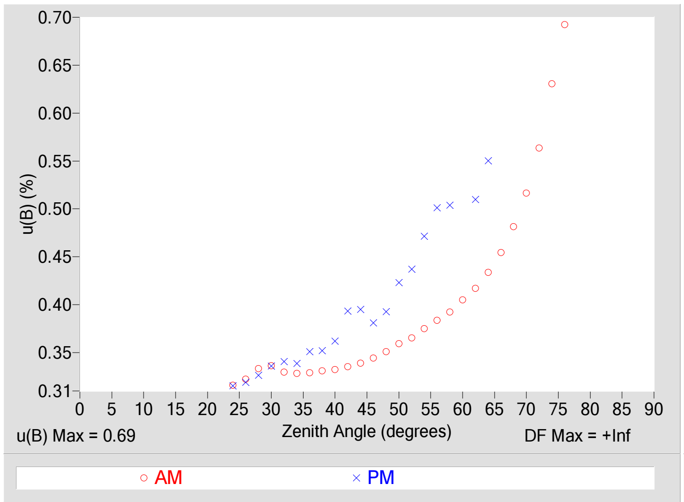


Figure 4. Residuals from Spline Interpolation

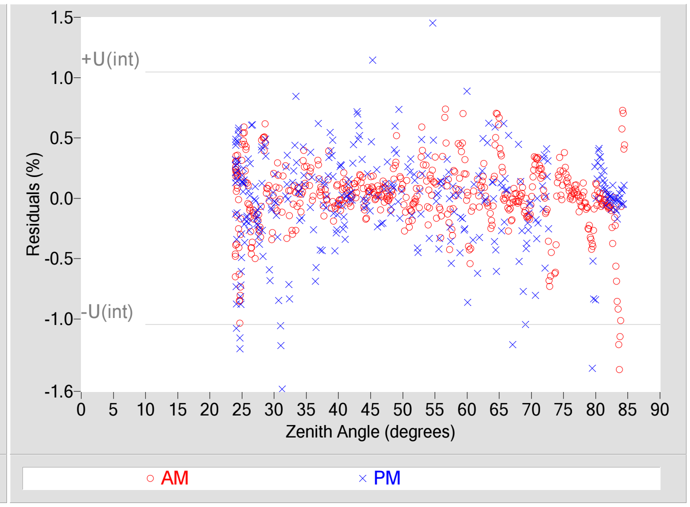


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.52
Combined Standard Uncertainty, u(c) (%)	±0.87
Effective degrees of freedom, DF(c)	5166
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.7
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

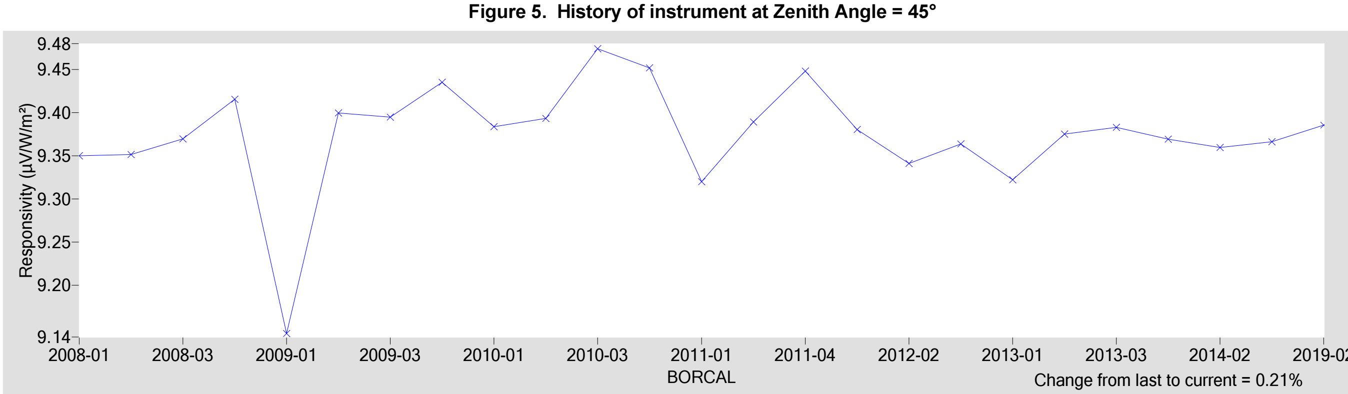
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.3855	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+2.7 / -1.1
Expanded Uncertainty, U (%)	+3.7 / -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:	GPP Pyranometer	**Manufacturer:**	Eppley
Model:	GPP	**Serial Number:**	37831F3
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

______________________________ ____________

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

37831F3 Eppley GPP

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

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

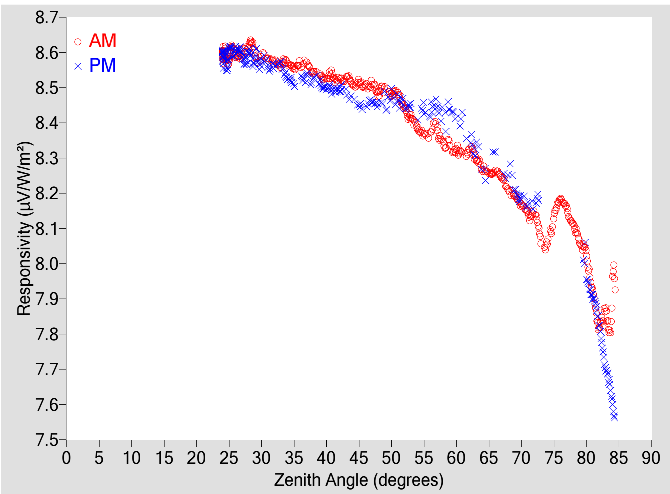


Figure 2. Responsivity vs Local Standard Time

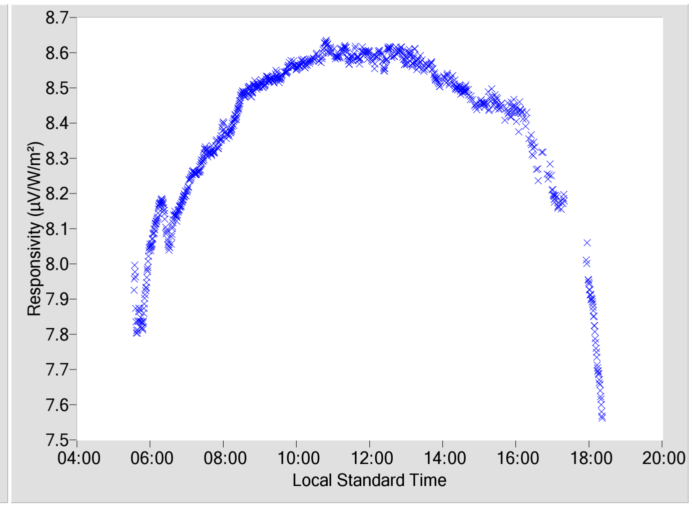


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5061	0.35	108.20	8.4457	0.38	252.15
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4841	0.35	105.94	8.4501	0.39	254.02
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4827	0.36	103.79	8.4783	0.44	256.35
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4431	0.37	101.68	8.4526	0.44	258.34
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3868	0.38	99.72	8.4080	0.48	260.49
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3682	0.39	97.84	8.4314	0.51	262.38
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3364	0.40	95.88	8.4367	0.52	264.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3223	0.41	94.19	8.4117	N/A	265.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3202	0.42	92.58	8.3440	0.51	267.86
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2705	0.44	90.78	8.2684	0.55	269.25
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2619	0.46	89.16	8.3176	N/A	271.01
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.2089	0.49	87.48	8.2683	N/A	272.76
24	8.5926	0.32	174.08	8.5894	0.32	185.42	70	8.1672	0.52	85.84	8.1895	N/A	274.17
26	8.5980	0.32	154.09	8.6010	0.32	205.50	72	8.1420	0.57	84.24	8.1637	N/A	275.94
28	8.6152	0.33	144.18	8.6004	0.33	216.34	74	8.0593	0.64	82.69	N/A	N/A	N/A
30	8.5849	0.34	137.49	8.5709	0.34	222.41	76	8.1791	0.70	81.03	N/A	N/A	N/A
32	8.5762	0.33	131.85	8.5610	0.34	228.26	78	8.1100	N/A	79.42	N/A	N/A	N/A
34	8.5693	0.33	127.01	8.5264	0.34	233.02	80	8.0249	N/A	77.81	7.9834	N/A	282.39
36	8.5642	0.33	123.02	8.5322	0.35	237.49	82	7.8252	N/A	76.16	7.8242	N/A	284.04
38	8.5437	0.33	119.57	8.5279	0.35	240.71	84	7.9084	N/A	74.50	7.6043	N/A	285.71
40	8.5223	0.33	116.30	8.4991	0.36	243.81	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5266	0.34	113.28	8.4968	0.40	246.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5099	0.34	110.72	8.4714	0.40	249.40	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

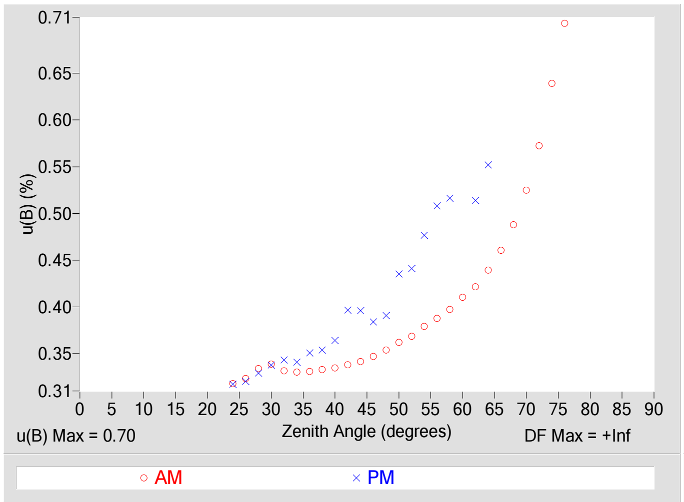


Figure 4. Residuals from Spline Interpolation

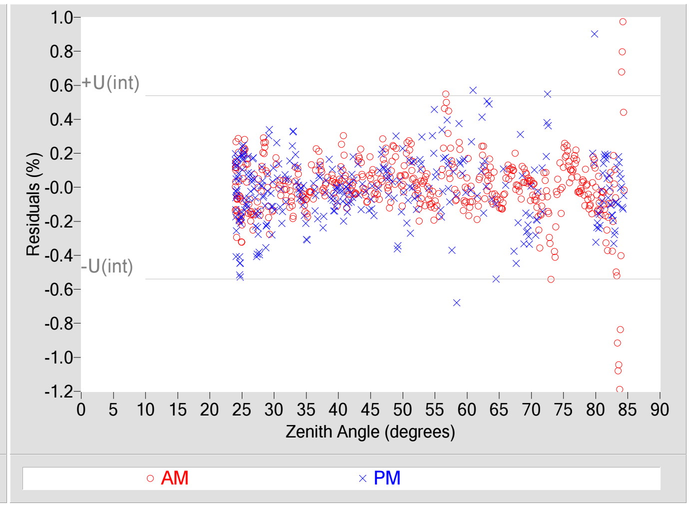


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.70
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	40251
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

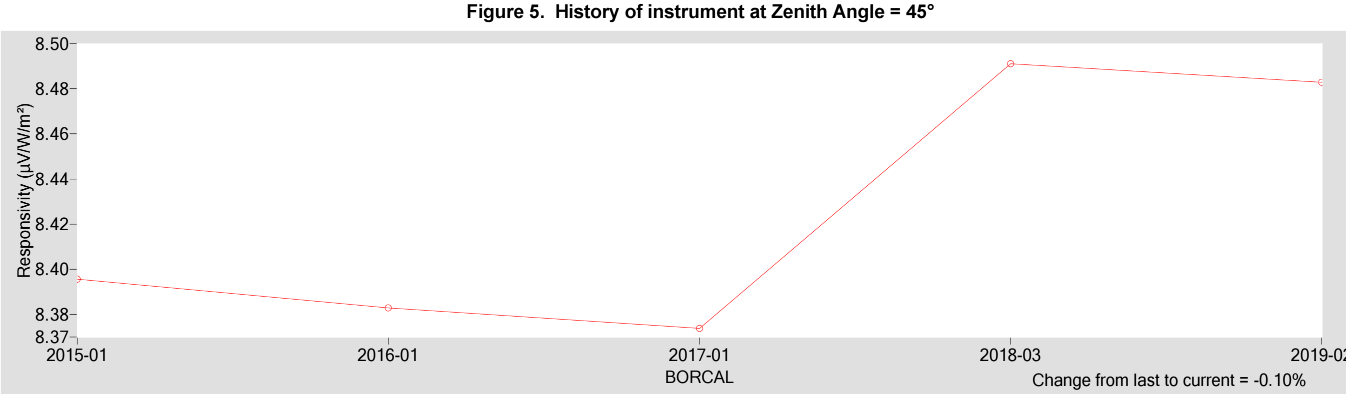
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4828	0.15000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.2 / -1.9
Expanded Uncertainty, U (%)	+2.2 / -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

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument: Standard Precision Pyranometer (Ventilated)
Manufacturer: Eppley
Model: SPP
Serial Number: 37839F3
Calibration Date: 5/3/2019
Due Date: 5/3/2020
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/3

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 37757F3	04/02/2019	04/02/2023

† 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: RCC

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

37839F3 Eppley SPP

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

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

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

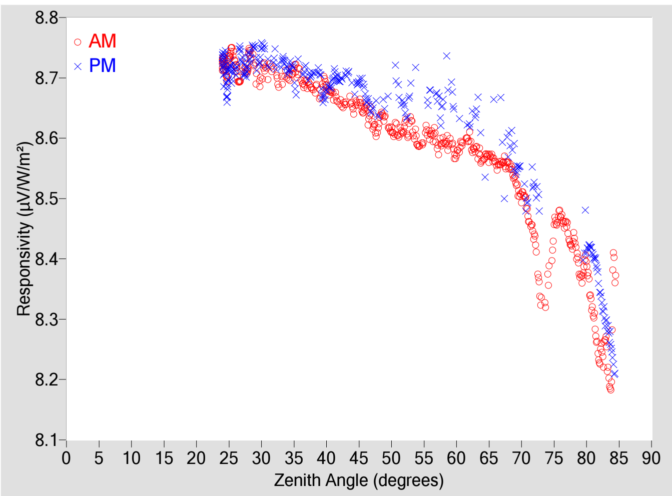


Figure 2. Responsivity vs Local Standard Time

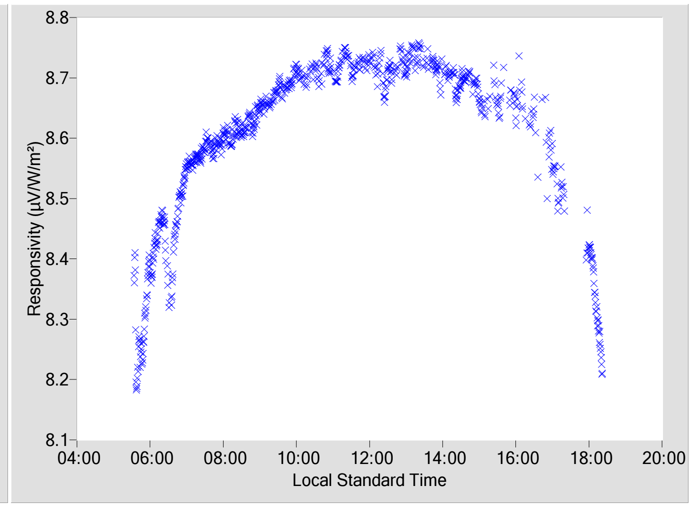


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6512	0.35	108.27	8.6686	0.39	251.97
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6247	0.36	105.85	8.6372	0.40	254.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6128	0.37	103.76	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6189	0.38	101.71	8.6513	0.45	258.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5911	0.39	99.70	8.7174	0.48	260.15
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6069	0.40	97.80	8.6797	0.52	262.26
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5940	0.41	95.99	8.6563	0.52	264.00
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5742	0.42	94.22	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5985	0.43	92.49	8.6213	0.52	267.70
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5628	0.45	90.76	8.6091	0.54	269.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5585	0.48	89.12	8.6645	N/A	270.81
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5566	0.50	87.50	8.5915	N/A	272.67
24	8.7243	0.32	174.48	8.7218	0.32	185.80	70	8.5059	0.54	85.86	8.5542	N/A	274.11
26	8.7235	0.33	153.87	8.7135	0.32	205.88	72	8.4320	0.59	84.24	8.5162	N/A	275.88
28	8.7295	0.34	144.21	8.7293	0.33	215.89	74	8.3598	0.66	82.62	N/A	N/A	N/A
30	8.7001	0.34	137.27	8.7453	0.34	222.70	76	8.4728	0.73	81.01	N/A	N/A	N/A
32	8.7148	0.34	132.06	8.7300	0.35	228.48	78	8.4283	N/A	79.45	N/A	N/A	N/A
34	8.7037	0.33	127.04	8.7132	0.34	233.22	80	8.3895	N/A	77.80	8.4315	N/A	282.42
36	8.7002	0.34	122.82	N/A	N/A	N/A	82	8.2401	N/A	76.14	8.3529	N/A	284.03
38	8.6799	0.34	119.53	8.7084	0.36	240.67	84	8.3092	N/A	74.48	8.2376	N/A	285.69
40	8.6879	0.34	116.31	8.6776	0.37	243.83	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6601	0.34	113.18	8.6958	0.40	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6511	0.35	110.72	8.6918	0.40	249.31	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

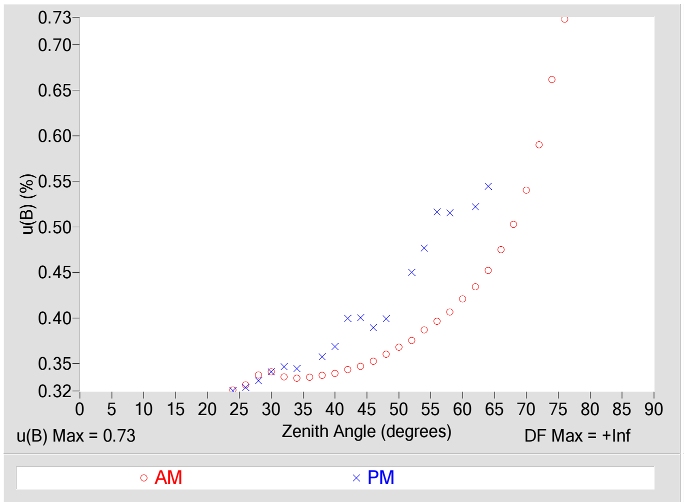


Figure 4. Residuals from Spline Interpolation

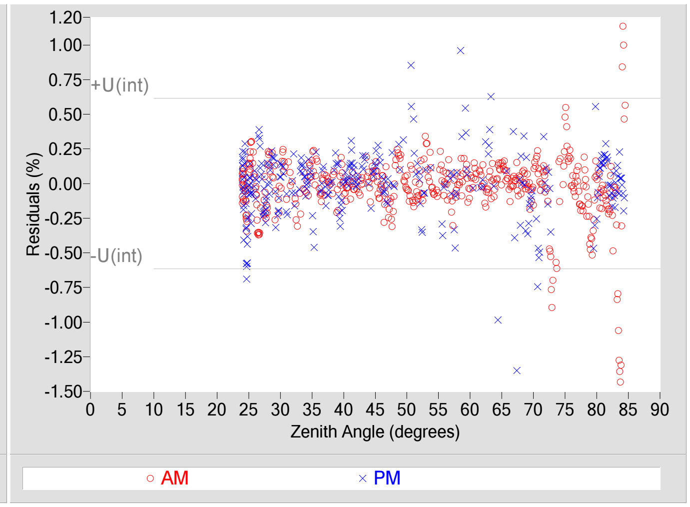


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.73
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.79
Effective degrees of freedom, DF(c)	28688
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

