Broadband Outdoor Radiometer Calibration Shortwave

BORCAL-SW 2020-02

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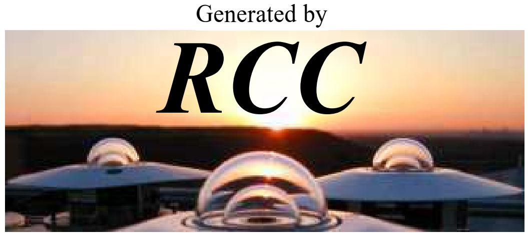


Radiometer Calibration and Characterization

<u>Customer</u>

NREL-SRRL-BMS

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

<u>Calibration Facility</u>

Solar Radiation Research Laboratory

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

Calibration date
05/04/2020 to 05/05/2020

Report Date
December 9, 2021

NREL

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

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

This report includes these sections:

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

BORCAL Notes or Comments

This report has been revised to accommodate updated responsivities given by the calibration provider of the BORCAL reference irradiance instruments. This report replaces the report with an issue date of May 12, 2020. This update affects all responsivities for the devices under test issued in this report by approximately -0.675%. There will also be a very slightly change in reported uncertainties due the reference irradiance instruments' uncertainties changing as well.

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

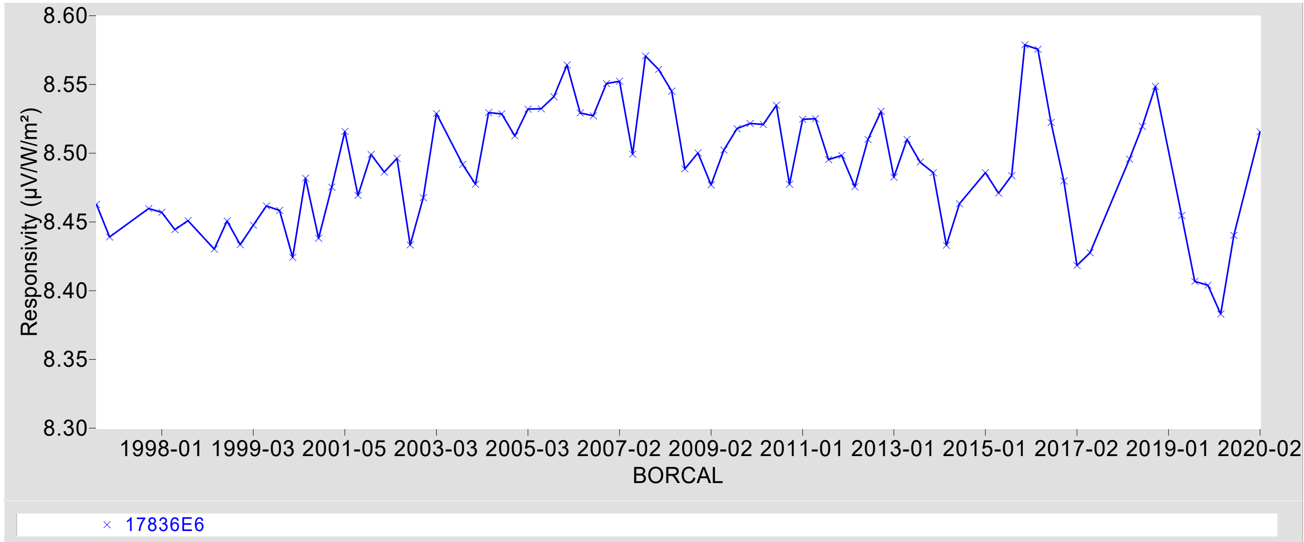
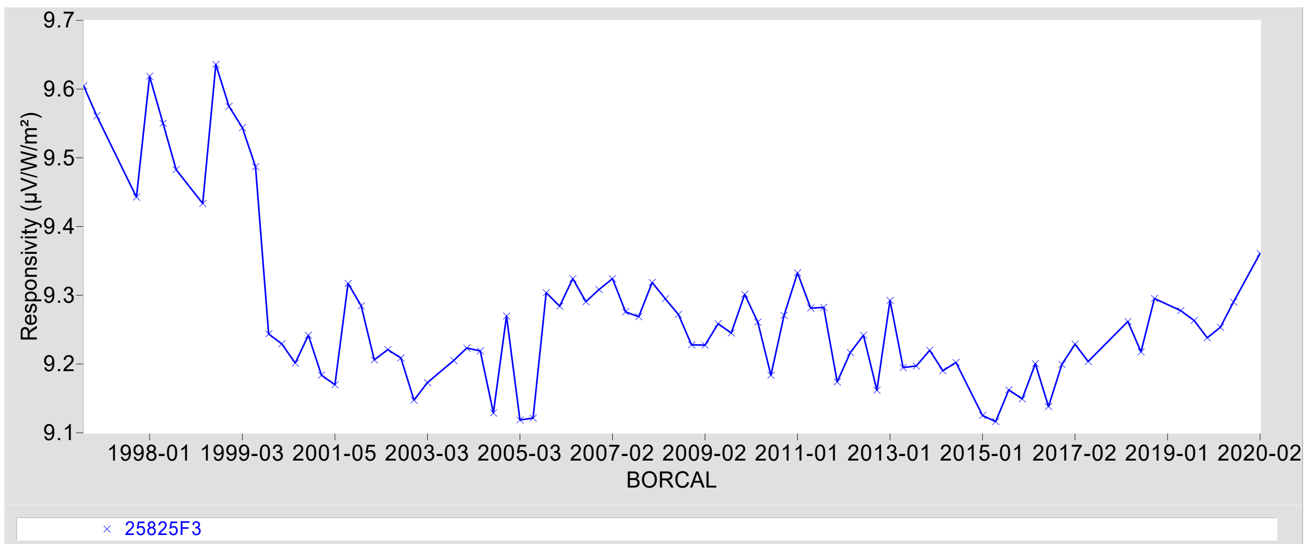