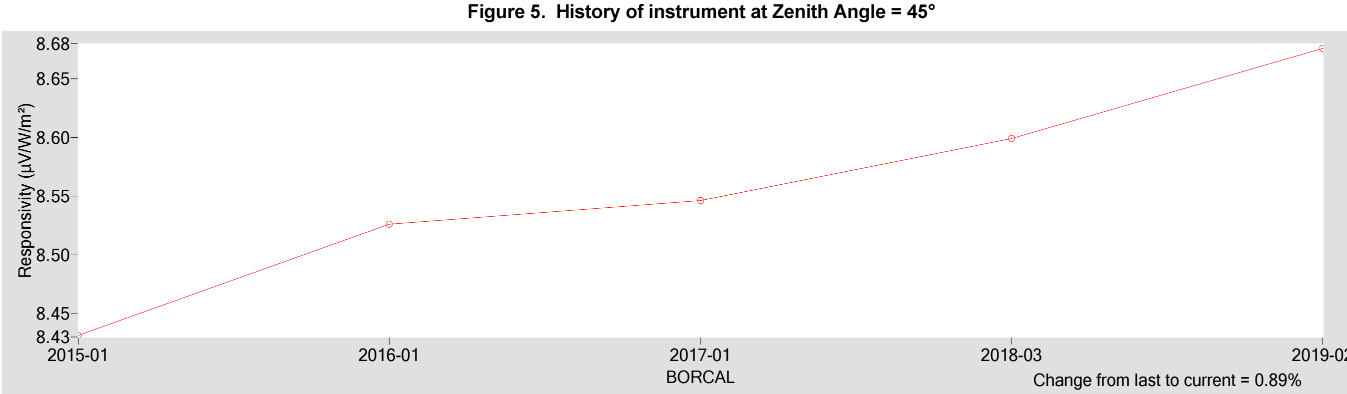
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6758	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+0.80 / -1.2
Expanded Uncertainty, U (%)	+1.8 / -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:	Short Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37882E6
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

____________________________ ____________

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

37882E6 Eppley sNIP

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

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

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

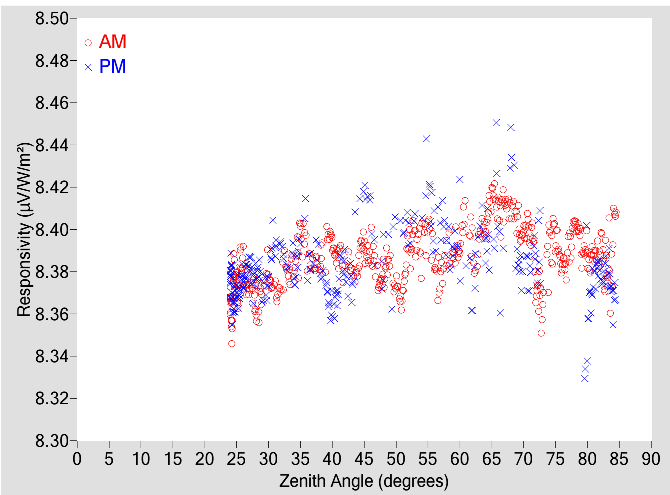


Figure 2. Responsivity vs Local Standard Time

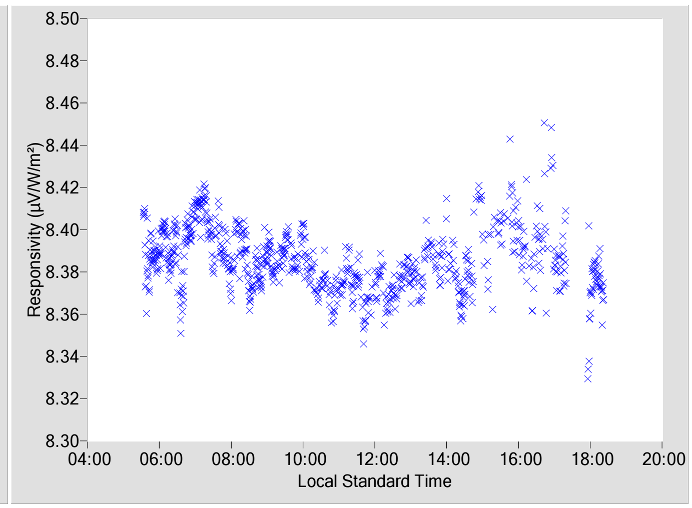


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3920	0.28	108.27	8.4093	0.28	251.87
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3779	0.28	105.93	8.3827	0.29	254.07
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3736	0.28	103.72	8.4059	0.29	256.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3919	0.28	101.68	8.3993	0.29	258.42
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3895	0.28	99.82	8.4055	0.30	260.53
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3814	0.28	97.72	8.3956	0.30	262.27
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3920	0.28	95.96	8.3948	0.30	264.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3903	0.29	94.24	8.3997	N/A	265.96
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3914	0.29	92.49	8.3685	0.30	267.68
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3998	0.29	90.77	8.3912	0.30	269.42
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4097	0.29	89.13	8.4090	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.4085	0.29	87.52	8.4372	N/A	272.66
24	8.3627	0.28	173.36	8.3772	0.28	185.35	70	8.3988	0.29	85.88	8.3799	N/A	274.17
26	8.3825	0.28	154.55	8.3769	0.28	206.04	72	8.3717	0.30	84.25	8.3807	N/A	275.93
28	8.3636	0.28	144.51	8.3789	0.28	216.05	74	8.3911	0.30	82.64	N/A	N/A	N/A
30	8.3793	0.28	137.14	8.3786	0.28	222.92	76	8.3828	0.30	81.03	N/A	N/A	N/A
32	8.3740	0.28	131.70	8.3918	0.28	228.51	78	8.4020	N/A	79.42	N/A	N/A	N/A
34	8.3812	0.28	126.84	8.3817	0.28	233.07	80	8.3852	N/A	77.74	8.3651	N/A	282.46
36	8.3888	0.28	123.06	8.3953	0.28	237.04	82	8.3917	N/A	76.16	8.3802	N/A	284.03
38	8.3849	0.28	119.34	8.3829	0.28	240.75	84	8.3966	N/A	74.45	8.3686	N/A	285.75
40	8.3939	0.28	116.29	8.3622	0.28	243.82	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3790	0.28	113.55	8.3813	0.28	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3816	0.28	110.71	8.4146	0.28	249.79	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

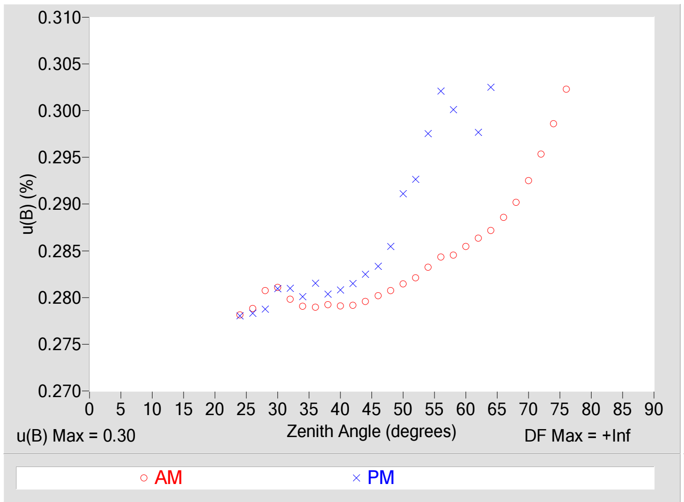


Figure 4. Residuals from Spline Interpolation

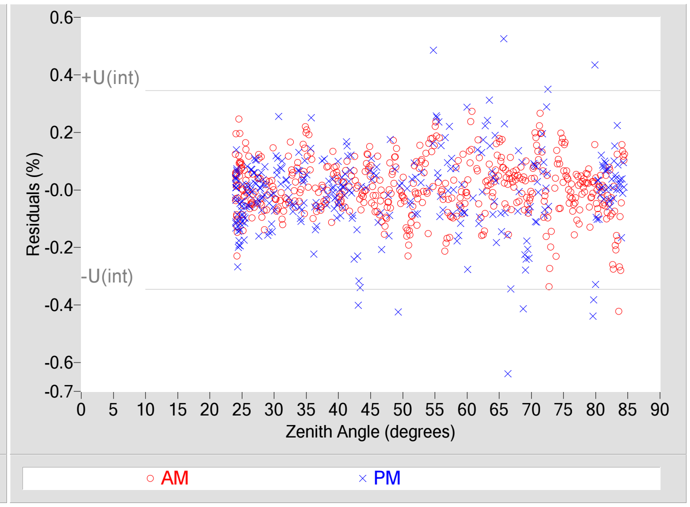


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	11080
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.68
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

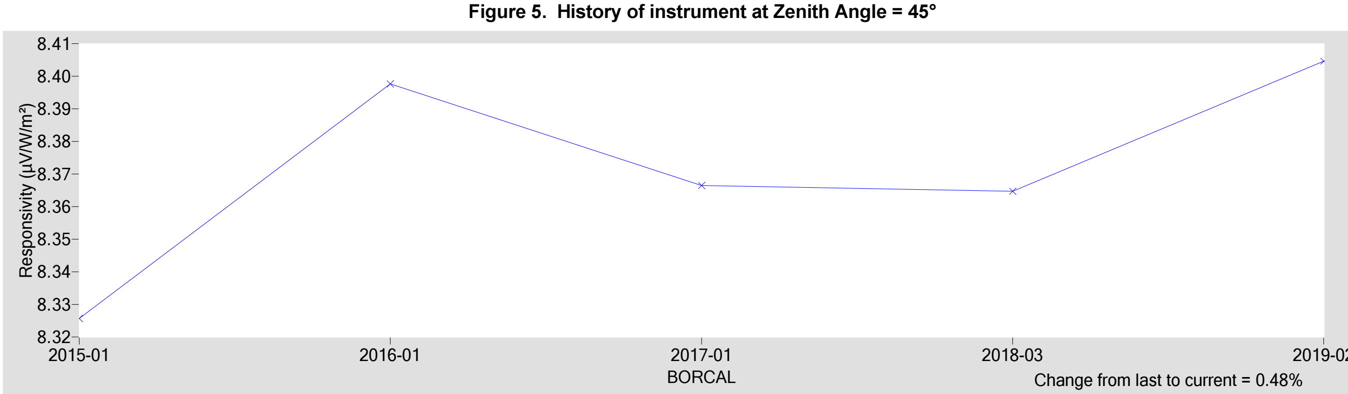
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4047	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.12 / -0.51
Expanded Uncertainty, U (%)	+0.71 / -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:	Si pyranometer	**Manufacturer:**	Apogee
Model:	SP-110	**Serial Number:**	40337
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

_______________________________________ ____________

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

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

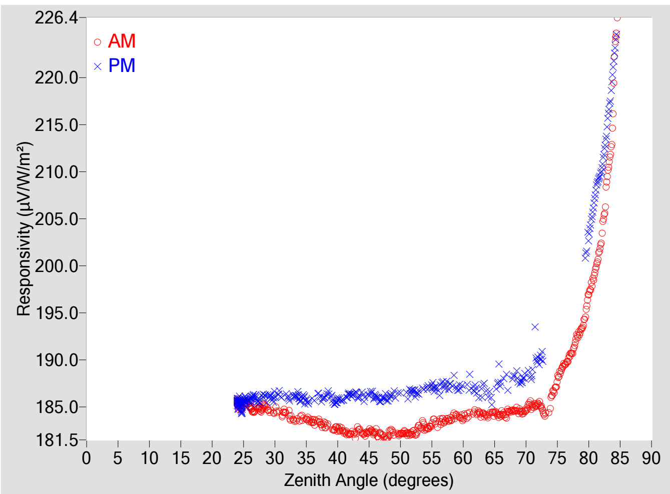


Figure 2. Responsivity vs Local Standard Time

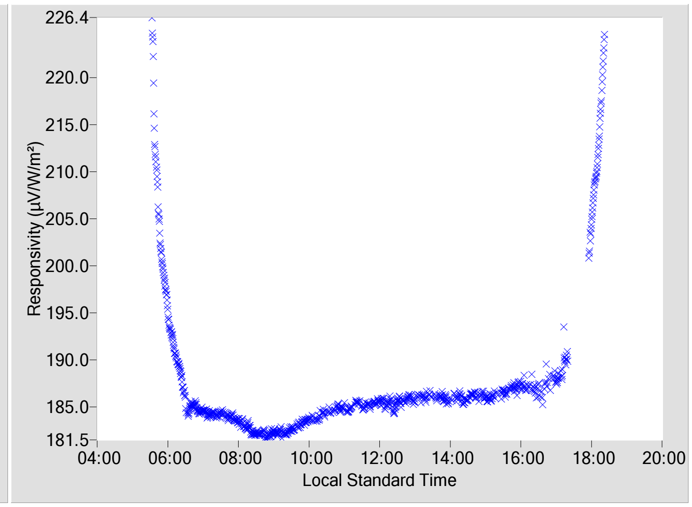


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	182.30	0.34	108.33	186.05	0.38	251.87
2	N/A	N/A	N/A	N/A	N/A	N/A	48	181.88	0.35	105.92	185.76	0.39	254.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	182.14	0.36	103.70	186.50	0.43	256.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	182.28	0.36	101.72	186.71	0.44	258.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	182.77	0.37	99.70	186.97	N/A	260.67
10	N/A	N/A	N/A	N/A	N/A	N/A	56	183.15	0.38	97.75	186.66	0.49	262.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	183.64	0.39	96.01	187.25	0.51	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	183.93	0.40	94.22	187.27	N/A	265.80
16	N/A	N/A	N/A	N/A	N/A	N/A	62	184.42	0.41	92.47	186.86	0.51	267.65
18	N/A	N/A	N/A	N/A	N/A	N/A	64	184.12	0.43	90.81	186.35	0.55	269.46
20	N/A	N/A	N/A	N/A	N/A	N/A	66	184.24	0.45	89.12	187.42	N/A	270.99
22	N/A	N/A	N/A	N/A	N/A	N/A	68	184.60	0.48	87.46	188.19	N/A	272.68
24	185.37	0.31	174.67	185.45	0.31	185.88	70	184.68	0.51	85.86	188.31	N/A	274.11
26	184.91	0.32	153.48	185.74	0.32	206.15	72	185.33	0.56	84.24	189.91	N/A	275.92
28	184.82	0.33	144.53	186.21	0.33	215.95	74	186.00	0.63	82.58	N/A	N/A	N/A
30	184.57	0.34	137.22	186.05	0.33	222.49	76	189.37	0.68	81.06	N/A	N/A	N/A
32	184.37	0.33	131.48	186.01	0.34	228.66	78	192.20	N/A	79.40	N/A	N/A	N/A
34	183.87	0.33	126.81	185.85	0.34	233.04	80	197.00	N/A	77.80	203.60	N/A	282.44
36	183.47	0.33	122.94	185.80	0.35	237.37	82	202.70	N/A	76.19	210.37	N/A	284.07
38	183.09	0.33	119.53	186.10	0.35	240.65	84	219.27	N/A	74.48	222.18	N/A	285.74
40	182.69	0.33	116.27	185.72	0.36	243.76	86	N/A	N/A	N/A	N/A	N/A	N/A
42	182.11	0.33	113.46	186.34	0.39	246.71	88	N/A	N/A	N/A	N/A	N/A	N/A
44	182.15	0.34	110.57	186.12	0.39	249.54	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

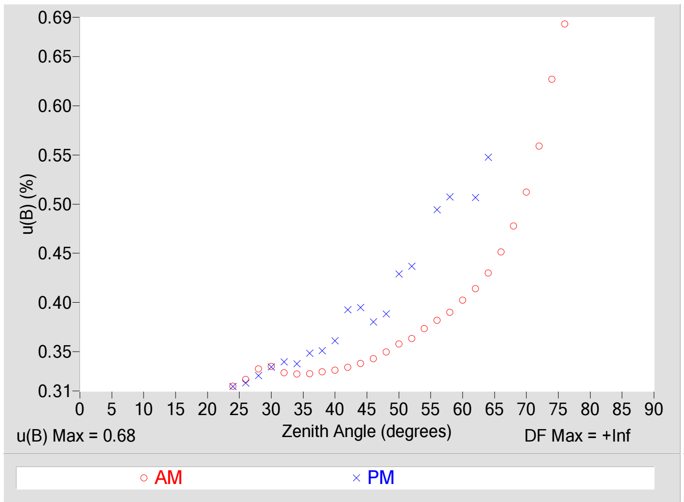


Figure 4. Residuals from Spline Interpolation

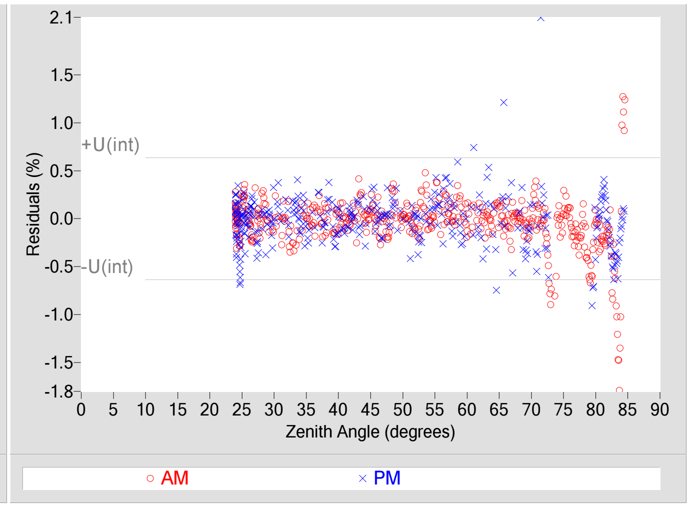


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.68
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.75
Effective degrees of freedom, DF(c)	22782
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

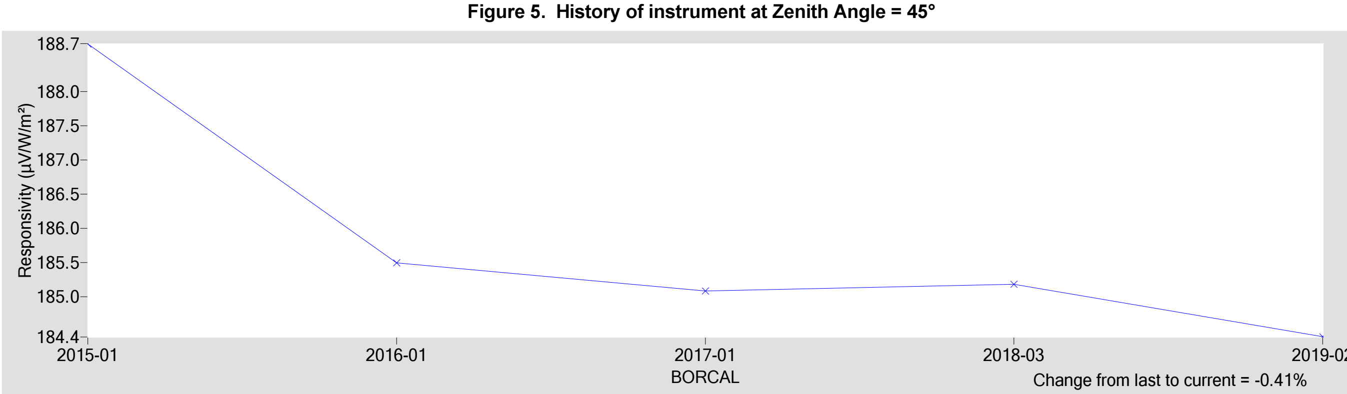
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
184.41	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.6 / -1.4
Expanded Uncertainty, U (%)	+2.5 / -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:	Pyrheliometer	**Manufacturer:**	Hukseflux
Model:	DR02	**Serial Number:**	9206
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

______________________________ ____________

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

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

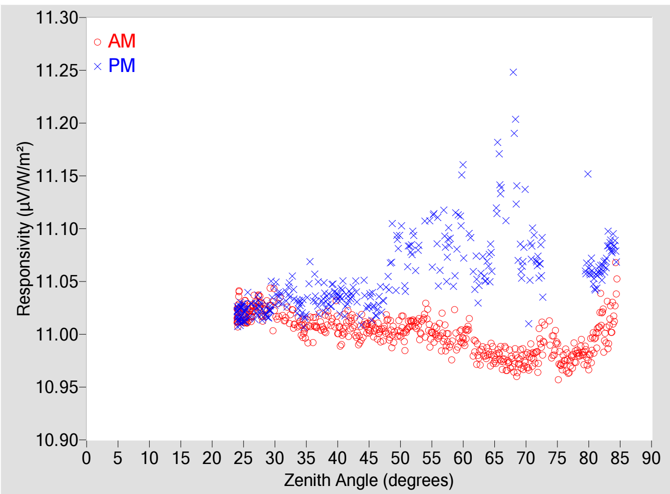


Figure 2. Responsivity vs Local Standard Time

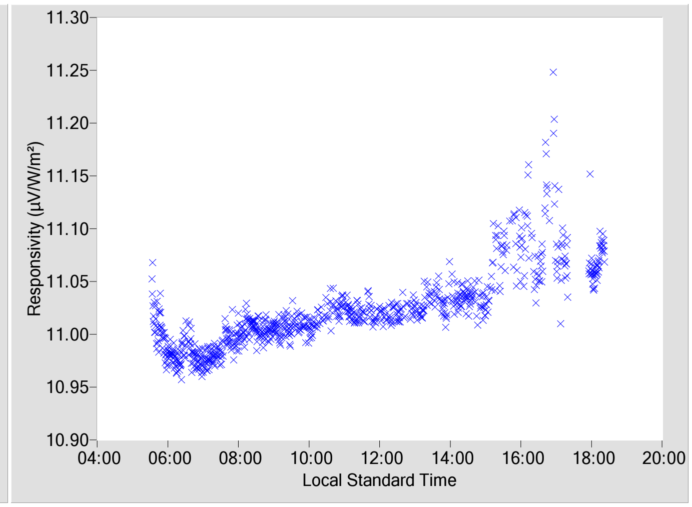


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	11.004	0.28	108.23	11.021	0.28	251.95
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.008	0.28	105.94	11.047	0.29	254.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.006	0.28	103.72	11.098	0.29	256.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.011	0.28	101.74	11.088	0.29	258.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.015	0.28	99.75	11.107	0.30	260.33
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.003	0.28	97.79	11.076	0.30	262.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.987	0.28	95.93	11.088	0.30	264.02
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.993	0.28	94.19	11.128	N/A	265.88
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.987	0.29	92.49	11.056	0.30	267.69
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.983	0.29	90.82	11.065	0.30	269.40
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.977	0.29	89.13	11.138	N/A	270.96
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.974	0.29	87.47	11.219	N/A	272.71
24	11.021	0.28	174.05	11.019	0.28	185.09	70	10.975	0.29	85.88	11.137	N/A	274.17
26	11.019	0.28	153.79	11.021	0.28	205.89	72	10.984	0.29	84.25	11.065	N/A	275.94
28	11.021	0.28	144.32	11.021	0.28	215.48	74	10.992	0.30	82.63	N/A	N/A	N/A
30	11.023	0.28	137.63	11.041	0.28	222.90	76	10.974	0.30	81.03	N/A	N/A	N/A
32	11.017	0.28	131.72	11.038	0.28	228.46	78	10.980	N/A	79.42	N/A	N/A	N/A
34	11.009	0.28	127.00	11.027	0.28	233.01	80	10.978	N/A	77.77	11.061	N/A	282.51
36	11.005	0.28	122.71	11.032	0.28	237.39	82	11.022	N/A	76.16	11.060	N/A	284.04
38	11.007	0.28	119.46	11.034	0.28	240.63	84	11.027	N/A	74.45	11.085	N/A	285.75
40	11.011	0.28	116.29	11.035	0.28	243.82	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.009	0.28	113.40	11.036	0.28	246.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.005	0.28	110.78	11.032	0.28	249.53	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

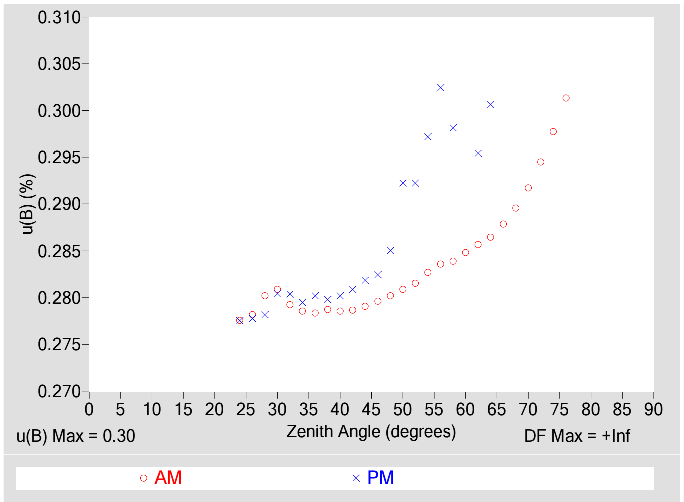


Figure 4. Residuals from Spline Interpolation

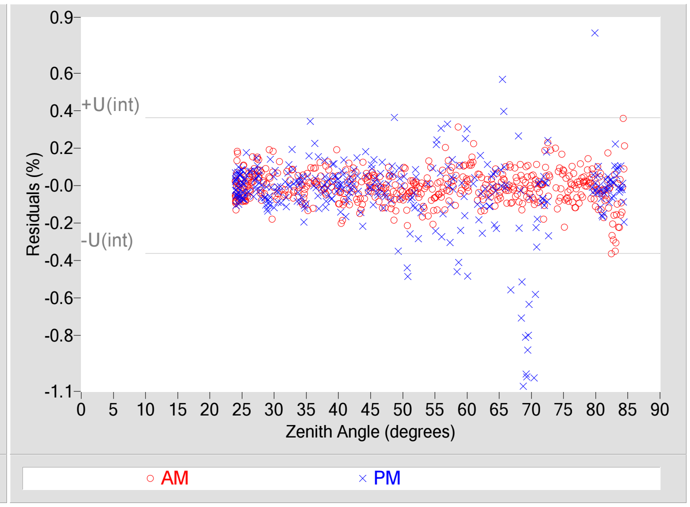


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	9777
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

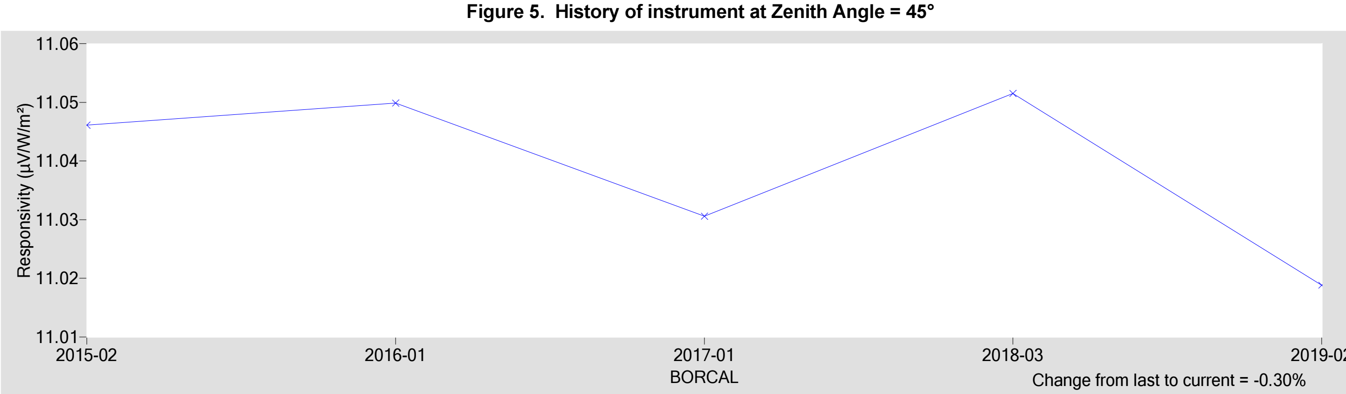
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
11.019	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.59
Offset Uncertainty, U(off) (%)	+0.99 / -0.29
Expanded Uncertainty, U (%)	+1.6 / -0.88
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:	Sunshine Pyranometer - Global Output	**Manufacturer:**	Delta-T
Model:	SPN1	**Serial Number:**	A360
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

________________________________ ________________

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:

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

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

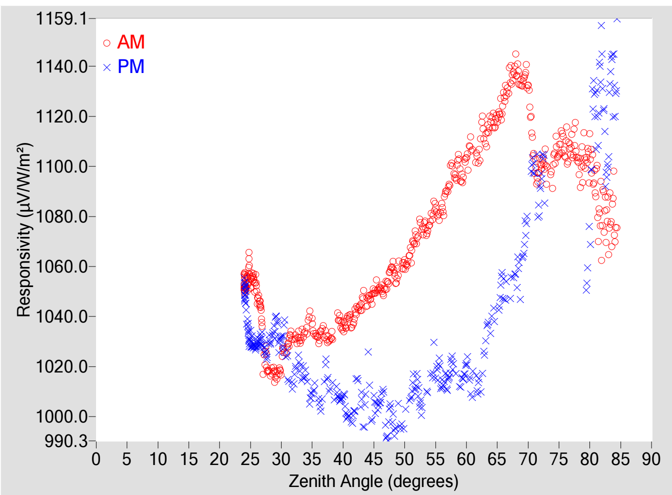


Figure 2. Responsivity vs Local Standard Time

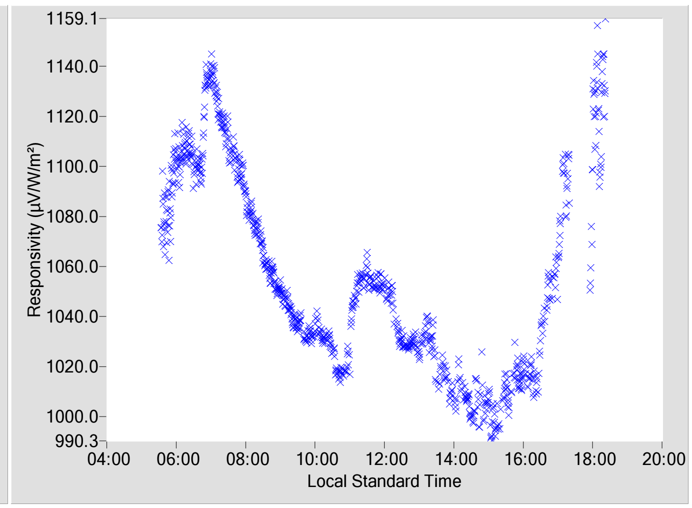


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	1051.4	0.34	108.28	1006.4	0.38	251.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	1059.9	0.35	105.92	999.28	0.39	254.23
4	N/A	N/A	N/A	N/A	N/A	N/A	50	1060.6	0.36	103.71	999.08	0.43	256.36
6	N/A	N/A	N/A	N/A	N/A	N/A	52	1071.3	0.36	101.69	1012.5	0.44	258.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	1077.3	0.37	99.67	1017.1	N/A	260.63
10	N/A	N/A	N/A	N/A	N/A	N/A	56	1083.1	0.38	97.78	1013.6	0.50	262.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	1096.9	0.39	95.94	1020.0	0.50	264.01
14	N/A	N/A	N/A	N/A	N/A	N/A	60	1102.5	0.40	94.22	1020.7	N/A	265.90
16	N/A	N/A	N/A	N/A	N/A	N/A	62	1105.1	0.41	92.44	1012.0	0.50	267.56
18	N/A	N/A	N/A	N/A	N/A	N/A	64	1117.7	0.43	90.81	1036.8	0.55	269.37
20	N/A	N/A	N/A	N/A	N/A	N/A	66	1125.6	0.45	89.12	1051.7	N/A	270.99
22	N/A	N/A	N/A	N/A	N/A	N/A	68	1139.2	0.48	87.46	1057.3	N/A	272.74
24	1052.8	0.31	174.66	1049.6	0.31	186.01	70	1131.8	0.51	85.87	1078.6	N/A	274.11
26	1050.5	0.32	153.98	1028.7	0.32	205.98	72	1100.1	0.56	84.24	1091.2	N/A	275.92
28	1017.8	0.33	144.51	1030.2	0.33	216.16	74	1099.9	0.63	82.60	N/A	N/A	N/A
30	1020.8	0.34	137.42	1030.2	0.33	223.01	76	1108.7	0.68	81.06	N/A	N/A	N/A
32	1031.4	0.33	131.55	1015.0	0.34	228.41	78	1102.3	N/A	79.40	N/A	N/A	N/A
34	1034.0	0.33	127.10	1016.0	0.34	233.00	80	1104.4	N/A	77.80	1085.5	N/A	282.47
36	1031.3	0.33	122.97	1005.5	0.35	237.43	82	1082.7	N/A	76.15	1135.2	N/A	284.07
38	1031.4	0.33	119.44	1011.6	0.35	240.63	84	1080.6	N/A	74.48	1129.4	N/A	285.74
40	1036.2	0.33	116.27	1008.0	0.36	243.83	86	N/A	N/A	N/A	N/A	N/A	N/A
42	1040.9	0.33	113.40	1005.5	0.39	246.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	1046.6	0.34	110.70	1019.2	0.40	249.65	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

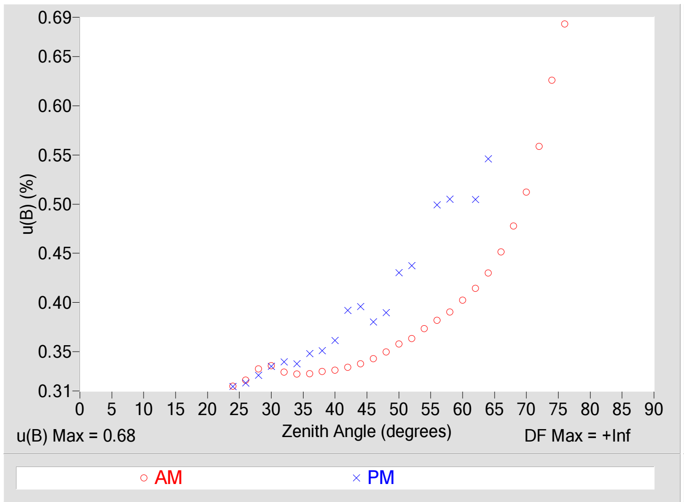


Figure 4. Residuals from Spline Interpolation

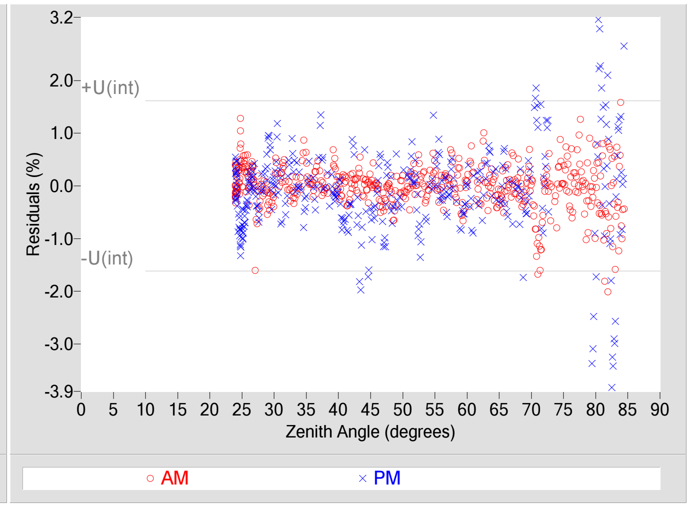


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.68
Type-A Interpolating Function, u(int) (%)	±0.81
Combined Standard Uncertainty, u(c) (%)	±1.1
Effective degrees of freedom, DF(c)	2203
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±2.1
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