Figure 2. Eppley PSP Control Instrument History



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
010046 Kipp & Zonen CM22	9.3651	106.78	+1.5 / -1.2	0.087000	A1-2
010284-DW-CM3 Kipp & Zonen CM3	17.344	57.657	+1.9 / -2.2	0.40000	A1-5
010995 Kipp & Zonen SP-LITE	75.850	13.184	+5.1 / -3.3	0	A1-8
014261 Kipp & Zonen CM3	22.577	44.293	+1.2 / -2.2	0.40000	A1-11
015189 Kipp & Zonen CM6B	11.069	90.340	+2.0 / -2.5	0.30000	A1-14
0212-2 Yankee TSP-700	3000.1	0.33333	+1.7 / -1.4	0	A1-17
080009 Kipp & Zonen CHP1	7.9207	126.25	+0.83 / -0.75	0	A1-20
080017 Kipp & Zonen CMP22	10.501	95.229	+1.3 / -1.7	0.087000	A1-23
100174 Kipp & Zonen CMP22	9.8524	101.50	+0.88 / -1.1	0.087000	A1-26
1171 Apogee SP-510	53.397	18.728	+2.1 / -4.1	2.5000	A1-29
140043 Kipp & Zonen CMP22	9.0791	110.14	+0.94 / -1.1	0.087000	A1-32
140108 Kipp & Zonen CHP1	8.0747	123.84	+0.78 / -0.70	0	A1-35
140712 Kipp & Zonen CMP11	9.1796	108.94	+1.1 / -2.3	0.20500	A1-38
140713 Kipp & Zonen CMP11	8.6806	115.20	+1.0 / -1.8	0.20500	A1-41
151027 Kipp & Zonen SP-LITE2	69.009	14.491	+2.6 / -2.1	0	A1-44
160430 Kipp & Zonen CMP22	9.8050	101.99	+0.87 / -1.5	0.087000	A1-47
194362 Kipp & Zonen SP-LITE2	72.703	13.755	+2.5 / -2.1	0	A1-50
21096 Eppley 8-48	11.649	85.844	+3.6 / -1.6	0	A1-53
2530 Hukseflux SR25	11.142	89.749	+1.9 / -1.6	0.043000	A1-56
2543 Hukseflux SR25	9.5397	104.83	+1.1 / -1.2	0.043000	A1-59
28402F3 Eppley PSP	6.9486	143.91	+2.0 / -2.0	0.64000	A1-62
31137E6 Eppley NIP	8.4394	118.49	+1.6 / -0.86	0	A1-65
34722 Eppley 8-48	9.7590	102.47	+3.0 / -1.5	0	A1-68
37831F3 Eppley GPP	8.5290	117.25	+1.7 / -2.9	0.15000	A1-71
37839F3 Eppley SPP	8.6353	115.80	+1.5 / -1.7	0.30000	A1-74
37882E6 Eppley sNIP	8.3611	119.60	+1.0 / -0.77	0	A1-77
38924F3 Eppley SPP	7.9068	126.47	+1.8 / -2.4	0.22000	A1-80
40337 Apogee SP-110	181.86	5.4986	+2.0 / -1.8	0	A1-83
9206 Hukseflux DR02	11.020	90.746	+0.80 / -0.74	0	A1-86
970003 Kipp & Zonen SP-LITE	81.550	12.262	+4.7 / -3.4	0	A1-89
A360 Delta-T SPN1	1019.4	0.98097	+8.8 / -5.0	0	A1-92
F14077R EKO MS-802	7.1082	140.68	+1.3 / -2.3	0.18000	A1-95
PY100360 Licor LI200R	10.757	92.960	+1.4 / -1.1	0	A1-98
PY108623 Licor LI200R	9.9311	100.69	+1.8 / -1.5	0	A1-101
PY1750 Licor LI200	13.157	76.007	+1.3 / -1.3	0	A1-104
PY28257 Licor LI200	13.751	72.722	+2.0 / -2.3	0	A1-107
PYHR101 Licor LI201SB	6.0067	166.48	+3.0 / -1.9	0	A1-110
S13071483 EKO MS-602	7.1318	140.22	+1.9 / -4.4	0.30000	A1-113
S13135063 EKO ML-01	40.432	24.733	+1.8 / -0.93	0	A1-116
S13144.085R EKO MS-410	9.3463	106.99	+1.5 / -1.5	0.20000	A1-119
S17096005 EKO MS-80	10.633	94.049	+1.2 / -1.3	0.043000	A1-122
S18015.22 EKO MS-57	6.6728	149.86	+0.78 / -0.70	0	A1-125

[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 A1-128.

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:**	010046
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