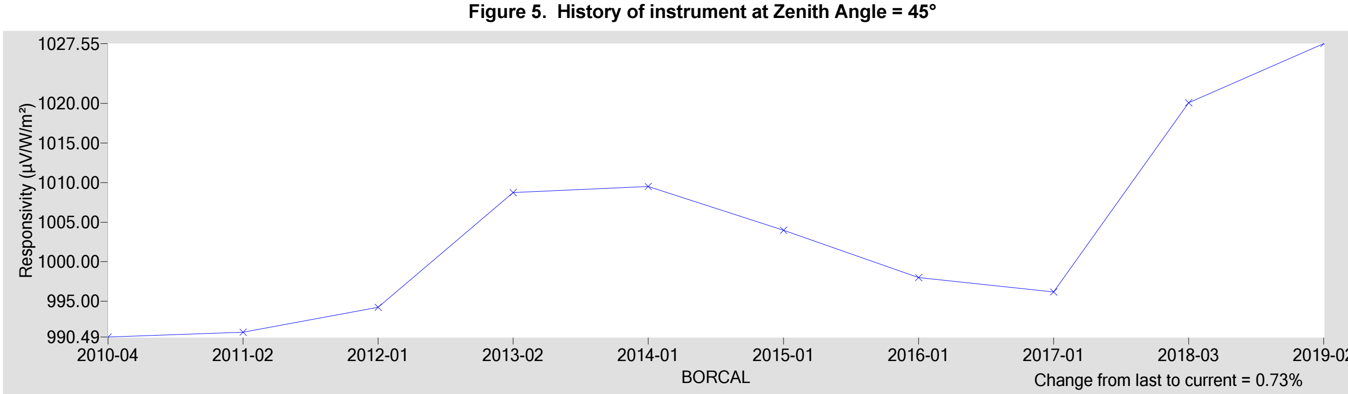
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
1027.5	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+7.3 / -2.8
Expanded Uncertainty, U (%)	+8.3 / -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:	Pyranometer	**Manufacturer:**	EKO
Model:	MS-802	**Serial Number:**	F14077R
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

______________________________ _______________

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

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

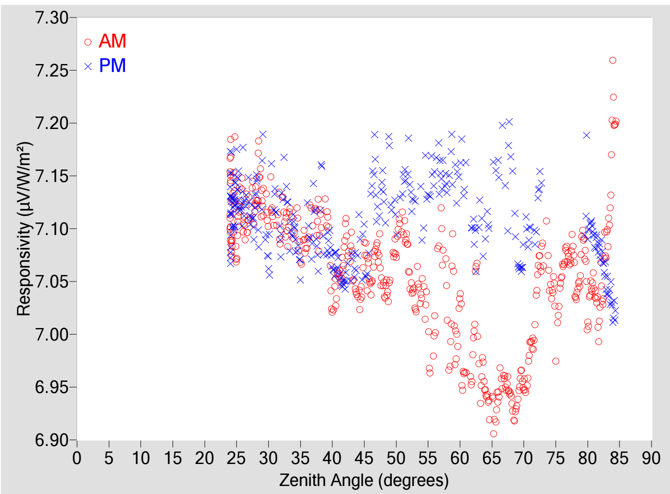


Figure 2. Responsivity vs Local Standard Time

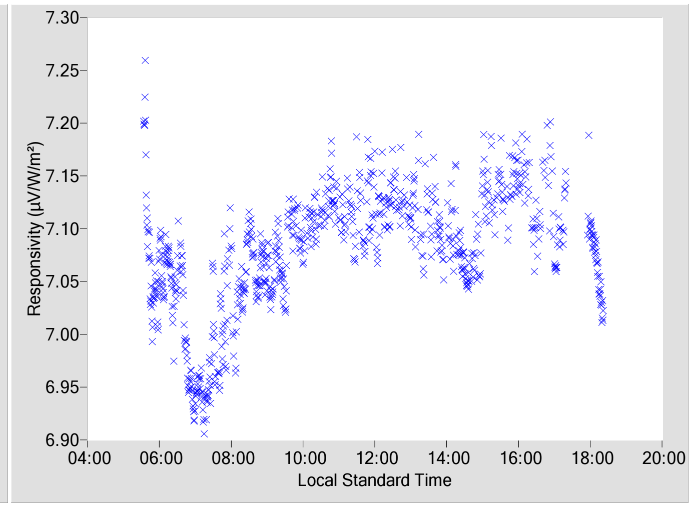


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.0479	0.35	108.23	7.1368	0.39	252.01
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.0437	0.36	105.90	7.1329	0.40	254.21
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.0817	0.36	103.81	7.1116	0.44	256.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.0663	0.37	101.74	7.1598	0.45	258.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.0385	0.38	99.77	7.1098	0.48	260.49
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.9993	0.39	97.82	7.1474	0.51	262.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.0243	0.40	96.00	7.1450	0.52	264.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.0154	0.42	94.14	7.1655	N/A	265.99
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9775	0.43	92.48	7.0989	0.52	267.67
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9460	0.44	90.77	7.1033	0.55	269.47
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.9439	0.47	89.14	7.1566	N/A	271.05
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.9381	0.49	87.47	7.1747	N/A	272.65
24	7.1167	0.32	174.69	7.1208	0.32	185.37	70	6.9503	0.53	85.83	7.0741	N/A	274.17
26	7.1170	0.33	154.01	7.1202	0.32	205.85	72	7.0418	0.58	84.23	7.1120	N/A	275.96
28	7.1254	0.34	144.19	7.1382	0.33	216.00	74	7.0559	0.65	82.66	N/A	N/A	N/A
30	7.1084	0.34	137.76	7.0723	0.34	222.88	76	7.0588	0.71	81.03	N/A	N/A	N/A
32	7.1069	0.33	131.72	7.1036	0.34	228.39	78	7.0492	N/A	79.42	N/A	N/A	N/A
34	7.0934	0.33	127.12	7.0975	0.34	233.16	80	7.0297	N/A	77.81	7.1000	N/A	282.42
36	7.0844	0.33	123.00	7.1136	0.35	237.48	82	7.0294	N/A	76.16	7.0802	N/A	284.03
38	7.1055	0.34	119.40	7.1126	0.36	240.78	84	7.2087	N/A	74.50	7.0216	N/A	285.71
40	7.0274	0.34	116.33	7.0631	0.37	243.95	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0907	0.34	113.35	7.0498	0.40	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.0346	0.34	110.61	7.0827	0.40	249.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

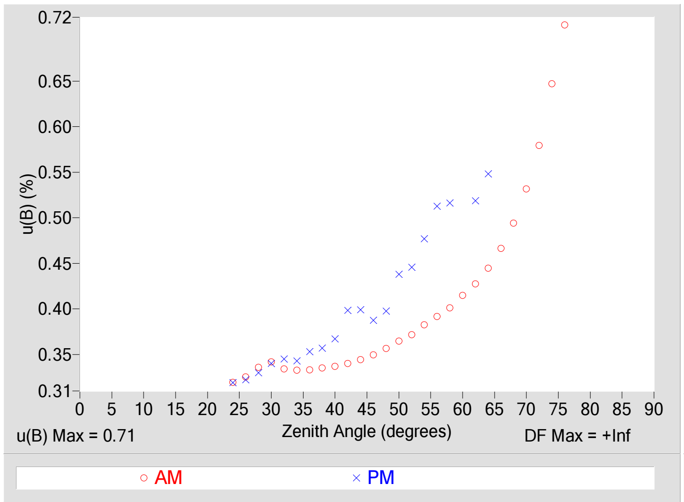


Figure 4. Residuals from Spline Interpolation

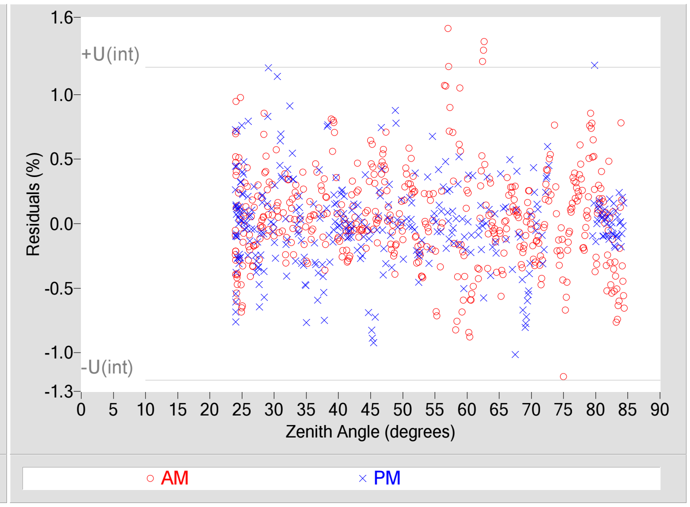


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.71
Type-A Interpolating Function, u(int) (%)	±0.61
Combined Standard Uncertainty, u(c) (%)	±0.93
Effective degrees of freedom, DF(c)	3805
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.8
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

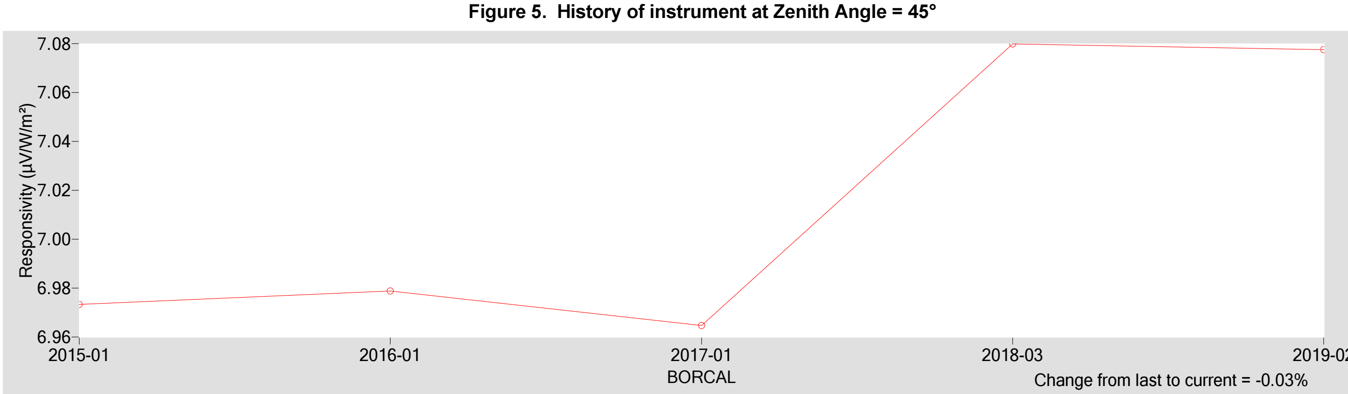
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.0776	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.2 / -1.1
Expanded Uncertainty, U (%)	+2.3 / -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:	Revised Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200R	**Serial Number:**	PY100360
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

______________________________ ____________

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

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

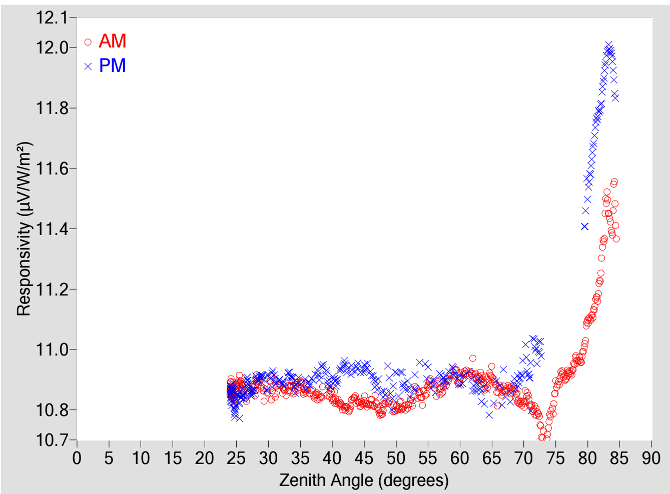


Figure 2. Responsivity vs Local Standard Time

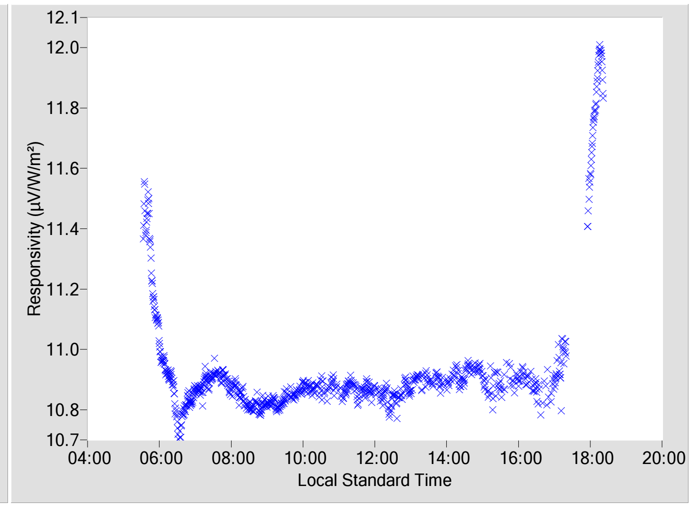


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.823	0.34	108.12	10.920	0.38	251.96
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.806	0.35	105.89	10.854	0.39	254.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.802	0.36	103.74	10.923	0.43	256.34
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.818	0.36	101.72	10.869	0.44	258.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.843	0.37	99.73	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.866	0.38	97.70	10.878	0.50	262.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.894	0.39	95.94	10.911	0.51	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.897	0.40	94.25	10.892	N/A	265.89
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.929	0.42	92.52	10.881	0.51	267.66
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.887	0.43	90.78	10.857	0.54	269.36
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.859	0.45	89.10	10.887	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.865	0.48	87.48	10.840	N/A	272.64
24	10.865	0.32	174.34	10.852	0.32	186.43	70	10.829	0.52	85.85	10.990	N/A	274.36
26	10.869	0.32	154.44	10.849	0.32	206.07	72	10.790	0.56	84.26	10.991	N/A	275.87
28	10.886	0.33	143.99	10.893	0.33	215.87	74	10.762	0.63	82.65	N/A	N/A	N/A
30	10.875	0.34	137.05	10.900	0.34	222.72	76	10.920	0.69	81.04	N/A	N/A	N/A
32	10.873	0.33	131.60	10.892	0.34	228.69	78	10.959	N/A	79.43	N/A	N/A	N/A
34	10.874	0.33	127.01	10.885	0.34	233.09	80	11.093	N/A	77.78	11.539	N/A	282.43
36	10.865	0.33	123.07	10.886	0.35	237.15	82	11.261	N/A	76.12	11.812	N/A	284.04
38	10.844	0.33	119.48	10.918	0.35	240.68	84	11.468	N/A	74.46	11.918	N/A	285.72
40	10.844	0.33	116.31	10.896	0.36	243.85	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.808	0.34	113.32	10.947	0.39	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.825	0.34	110.71	10.945	0.39	249.29	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

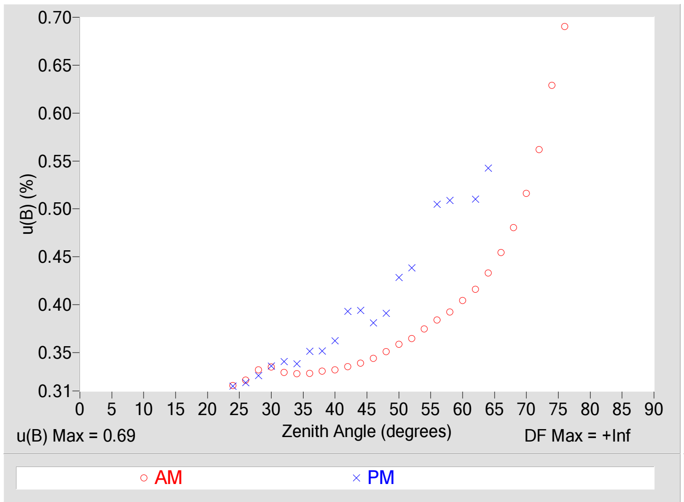


Figure 4. Residuals from Spline Interpolation

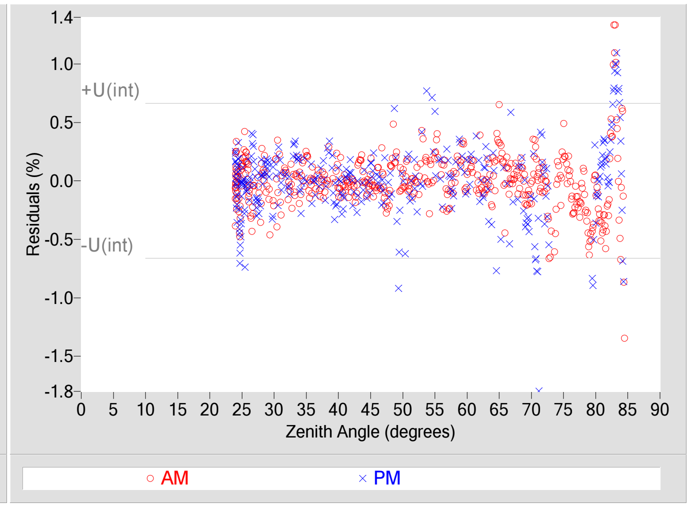


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	19950
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

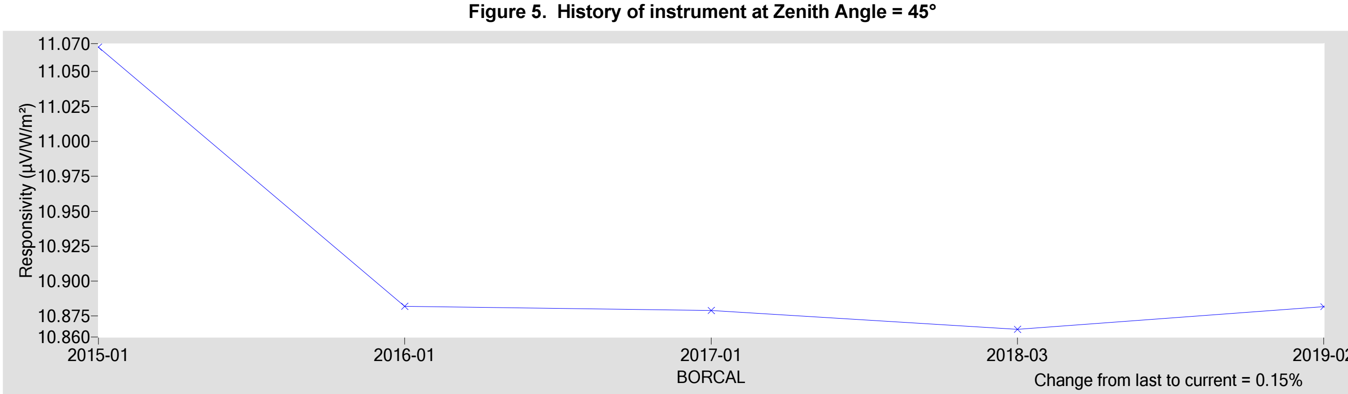
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.882	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+0.60 / -0.73
Expanded Uncertainty, U (%)	+1.6 / -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

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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: Revised Silicon Pyranometer