010046 Kipp & Zonen CM22

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

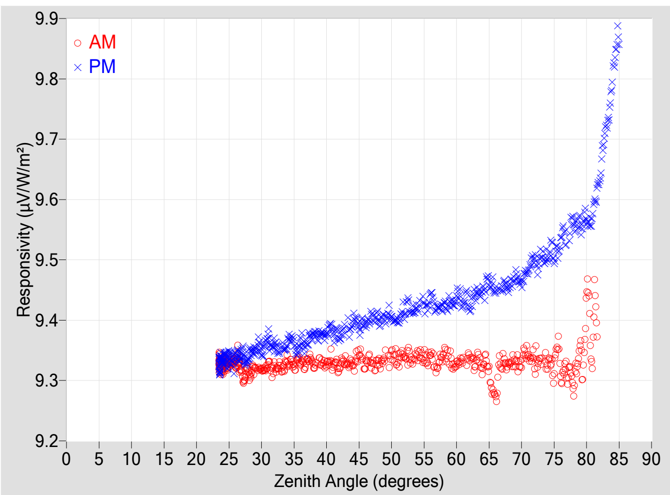


Figure 2. Responsivity vs Local Standard Time

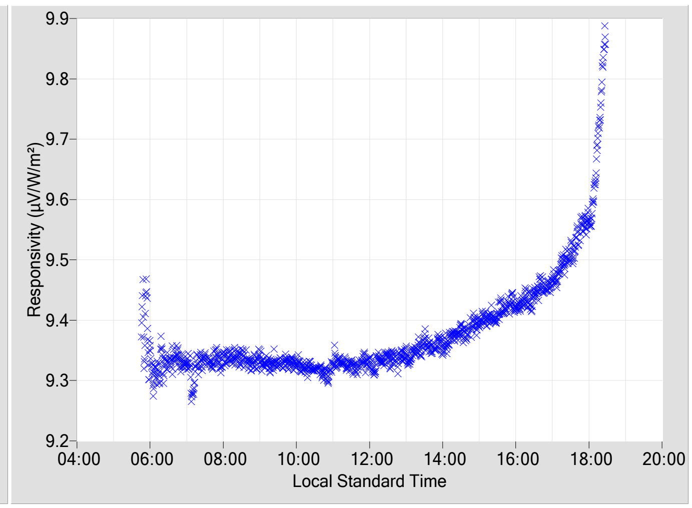


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.3255	0.31	106.78	9.3930	0.31	252.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.3292	0.33	104.51	9.4011	0.31	255.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3421	0.32	102.43	9.4034	0.33	257.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3388	0.32	100.39	9.4154	0.32	259.31
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3432	0.35	98.42	9.4209	0.33	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3425	0.37	96.60	9.4413	0.33	263.12
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3438	0.36	94.81	9.4244	0.34	264.93
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3267	0.35	93.07	9.4412	0.37	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3386	0.35	91.36	9.4220	0.36	268.41
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.3211	0.37	89.69	9.4495	0.37	270.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2752	0.38	88.05	9.4489	0.38	271.73
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.3275	0.43	86.39	9.4534	0.40	273.37
24	9.3229	0.31	166.80	9.3349	0.31	192.80	70	9.3310	0.42	84.79	9.4625	0.43	275.00
26	9.3316	0.33	150.95	9.3385	0.31	209.24	72	9.3350	0.45	83.20	9.5000	0.46	276.61
28	9.3126	0.33	140.77	9.3380	0.31	217.98	74	9.3301	0.50	81.62	9.5046	0.50	278.21
30	9.3187	0.32	134.34	9.3465	0.30	224.76	76	9.3158	0.55	80.00	9.5296	0.56	279.80
32	9.3199	0.33	129.28	9.3586	0.32	229.99	78	9.2952	0.62	78.40	9.5608	N/A	281.41
34	9.3303	0.33	124.77	9.3620	0.33	234.46	80	9.4253	N/A	76.76	9.5674	N/A	283.06
36	9.3320	0.31	121.03	9.3656	0.31	238.43	82	N/A	N/A	N/A	9.6327	N/A	284.71
38	9.3257	0.32	117.59	9.3762	0.31	241.85	84	N/A	N/A	N/A	9.8036	N/A	286.40
40	9.3273	0.31	114.53	9.3788	0.34	245.02	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3221	0.32	111.70	9.3704	0.32	247.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3255	0.32	109.17	9.3968	0.31	250.47	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

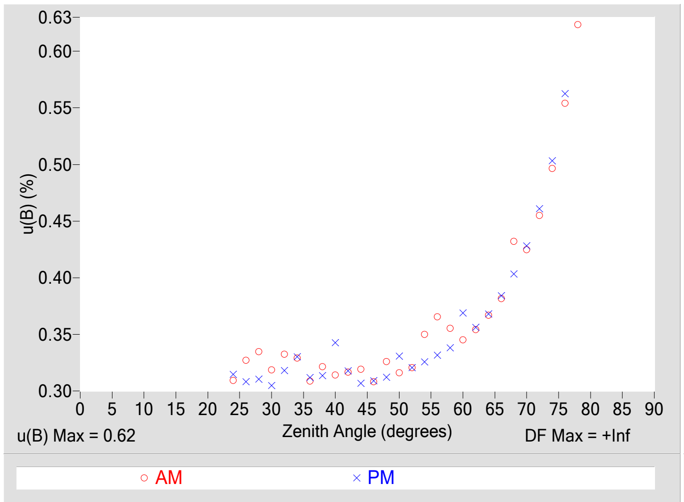


Figure 4. Residuals from Spline Interpolation

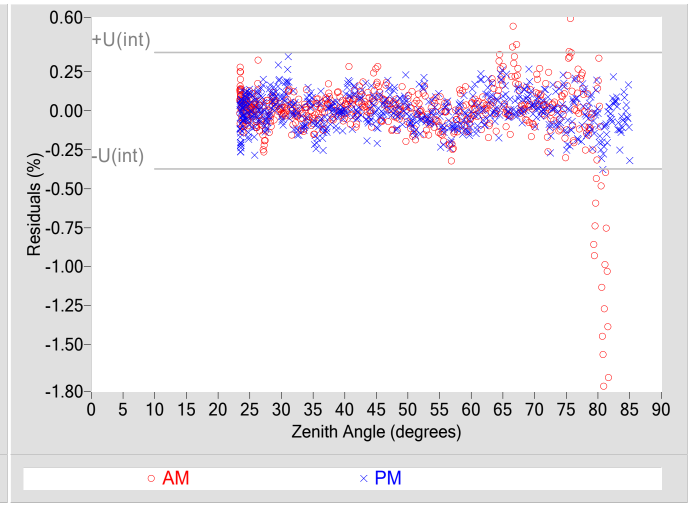


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	169568
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

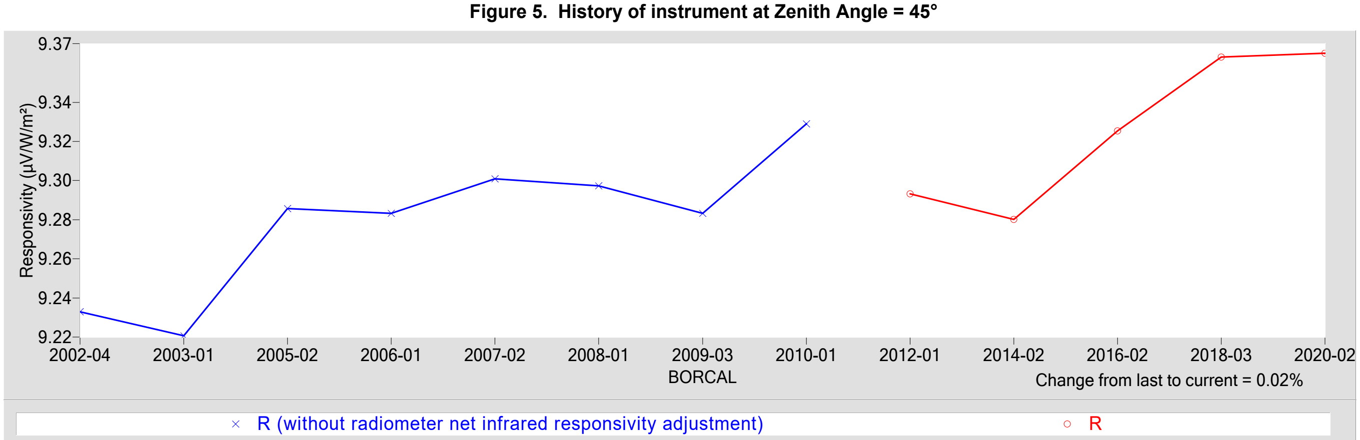
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3651	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.81 / -0.50
Expanded Uncertainty, U (%)	+1.5 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM3	**Serial Number:**	010284-DW-CM3
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