Manufacturer: Licor

Model: LI200R

Serial Number: PY102022

Calibration Date: 5/3/2019

Due Date: 5/3/2020

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/3

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

________________________________ 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

PY102022 Licor LI200R

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

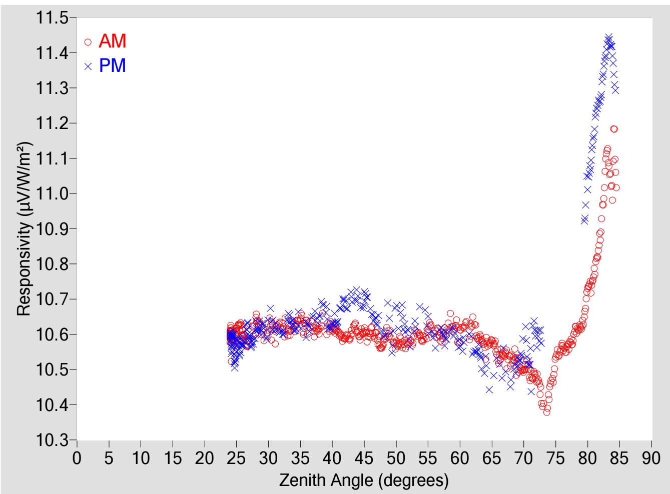


Figure 2. Responsivity vs Local Standard Time

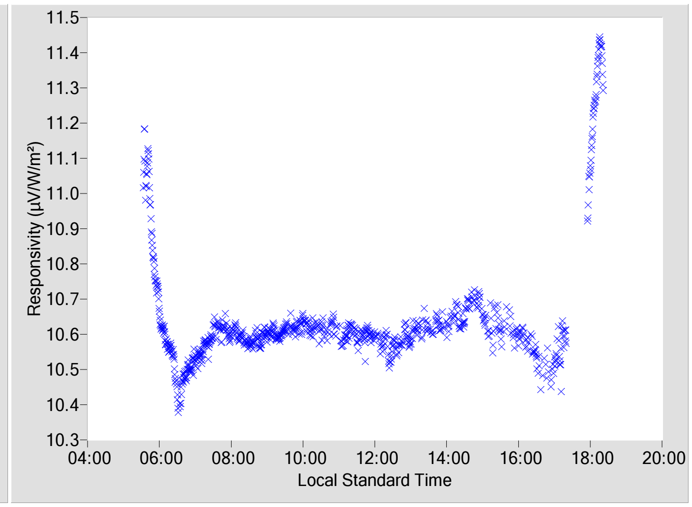


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.607	0.34	108.12	10.665	0.38	251.96
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.577	0.35	105.89	10.602	0.39	254.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.571	0.36	103.74	10.678	0.43	256.34
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.579	0.36	101.72	10.594	0.44	258.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.589	0.37	99.73	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.602	0.38	97.70	10.583	0.51	262.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.613	0.39	95.94	10.600	0.51	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.605	0.40	94.25	10.571	N/A	265.89
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.623	0.42	92.52	10.563	0.51	267.66
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.567	0.43	90.78	10.513	0.54	269.36
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.536	0.45	89.10	10.523	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.529	0.48	87.48	10.461	N/A	272.64
24	10.600	0.32	174.45	10.582	0.32	186.43	70	10.500	0.52	85.85	10.605	N/A	274.36
26	10.599	0.32	154.44	10.576	0.32	206.07	72	10.476	0.56	84.26	10.595	N/A	275.87
28	10.630	0.33	143.99	10.613	0.33	215.87	74	10.435	0.63	82.65	N/A	N/A	N/A
30	10.618	0.34	137.05	10.630	0.34	222.72	76	10.564	0.69	81.04	N/A	N/A	N/A
32	10.626	0.33	131.60	10.606	0.34	228.69	78	10.606	N/A	79.43	N/A	N/A	N/A
34	10.625	0.33	127.01	10.622	0.34	233.09	80	10.728	N/A	77.78	11.041	N/A	282.43
36	10.626	0.33	123.07	10.621	0.35	237.15	82	10.899	N/A	76.12	11.279	N/A	284.04
38	10.613	0.33	119.48	10.657	0.35	240.68	84	11.093	N/A	74.46	11.365	N/A	285.72
40	10.621	0.33	116.31	10.626	0.36	243.85	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.591	0.34	113.32	10.688	0.39	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.602	0.34	110.71	10.710	0.39	249.29	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

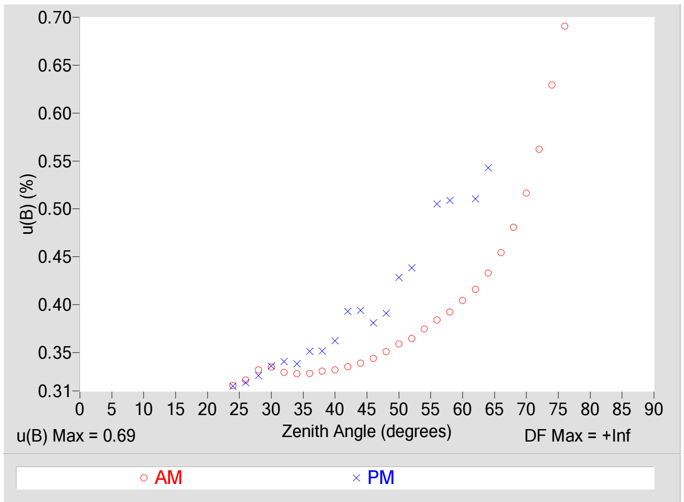


Figure 4. Residuals from Spline Interpolation

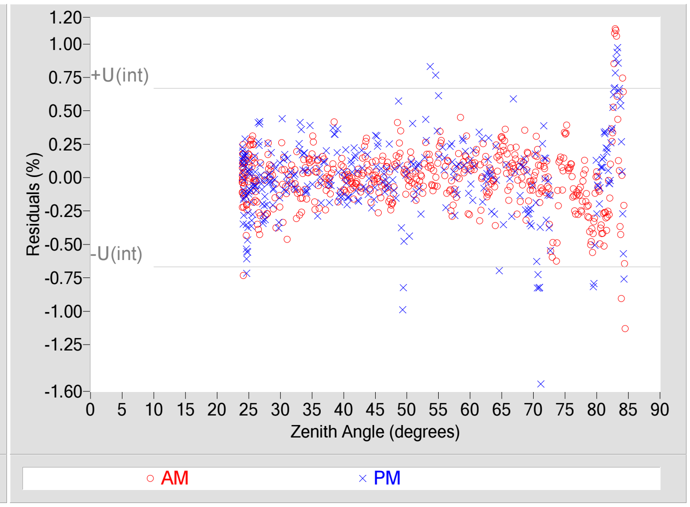


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	19316
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

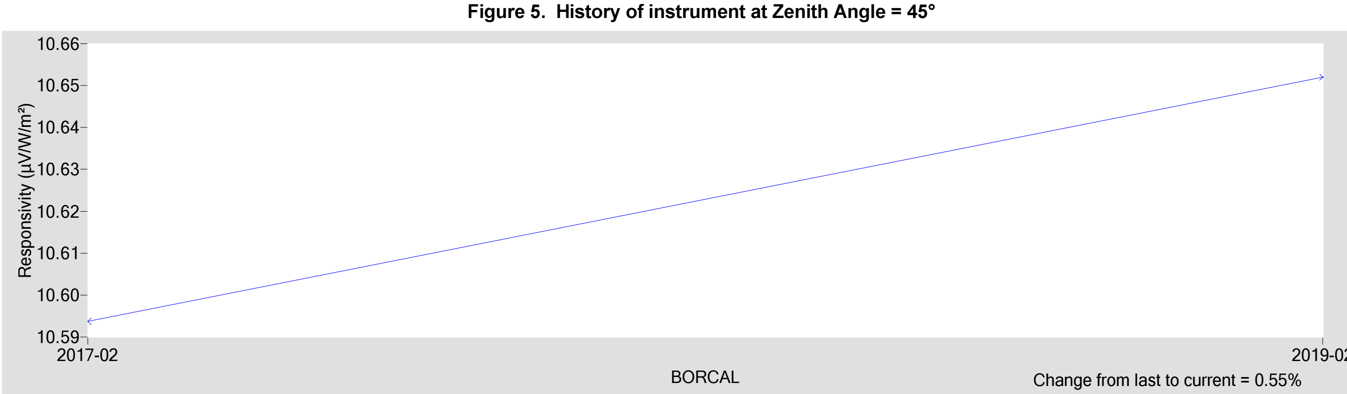
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.652	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+0.55 / -0.76
Expanded Uncertainty, U (%)	+1.5 / -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:**	Licor
Model:	LI200	**Serial Number:**	PY28257
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

____ ____________________

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

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

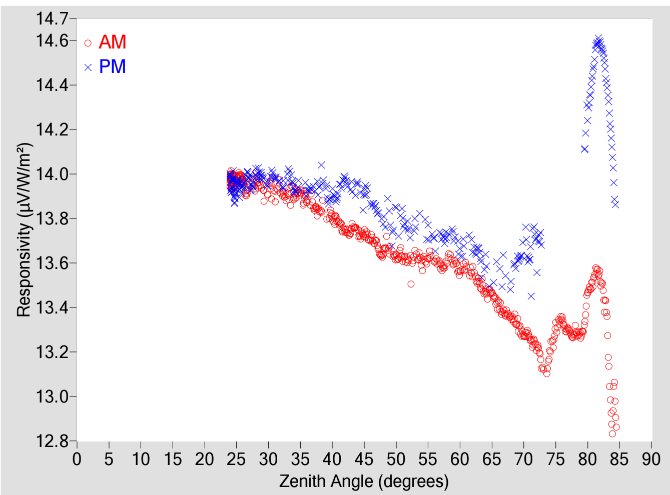


Figure 2. Responsivity vs Local Standard Time

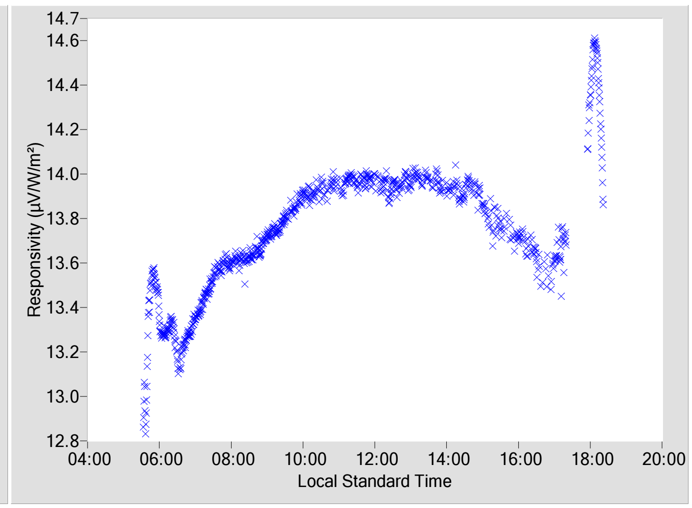


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	13.709	0.34	108.12	13.862	0.38	251.96
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.650	0.35	105.89	13.786	0.39	254.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.626	0.36	103.74	13.851	0.43	256.34
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.616	0.36	101.72	13.751	0.44	258.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.606	0.37	99.73	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	13.611	0.38	97.70	13.693	0.50	262.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.618	0.39	95.94	13.729	0.51	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.559	0.40	94.25	13.645	N/A	265.89
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.558	0.42	92.52	13.675	0.51	267.66
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.469	0.43	90.78	13.598	0.54	269.36
20	N/A	N/A	N/A	N/A	N/A	N/A	66	13.414	0.45	89.10	13.591	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	13.355	0.48	87.48	13.499	N/A	272.64
24	13.974	0.32	174.34	13.961	0.31	186.43	70	13.279	0.52	85.85	13.727	N/A	274.36
26	13.969	0.32	154.44	13.947	0.32	206.07	72	13.226	0.56	84.26	13.680	N/A	275.87
28	13.963	0.33	143.99	13.995	0.33	215.87	74	13.184	0.63	82.65	N/A	N/A	N/A
30	13.935	0.33	137.05	13.964	0.34	222.72	76	13.346	0.69	81.04	N/A	N/A	N/A
32	13.928	0.33	131.60	13.955	0.34	228.69	78	13.286	N/A	79.43	N/A	N/A	N/A
34	13.904	0.33	127.01	13.936	0.34	233.09	80	13.461	N/A	77.78	14.293	N/A	282.43
36	13.889	0.33	123.07	13.930	0.35	237.15	82	13.524	N/A	76.12	14.581	N/A	284.04
38	13.837	0.33	119.48	13.958	0.35	240.68	84	12.955	N/A	74.46	14.015	N/A	285.72
40	13.808	0.33	116.31	13.911	0.36	243.85	86	N/A	N/A	N/A	N/A	N/A	N/A
42	13.748	0.34	113.32	13.974	0.39	246.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	13.741	0.34	110.71	13.958	0.39	249.29	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

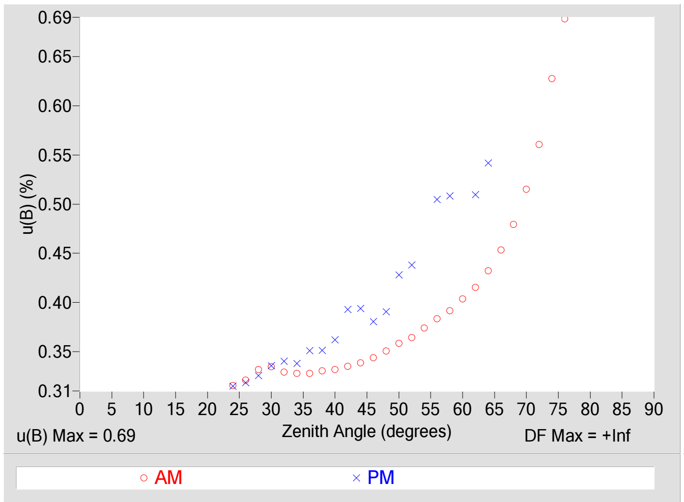


Figure 4. Residuals from Spline Interpolation

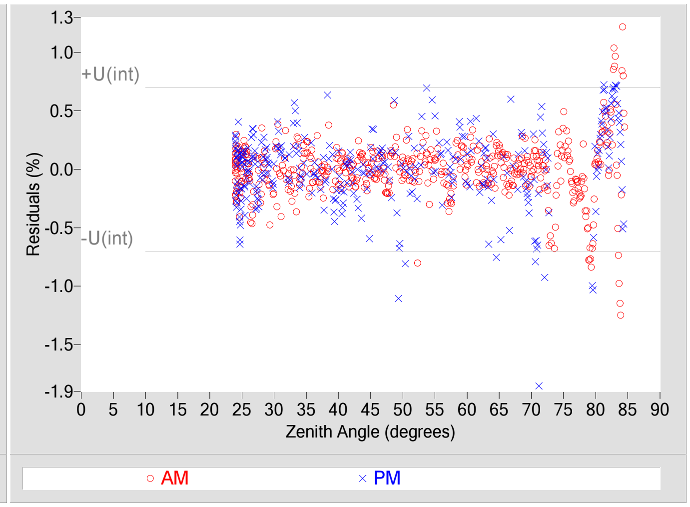


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.35
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	16502
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

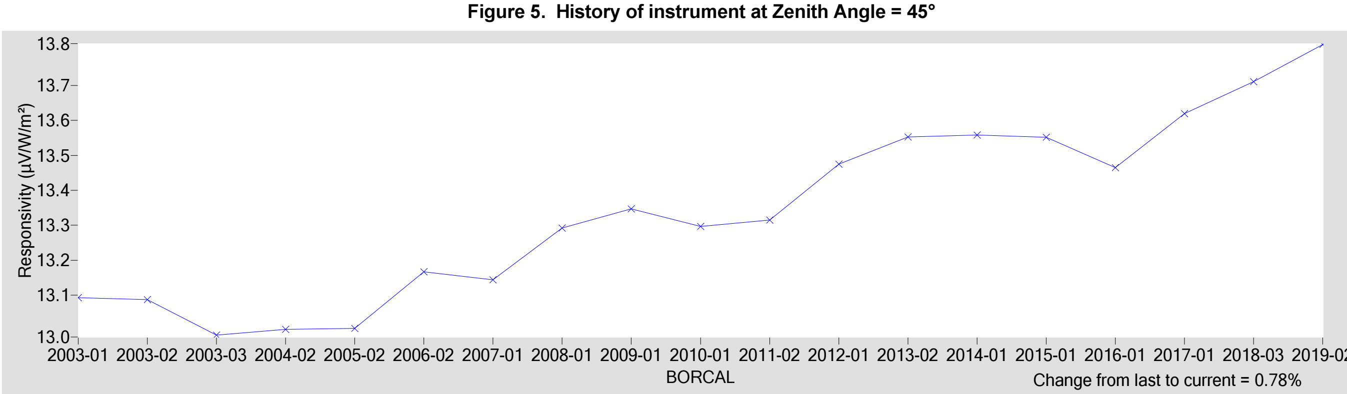
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
13.817	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+1.1 / -1.9
Expanded Uncertainty, U (%)	+2.1 / -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:	Semiconductor Pyrheliometer	**Manufacturer:**	Licor
Model:	LI201SB	**Serial Number:**	PYHR101
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

______________________________ _______________

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

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

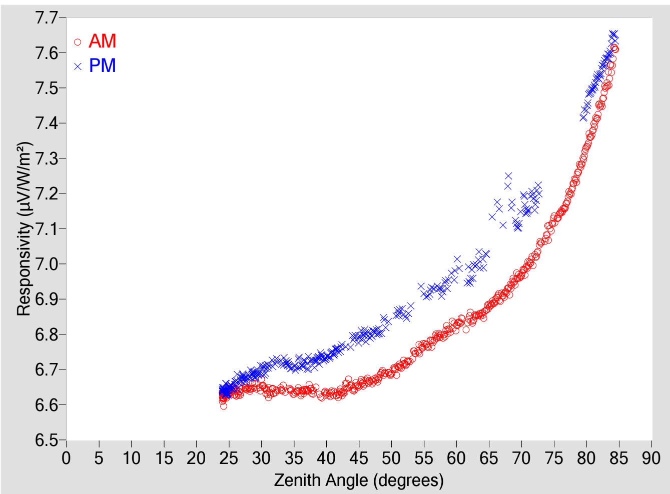


Figure 2. Responsivity vs Local Standard Time

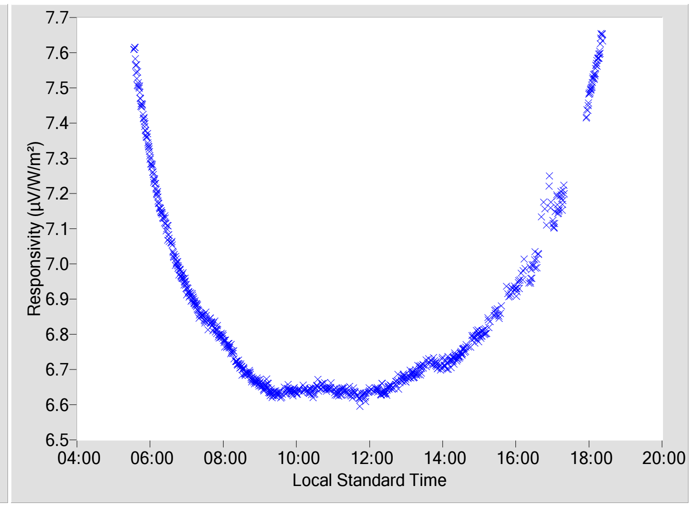


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	6.6678	0.28	108.22	6.7992	0.28	251.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.6754	0.28	105.93	6.8047	0.29	254.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.6891	0.28	103.77	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.7169	0.28	101.64	6.8509	0.29	258.54
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.7545	0.28	99.68	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.7779	0.29	97.68	6.9249	0.30	262.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.7946	0.29	95.89	6.9328	0.30	264.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.8237	0.29	94.15	6.9976	N/A	265.88
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.8456	0.29	92.47	6.9616	0.30	267.68
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.8549	0.29	90.74	7.0013	0.30	269.44
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.8967	0.29	89.11	7.1758	N/A	271.25
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.9274	0.29	87.48	7.2353	N/A	272.64
24	6.6249	0.28	174.79	6.6421	0.28	186.06	70	6.9708	0.29	85.85	7.1723	N/A	274.36
26	6.6365	0.28	154.41	6.6673	0.28	206.22	72	7.0150	0.30	84.18	7.1767	N/A	275.91
28	6.6443	0.28	144.25	6.6789	0.28	215.94	74	7.0869	0.30	82.65	N/A	N/A	N/A
30	6.6545	0.28	136.96	6.7034	0.28	223.17	76	7.1455	0.30	81.04	N/A	N/A	N/A
32	6.6390	0.28	131.78	6.7192	0.28	228.46	78	7.2268	N/A	79.43	N/A	N/A	N/A
34	N/A	N/A	N/A	6.7164	0.28	233.10	80	7.3320	N/A	77.78	7.4478	N/A	282.47
36	6.6340	0.28	122.90	6.7154	0.28	237.16	82	7.4466	N/A	76.12	7.5332	N/A	284.05
38	6.6355	0.28	119.66	6.7206	0.28	240.93	84	7.5808	N/A	74.46	7.6449	N/A	285.72
40	6.6331	0.28	116.39	6.7351	0.28	243.96	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.6331	0.28	113.30	6.7562	0.28	246.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.6471	0.28	110.72	6.7905	0.28	249.59	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

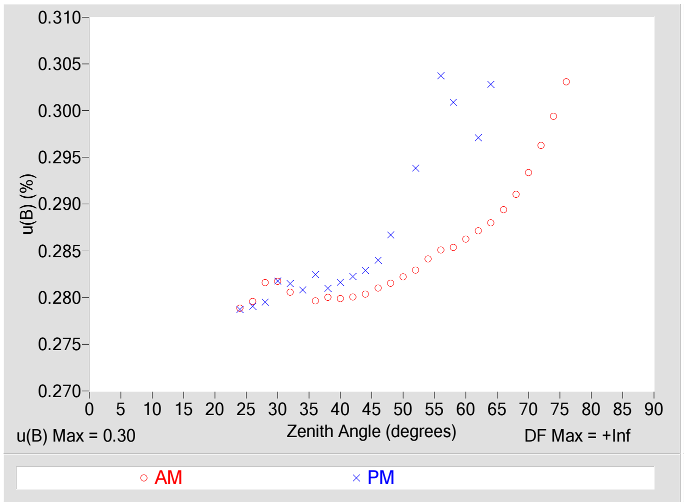


Figure 4. Residuals from Spline Interpolation

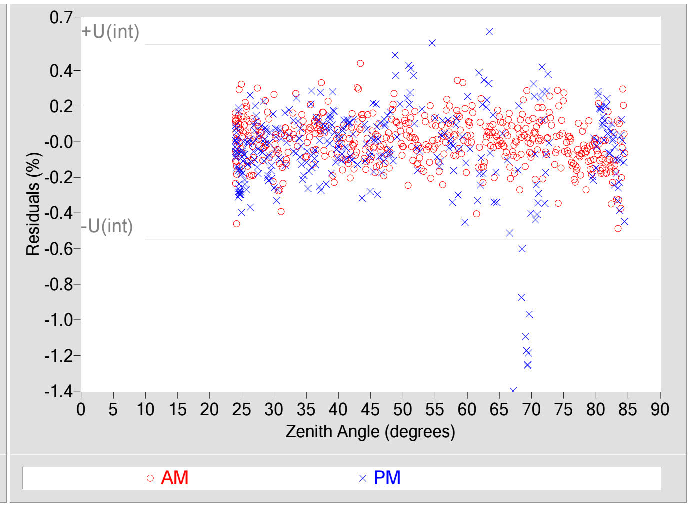


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	3348
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.80
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

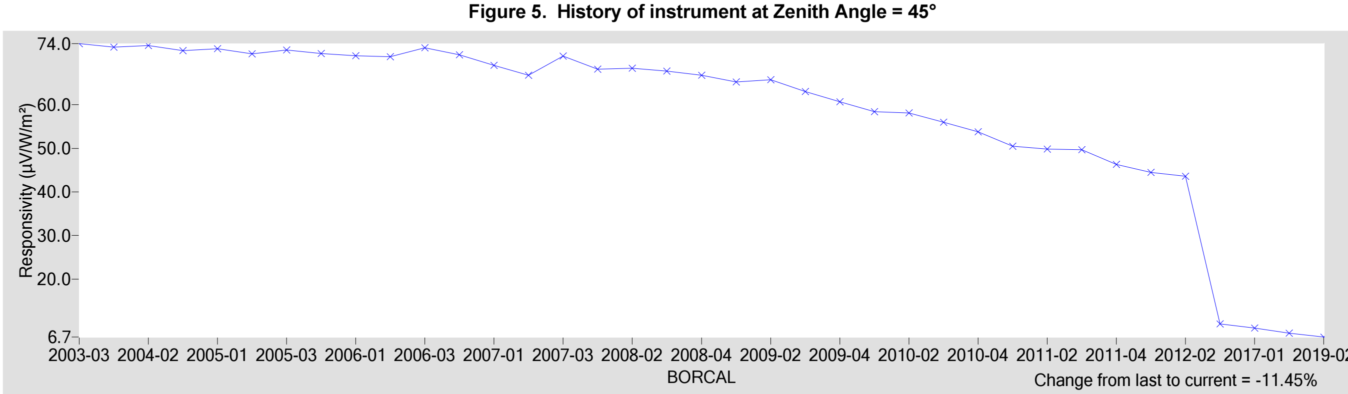
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
6.7215	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.60
Offset Uncertainty, U(off) (%)	+4.1 / -1.3
Expanded Uncertainty, U (%)	+4.7 / -1.9
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-602	**Serial Number:**	S13071483
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

______________________________ ____________

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

S13071483 EKO MS-602

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

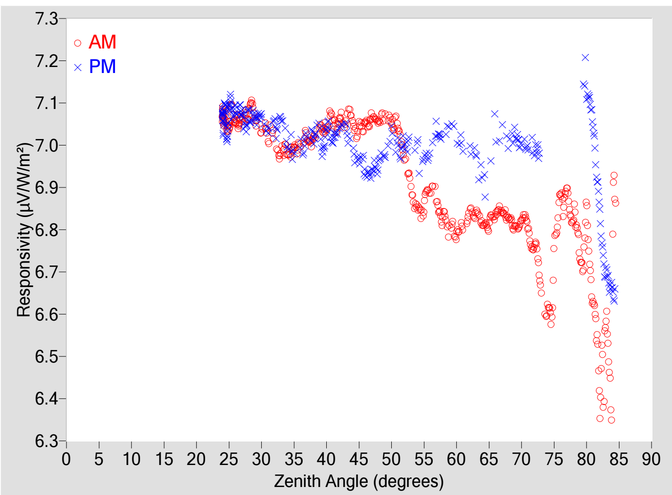


Figure 2. Responsivity vs Local Standard Time

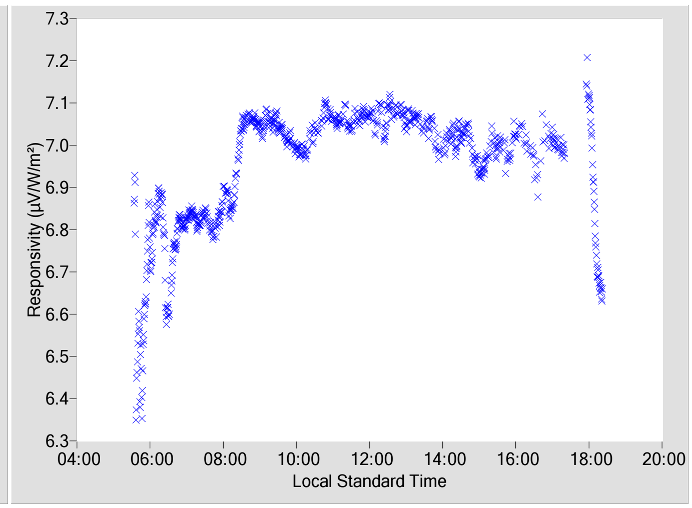


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.0542	0.36	108.22	6.9324	0.40	251.93
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.0564	0.36	105.93	6.9544	0.41	254.23
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.0547	0.37	103.72	7.0275	0.45	256.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.9745	0.38	101.76	7.0043	0.46	258.41
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.8533	0.40	99.71	6.9839	0.49	260.51
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.8918	0.41	97.76	6.9810	0.52	262.22
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.8311	0.42	95.97	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.7897	0.43	94.14	7.0045	N/A	266.05
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.8426	0.44	92.47	6.9889	0.53	267.80
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.8135	0.46	90.77	6.9353	0.56	269.36
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.8342	0.48	89.12	7.0410	N/A	271.00
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.8275	0.51	87.47	7.0096	N/A	272.65
24	7.0683	0.33	174.38	7.0660	0.33	184.81	70	6.8212	0.55	85.87	6.9991	N/A	274.16
26	7.0590	0.33	153.78	7.0812	0.33	205.83	72	6.7611	0.60	84.25	6.9854	N/A	275.95
28	7.0735	0.34	144.35	7.0686	0.34	215.84	74	6.6091	0.68	82.63	N/A	N/A	N/A
30	7.0323	0.35	137.27	7.0700	0.35	222.45	76	6.8783	0.74	81.02	N/A	N/A	N/A
32	7.0249	0.34	132.18	7.0475	0.35	228.58	78	6.8324	N/A	79.41	N/A	N/A	N/A
34	6.9777	0.34	126.98	6.9975	0.35	233.06	80	6.8179	N/A	77.81	7.1379	N/A	282.38
36	6.9997	0.34	123.22	7.0042	0.36	237.20	82	6.4402	N/A	76.15	6.8528	N/A	284.03
38	7.0189	0.34	119.39	7.0191	0.36	240.74	84	6.6707	N/A	74.48	6.6532	N/A	285.70
40	7.0422	0.34	116.16	7.0410	0.37	243.92	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0626	0.35	113.33	7.0440	0.41	246.92	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.0524	0.35	110.61	6.9858	0.41	249.65	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

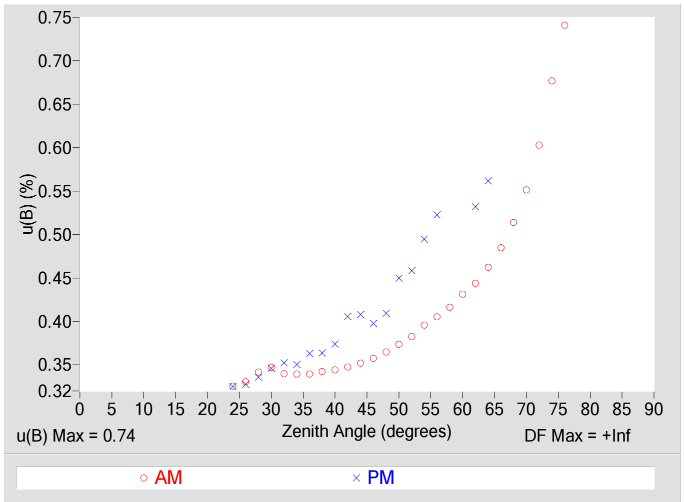


Figure 4. Residuals from Spline Interpolation

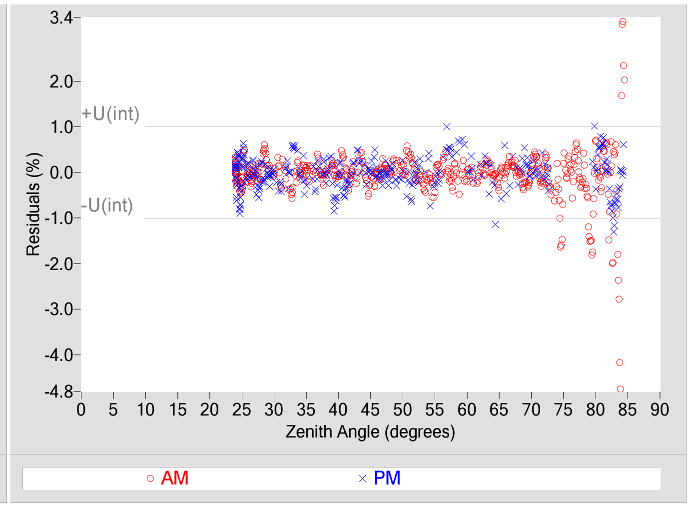


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.50
Combined Standard Uncertainty, u(c) (%)	±0.89
Effective degrees of freedom, DF(c)	6879
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.8
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

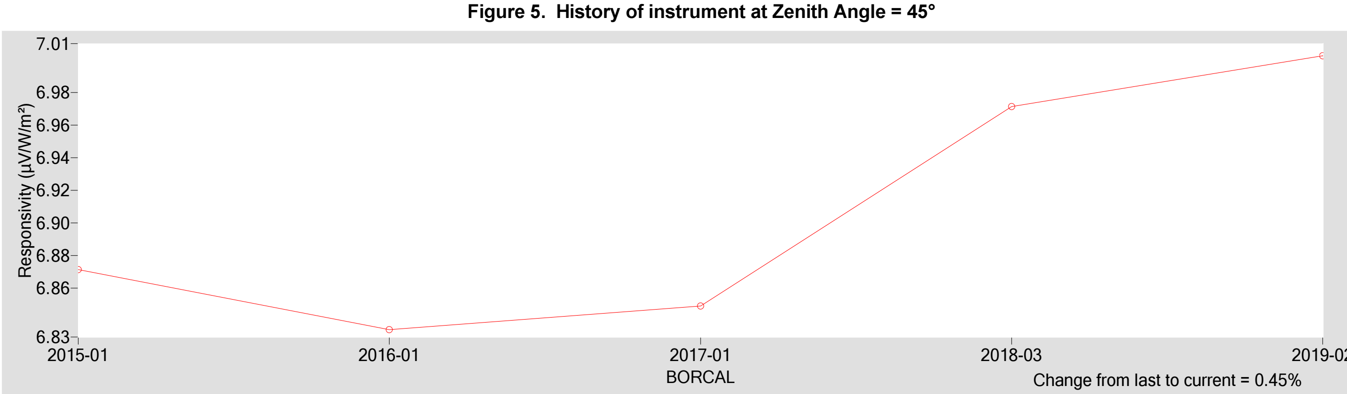
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.0025	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+0.96 / -3.0
Expanded Uncertainty, U (%)	+2.0 / -4.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	EKO
Model:	ML-01	**Serial Number:**	S13135063
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

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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

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

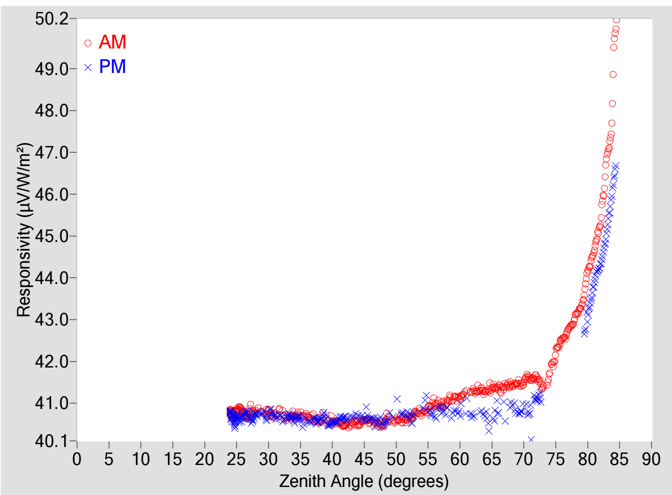


Figure 2. Responsivity vs Local Standard Time

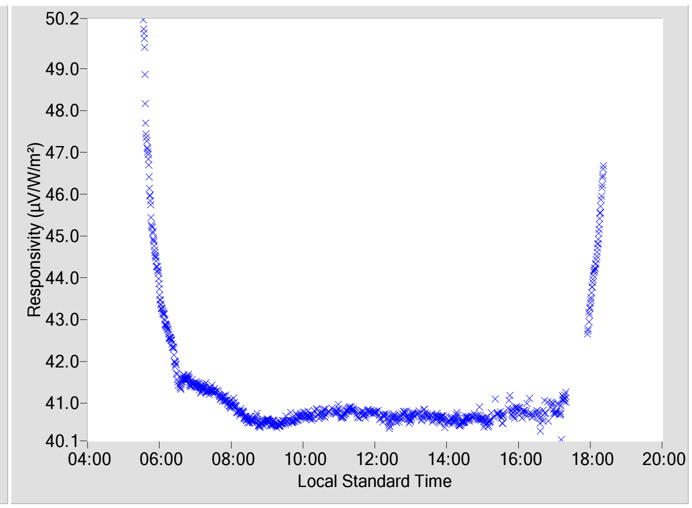


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	40.560	0.34	108.40	40.629	0.38	251.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	40.491	0.35	105.92	40.494	0.39	254.15
4	N/A	N/A	N/A	N/A	N/A	N/A	50	40.591	0.36	103.70	41.101	0.44	256.54
6	N/A	N/A	N/A	N/A	N/A	N/A	52	40.647	0.36	101.67	40.715	0.44	258.43
8	N/A	N/A	N/A	N/A	N/A	N/A	54	40.768	0.37	99.74	40.880	N/A	260.63
10	N/A	N/A	N/A	N/A	N/A	N/A	56	40.999	0.38	97.76	40.700	0.49	262.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	41.039	0.39	95.97	40.839	0.50	264.06
14	N/A	N/A	N/A	N/A	N/A	N/A	60	41.143	0.40	94.23	40.814	N/A	265.90
16	N/A	N/A	N/A	N/A	N/A	N/A	62	41.297	0.41	92.45	40.695	0.51	267.64
18	N/A	N/A	N/A	N/A	N/A	N/A	64	41.287	0.43	90.81	40.707	0.55	269.43
20	N/A	N/A	N/A	N/A	N/A	N/A	66	41.389	0.45	89.12	40.865	N/A	270.95
22	N/A	N/A	N/A	N/A	N/A	N/A	68	41.430	0.48	87.47	40.960	N/A	272.69
24	40.768	0.32	173.97	40.724	0.31	185.43	70	41.506	0.51	85.87	40.895	N/A	274.11
26	40.797	0.32	154.18	40.673	0.32	205.90	72	41.625	0.56	84.25	41.094	N/A	275.93
28	40.794	0.33	144.79	40.720	0.32	215.49	74	41.685	0.62	82.66	N/A	N/A	N/A
30	40.779	0.34	137.35	40.741	0.33	222.86	76	42.530	0.68	81.06	N/A	N/A	N/A
32	40.847	0.33	131.76	40.672	0.34	228.29	78	43.044	N/A	79.41	N/A	N/A	N/A
34	40.725	0.33	126.98	40.609	0.34	233.05	80	44.139	N/A	77.80	43.162	N/A	282.45
36	40.698	0.33	122.86	40.547	0.35	237.37	82	45.378	N/A	76.15	44.347	N/A	284.07
38	40.573	0.33	119.46	40.604	0.35	240.72	84	48.968	N/A	74.44	46.294	N/A	285.74
40	40.581	0.33	116.28	40.536	0.36	243.92	86	N/A	N/A	N/A	N/A	N/A	N/A
42	40.466	0.33	113.47	40.638	0.39	246.72	88	N/A	N/A	N/A	N/A	N/A	N/A
44	40.512	0.34	110.70	40.671	0.40	249.39	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