010284-DW-CM3 Kipp & Zonen CM3

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

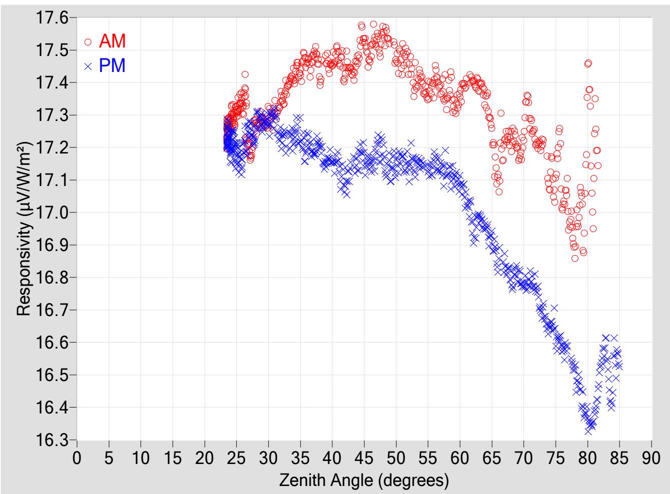


Figure 2. Responsivity vs Local Standard Time

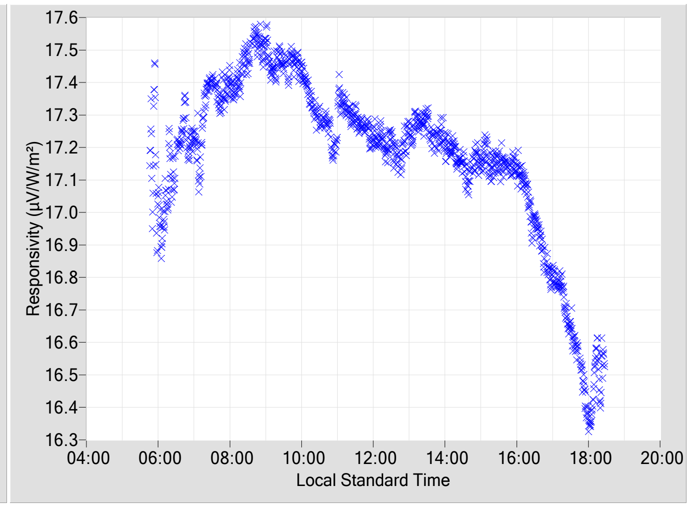


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	17.489	0.33	106.78	17.144	0.31	252.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	17.547	0.33	104.56	17.182	0.31	255.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	17.476	0.33	102.42	17.140	0.32	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	17.464	0.37	100.42	17.144	0.32	259.25
8	N/A	N/A	N/A	N/A	N/A	N/A	54	17.404	0.35	98.46	17.147	0.33	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	17.410	0.36	96.59	17.163	0.34	263.11
12	N/A	N/A	N/A	N/A	N/A	N/A	58	17.355	0.34	94.81	17.115	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	17.354	0.37	93.06	17.089	0.35	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	17.407	0.36	91.36	16.941	0.36	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	17.350	0.42	89.69	16.958	0.37	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	17.095	0.42	88.04	16.848	0.39	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	17.225	0.41	86.39	16.788	0.41	273.37
24	17.279	0.31	167.00	17.207	0.31	193.21	70	17.256	0.46	84.79	16.783	0.44	275.00
26	17.343	0.30	150.94	17.184	0.33	209.12	72	17.211	0.56	83.19	16.767	0.47	276.61
28	17.271	0.30	140.94	17.259	0.33	217.97	74	17.092	0.59	81.62	16.647	0.52	278.21
30	17.291	0.32	134.56	17.277	0.35	224.64	76	17.061	0.57	80.00	16.589	0.58	279.80
32	17.345	0.32	129.13	17.229	0.31	230.09	78	16.901	0.64	78.40	16.502	N/A	281.41
34	17.417	0.31	124.85	17.223	0.33	234.55	80	17.329	N/A	76.80	16.363	N/A	283.06
36	17.463	0.31	121.04	17.204	0.32	238.43	82	N/A	N/A	N/A	16.520	N/A	284.70
38	17.425	0.33	117.59	17.203	0.32	241.92	84	N/A	N/A	N/A	16.498	N/A	286.35
40	17.462	0.34	114.59	17.156	0.30	244.94	86	N/A	N/A	N/A	N/A	N/A	N/A
42	17.432	0.32	111.76	17.085	0.32	247.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	17.469	0.32	109.23	17.158	0.32	250.40	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