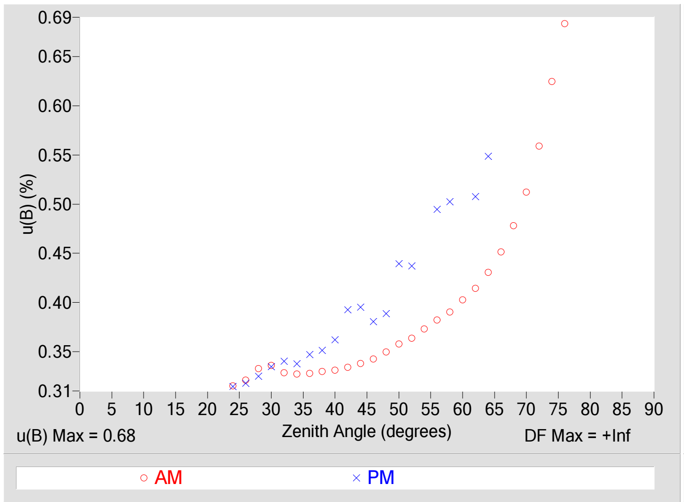


Figure 4. Residuals from Spline Interpolation

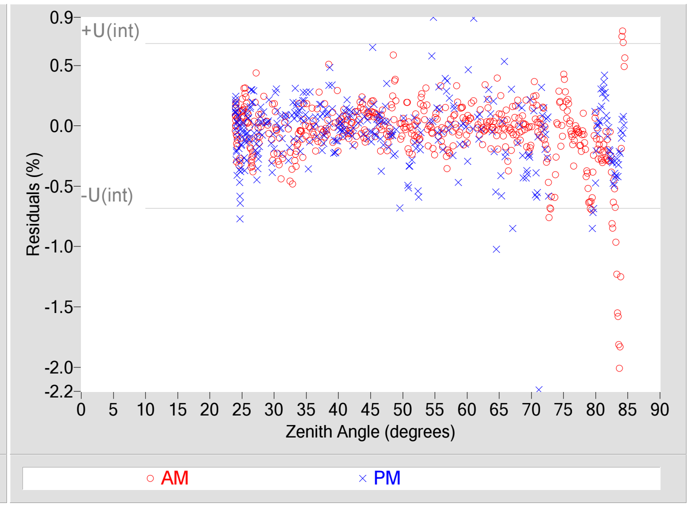


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.68
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.76
Effective degrees of freedom, DF(c)	17334
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

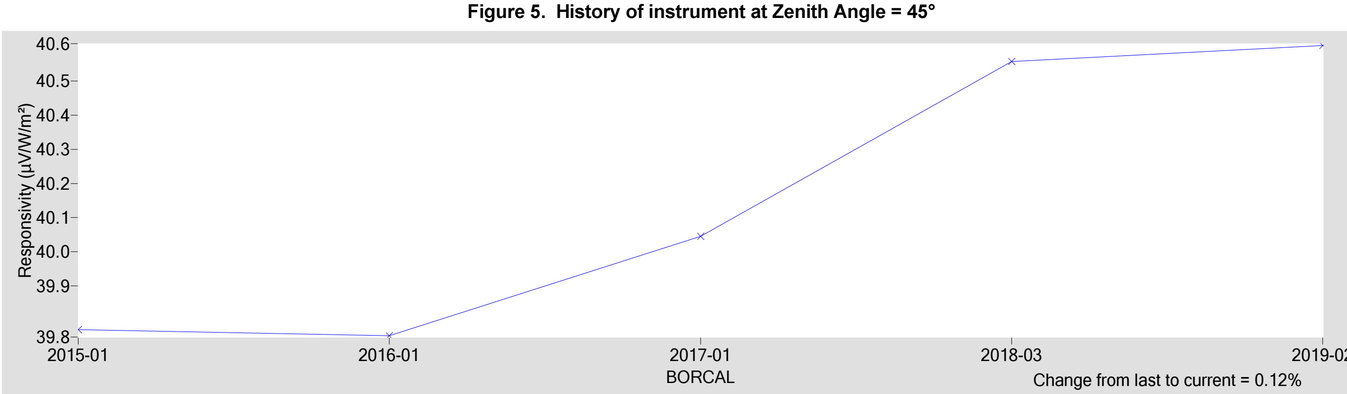
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
40.604	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.3 / -0.34
Expanded Uncertainty, U (%)	+2.3 / -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:	Pyranometer	**Manufacturer:**	EKO
Model:	MS-410	**Serial Number:**	S13144.085R
Calibration Date:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

____________________________________ ____________

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:

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

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

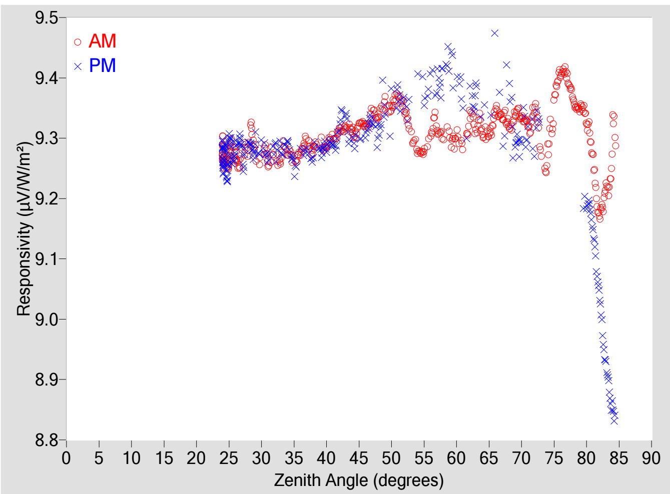


Figure 2. Responsivity vs Local Standard Time

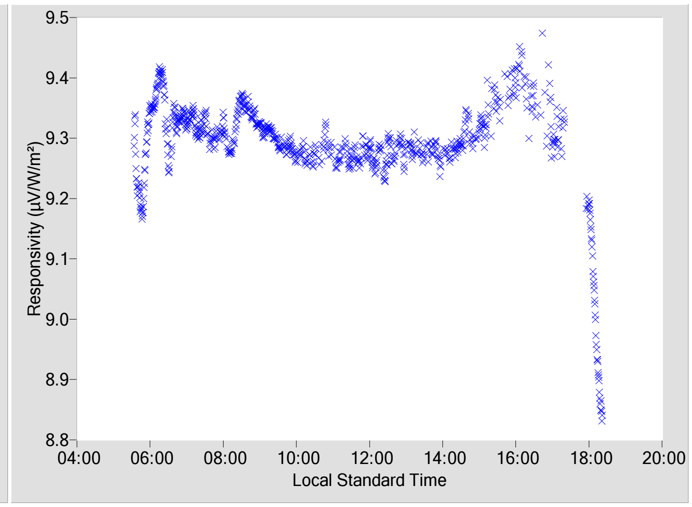


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.3222	0.35	108.28	9.3079	0.39	252.00
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.3367	0.35	105.96	9.3061	0.40	254.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3518	0.36	103.77	9.3429	0.43	256.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3480	0.37	101.67	9.3674	0.44	258.36
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2781	0.38	99.71	9.4068	0.48	260.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3051	0.39	97.76	9.4098	0.51	262.47
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2983	0.40	96.07	9.4153	0.51	263.96
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3036	0.41	94.23	9.4018	N/A	266.04
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3293	0.42	92.48	9.3866	0.51	267.75
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.3074	0.44	90.81	9.3451	0.54	269.37
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.3439	0.46	89.12	9.4742	N/A	270.91
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.3222	0.49	87.46	9.3756	N/A	272.84
24	9.2733	0.32	174.58	9.2697	0.32	185.11	70	9.3338	0.52	85.87	9.2955	N/A	274.16
26	9.2694	0.32	153.68	9.2786	0.32	205.56	72	9.3471	0.57	84.25	9.2898	N/A	275.91
28	9.2820	0.34	144.62	9.2914	0.33	216.22	74	9.2701	0.64	82.63	N/A	N/A	N/A
30	9.2676	0.34	138.04	9.2844	0.34	222.75	76	9.4074	0.70	81.02	N/A	N/A	N/A
32	9.2730	0.33	132.18	9.2808	0.34	228.52	78	9.3638	N/A	79.45	N/A	N/A	N/A
34	9.2750	0.33	126.67	9.2898	0.34	233.19	80	9.3276	N/A	77.80	9.1916	N/A	282.41
36	9.2782	0.33	122.85	9.2832	0.36	237.12	82	9.1761	N/A	76.15	9.0380	N/A	284.02
38	9.2827	0.33	119.46	9.2763	0.35	240.65	84	9.2925	N/A	74.49	8.8503	N/A	285.70
40	9.2864	0.34	116.28	9.2827	0.37	243.89	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3130	0.34	113.35	9.3284	0.40	246.93	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3115	0.34	110.70	9.2958	0.40	249.65	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

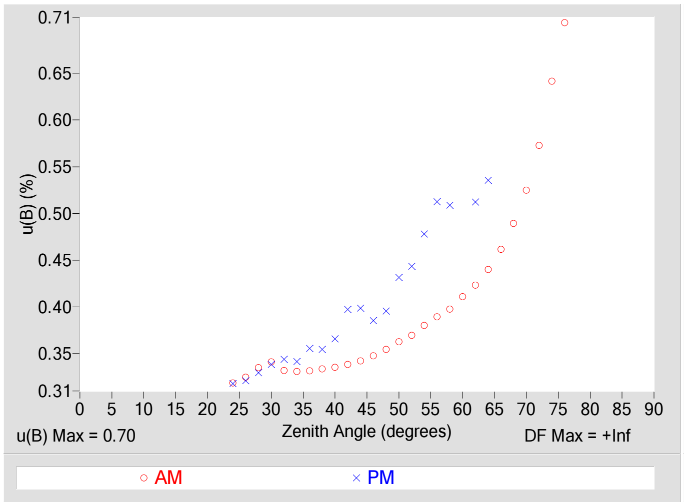


Figure 4. Residuals from Spline Interpolation

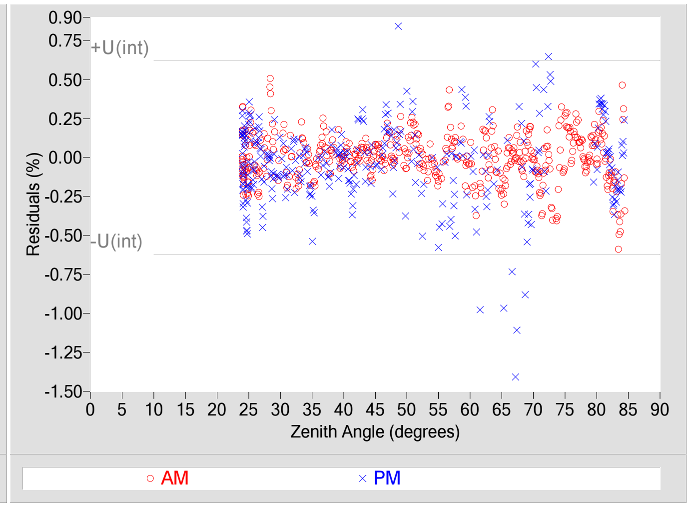


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.70
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	24535
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

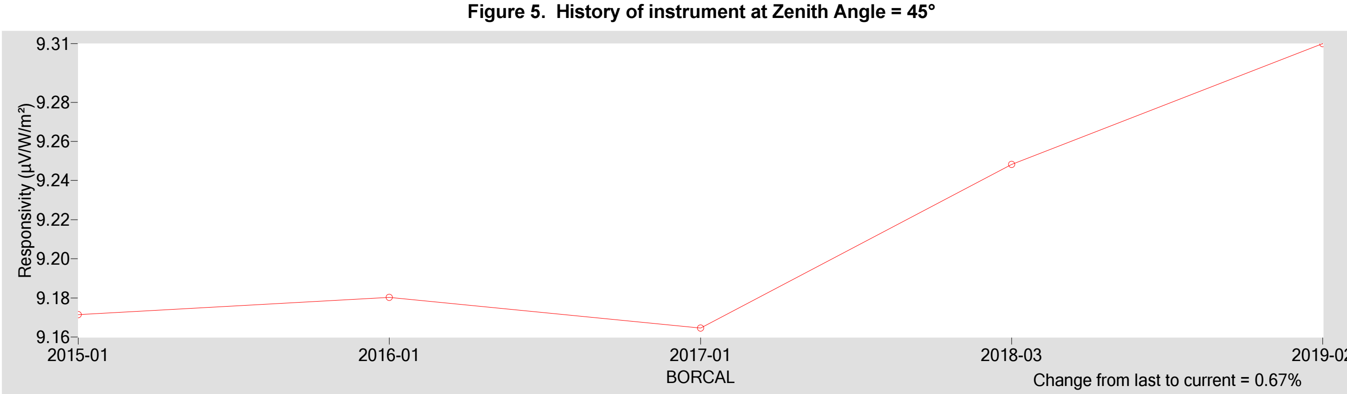
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3100	0.20000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.1 / -0.45
Expanded Uncertainty, U (%)	+2.1 / -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:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Kipp & Zonen Pyrgeometer Model CG4, S/N FT002	04/16/2018	04/16/2022

† 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: RCC

________________________________ ____________

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

S17096005 EKO MS-80

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

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

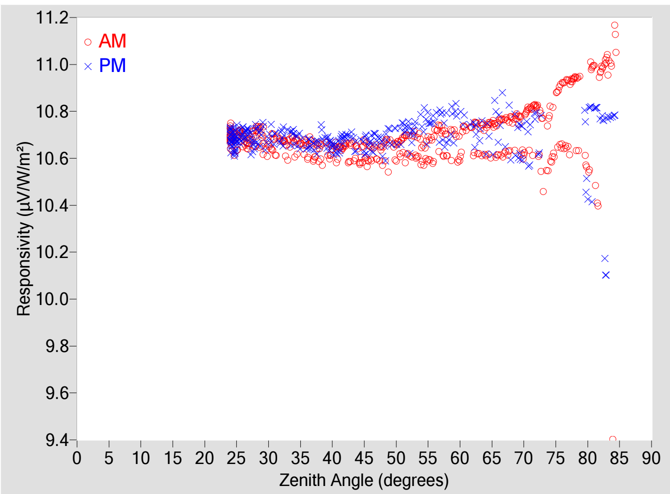


Figure 2. Responsivity vs Local Standard Time

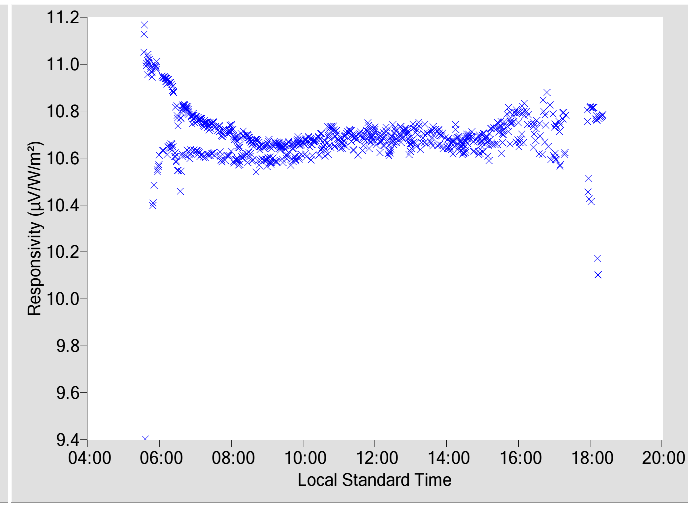


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.628	0.34	108.29	10.668	0.38	251.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.625	0.35	105.97	10.630	0.39	254.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.639	0.36	103.78	10.705	0.43	256.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.636	0.36	101.76	10.705	0.44	258.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.628	0.38	99.71	10.745	0.47	260.48
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.645	0.38	97.91	10.768	0.50	262.22
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.642	0.39	96.07	10.713	0.51	264.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.622	0.40	94.23	10.798	N/A	266.05
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.674	0.42	92.48	10.743	0.51	267.80
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.684	0.43	90.76	10.683	0.55	269.52
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.708	0.45	89.13	10.731	N/A	271.12
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.742	0.48	87.47	10.709	N/A	272.53
24	10.696	0.32	174.94	10.687	0.32	185.25	70	10.652	0.52	85.88	10.592	N/A	274.12
26	10.689	0.32	153.75	10.699	0.32	205.92	72	10.787	0.56	84.25	10.725	N/A	275.92
28	10.695	0.33	144.29	10.702	0.33	215.85	74	10.702	0.63	82.64	N/A	N/A	N/A
30	10.648	0.34	137.42	10.686	0.34	222.76	76	10.784	0.69	81.03	N/A	N/A	N/A
32	10.676	0.33	131.81	10.685	0.34	228.46	78	10.881	N/A	79.42	N/A	N/A	N/A
34	10.662	0.33	126.97	10.697	0.34	233.01	80	10.557	N/A	77.81	10.553	N/A	282.35
36	10.643	0.33	123.05	10.655	0.35	237.36	82	10.971	N/A	76.11	10.775	N/A	284.12
38	10.635	0.33	119.39	10.688	0.35	240.62	84	10.521	N/A	74.51	10.781	N/A	285.78
40	10.639	0.33	116.26	10.650	0.36	243.93	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.657	0.34	113.41	10.693	0.39	246.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.612	0.34	110.61	10.630	0.39	249.07	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