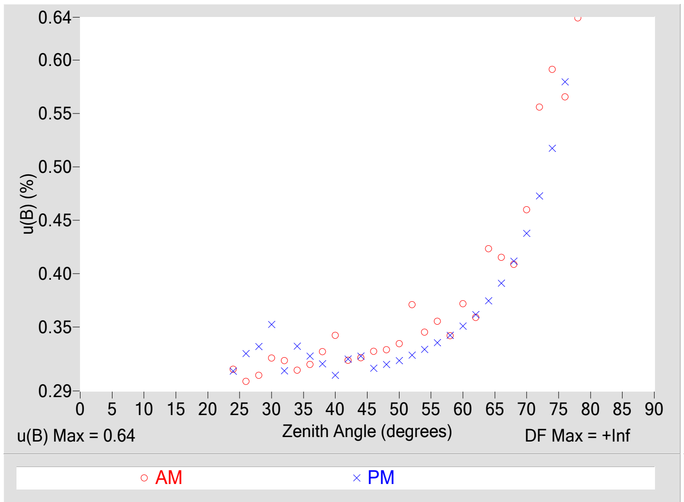


Figure 4. Residuals from Spline Interpolation

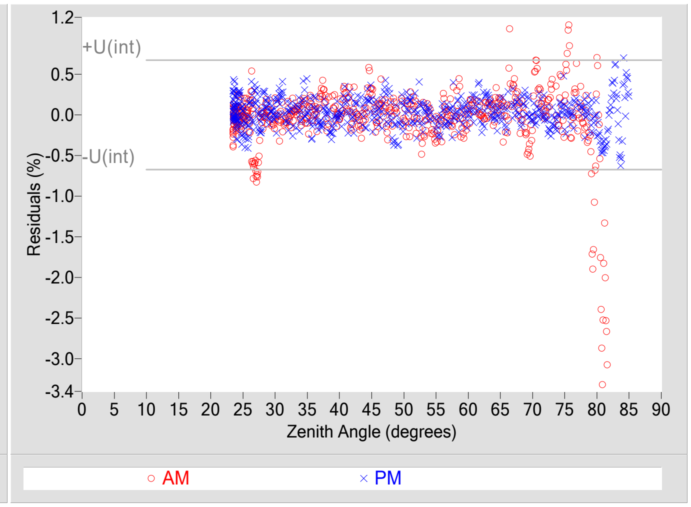


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.72
Effective degrees of freedom, DF(c)	24271
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