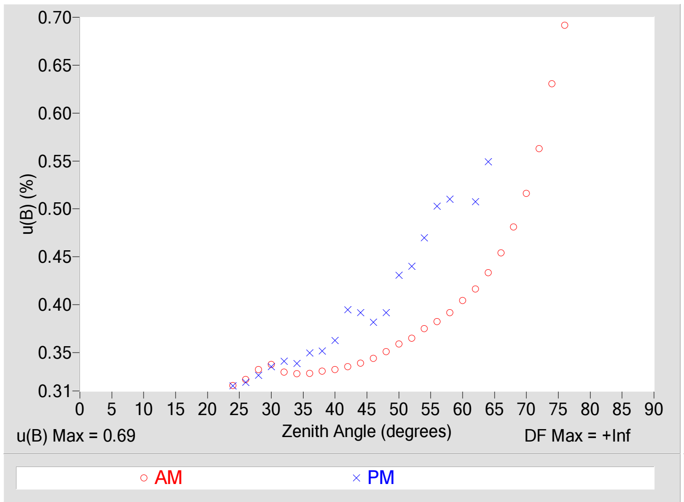


Figure 4. Residuals from Spline Interpolation

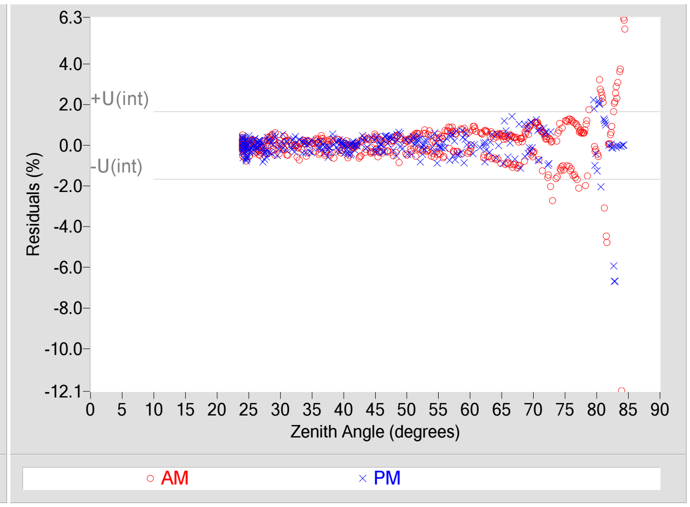


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.69
Type-A Interpolating Function, u(int) (%)	±0.83
Combined Standard Uncertainty, u(c) (%)	±1.1
Effective degrees of freedom, DF(c)	2001
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±2.1
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

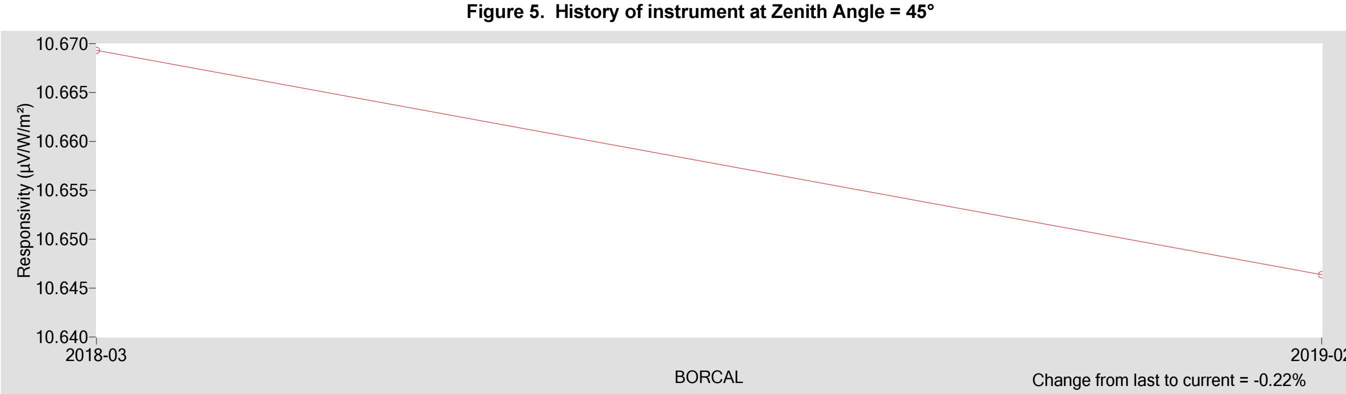
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.646	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+1.4 / -0.32
Expanded Uncertainty, U (%)	+2.4 / -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:	5/3/2019	**Due Date:**	5/3/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/3		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. 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	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021

† 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: RCC

_____________________________ _____________

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

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

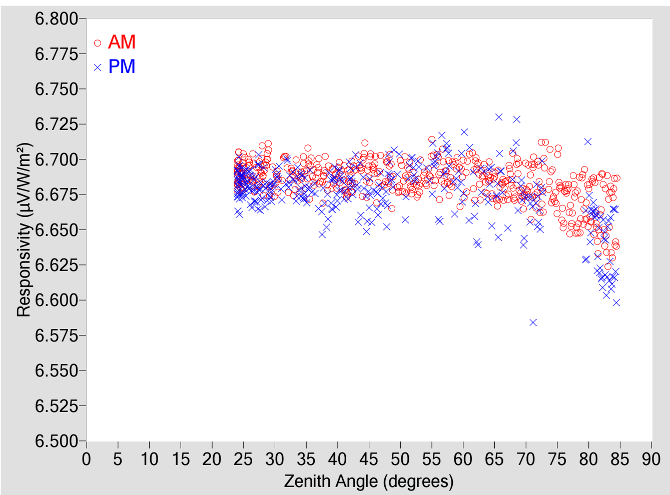


Figure 2. Responsivity vs Local Standard Time

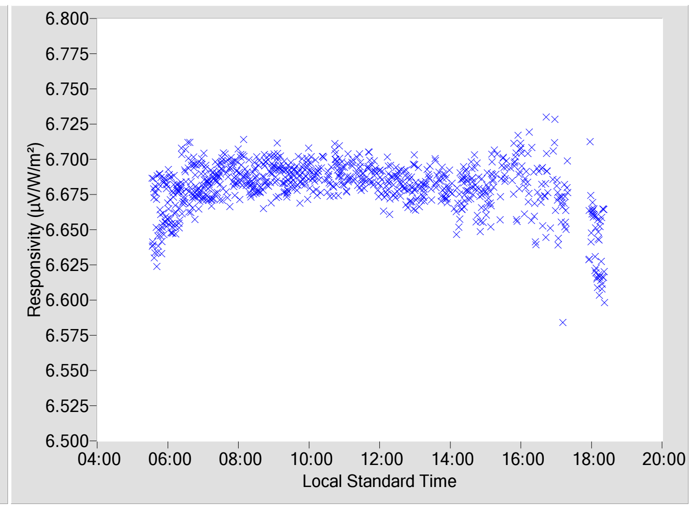


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	6.6904	0.28	108.32	6.6733	0.28	251.94
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.6917	0.28	105.93	6.6813	0.29	254.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.6860	0.28	103.73	6.7037	0.29	256.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.6819	0.28	101.73	6.6939	0.29	258.48
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.6859	0.28	99.70	6.6938	N/A	260.63
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.6914	0.28	97.76	6.6799	0.30	262.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.6845	0.29	95.98	6.6952	0.30	263.96
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.6865	0.29	94.18	6.6922	N/A	265.90
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.6921	0.29	92.48	6.6566	0.30	267.64
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.6863	0.29	90.76	6.6796	0.30	269.42
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.6794	0.29	89.13	6.6909	N/A	271.02
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.6809	0.29	87.47	6.6957	N/A	272.61
24	6.6913	0.28	174.17	6.6832	0.28	185.95	70	6.6794	0.29	85.87	6.6584	N/A	274.12
26	6.6925	0.28	154.51	6.6822	0.28	205.76	72	6.6834	0.30	84.25	6.6590	N/A	275.93
28	6.6924	0.28	144.27	6.6805	0.28	215.71	74	6.6859	0.30	82.63	N/A	N/A	N/A
30	6.6831	0.28	136.96	6.6880	0.28	223.03	76	6.6651	0.30	81.02	N/A	N/A	N/A
32	6.6907	0.28	131.84	6.6890	0.28	228.43	78	6.6623	N/A	79.41	N/A	N/A	N/A
34	6.6857	0.28	126.86	6.6814	0.28	233.13	80	6.6709	N/A	77.80	6.6689	N/A	282.48
36	6.6894	0.28	122.90	6.6765	0.28	236.86	82	6.6699	N/A	76.15	6.6299	N/A	284.07
38	6.6922	0.28	119.55	6.6667	0.28	240.58	84	6.6581	N/A	74.44	6.6411	N/A	285.75
40	6.6896	0.28	116.27	6.6761	0.28	243.83	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.6871	0.28	113.40	6.6881	0.28	246.73	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.6941	0.28	110.70	6.6832	0.28	249.58	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

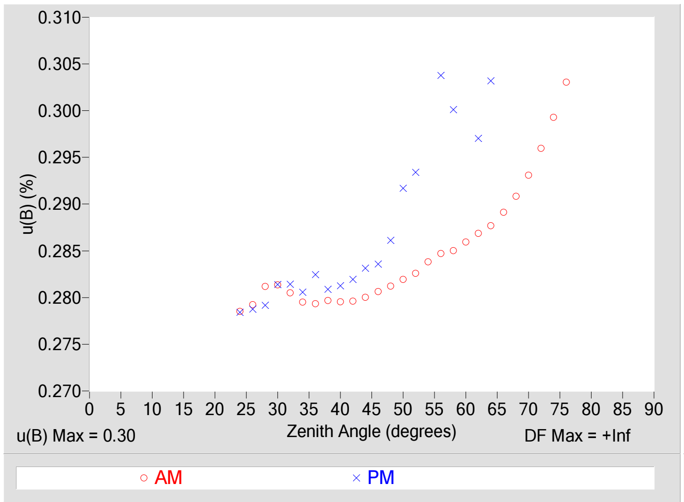


Figure 4. Residuals from Spline Interpolation

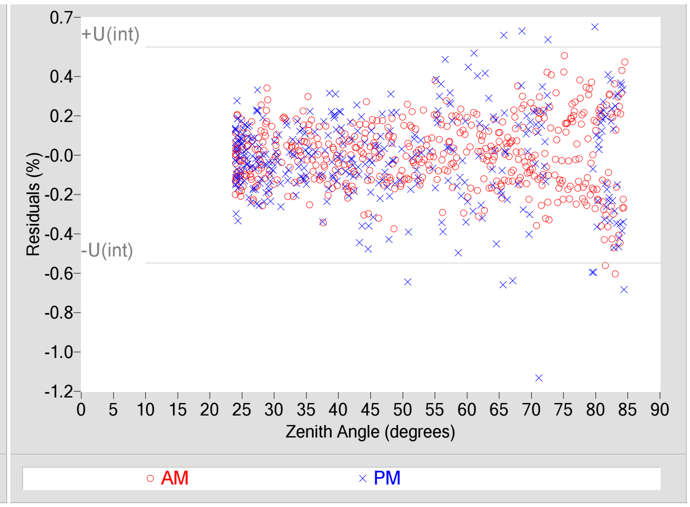


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	3382
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.80
AM Valid zenith angle range	24° to 76°
PM Valid zenith angle range	24° to 64°

‡ 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

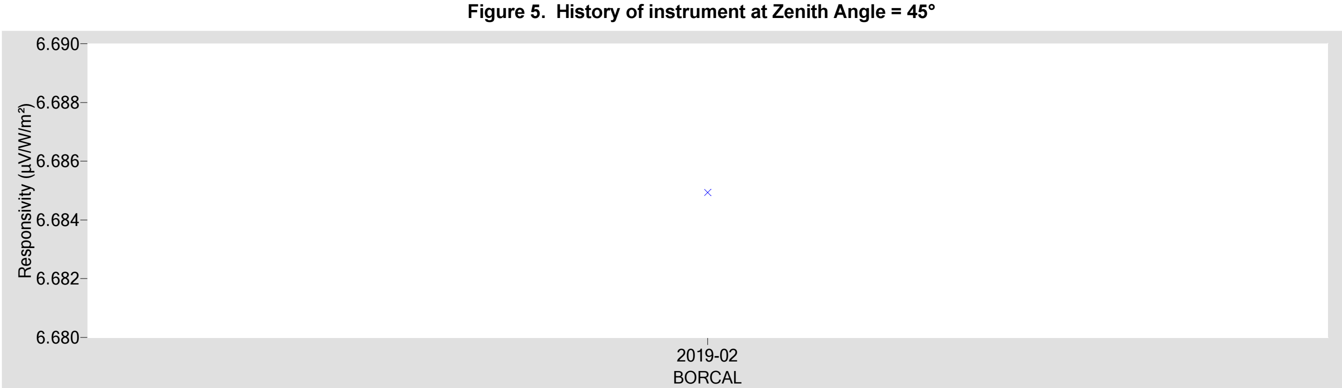
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
6.6849	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.60
Offset Uncertainty, U(off) (%)	+0.28 / -0.27
Expanded Uncertainty, U (%)	+0.88 / -0.87
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).

Environmental and Sky Conditions for BORCAL-SW 2019-02

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

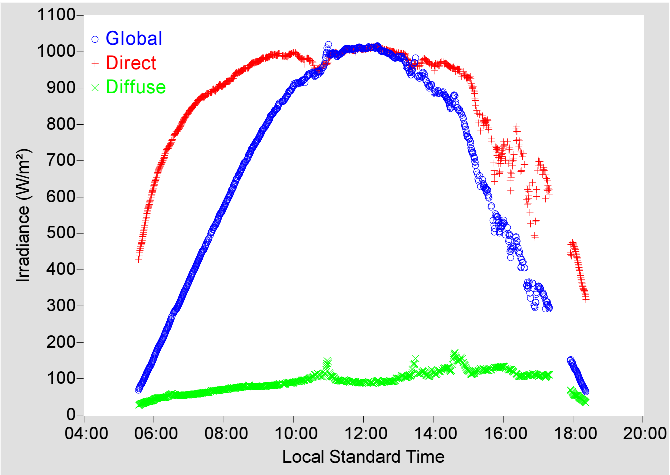
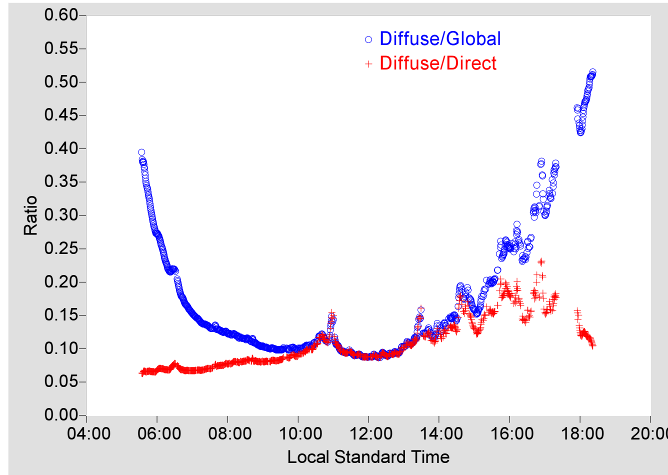


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

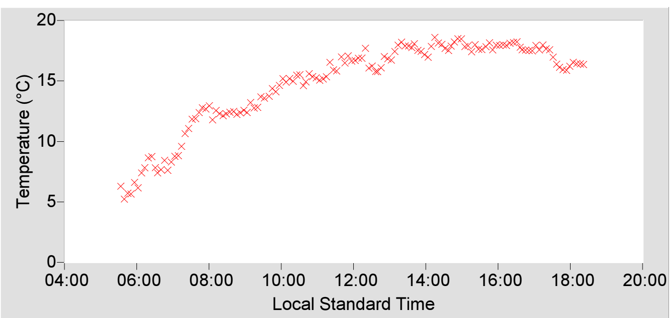


Figure 9. Humidity

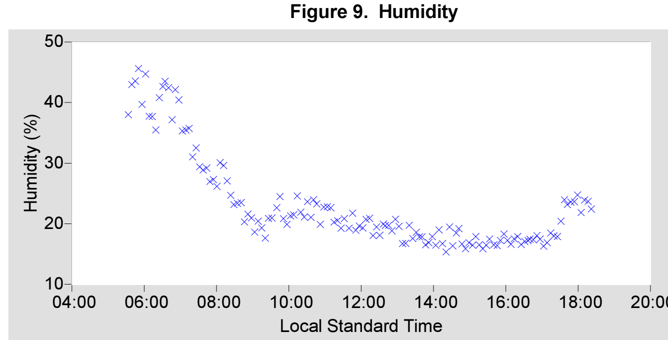


Figure 10. Pressure

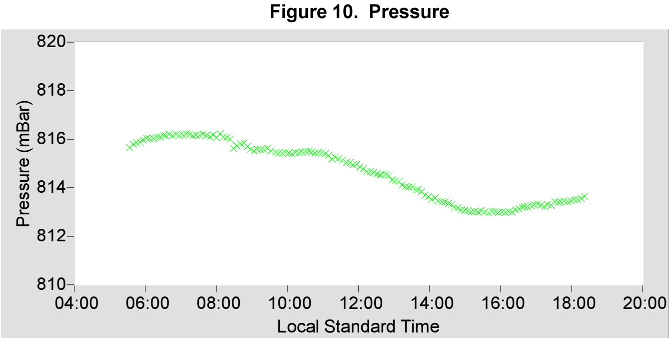


Figure 11. Effective Net Infrared

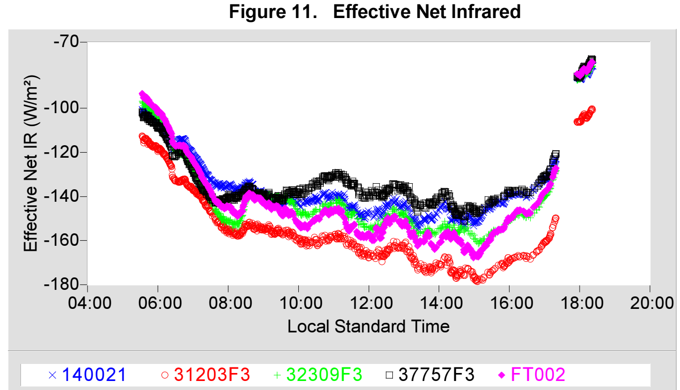


Figure 12. Estimated Broadband Aerosol Optical Depth

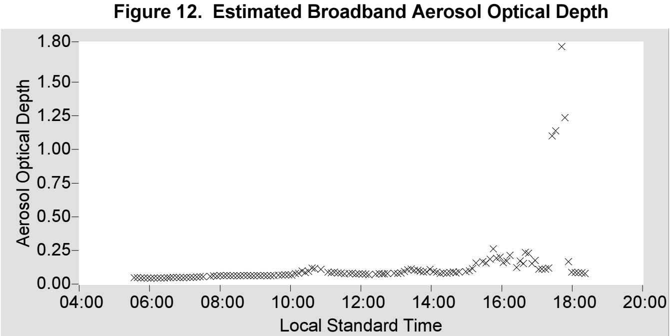


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	14.78	5.23	18.60
Humidity (%)	23.16	15.36	45.59
Pressure (mBar)	814.6	813.0	816.2
Est. Aerosol Optical Depth (BB)	0.128	0.044	1.764

For other information about the calibration facility visit: http://www.nrel.gov/esif/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).

Session Config: 1171 Apogee SP-510; Number: 1
Comments:
30K case measured using co-located Apogee Pyrgeometer.