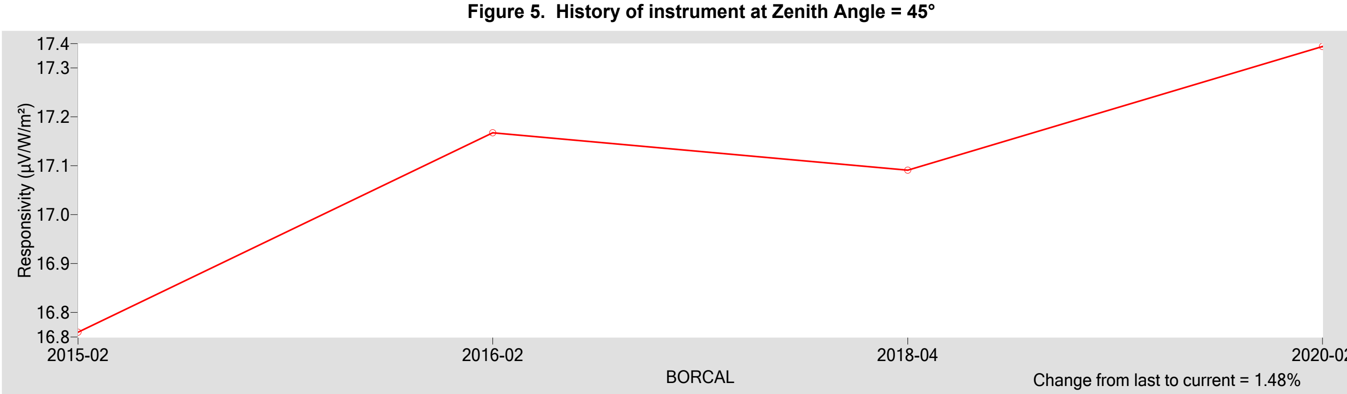
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
17.344	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+1.2 / -1.5
Expanded Uncertainty, U (%)	+1.9 / -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:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE	**Serial Number:**	010995
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

010995 Kipp & Zonen SP-LITE

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

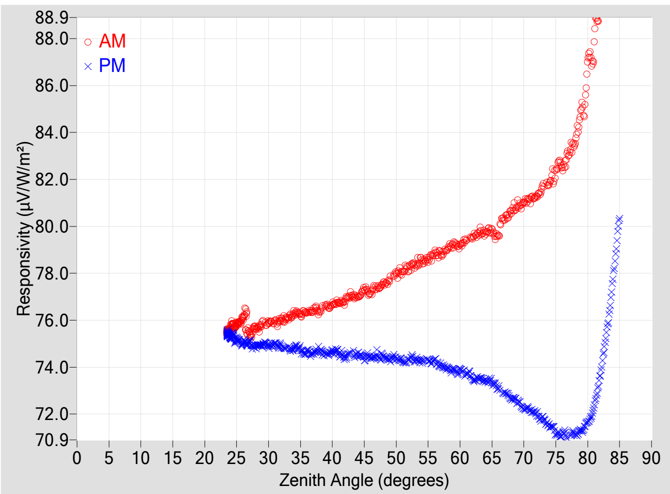


Figure 2. Responsivity vs Local Standard Time

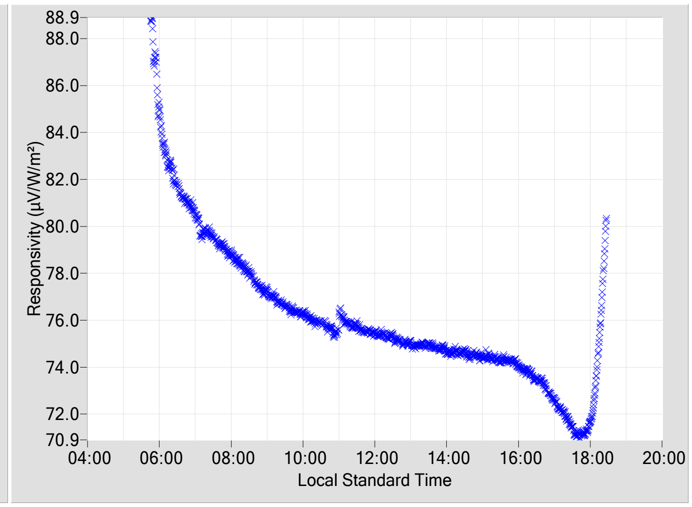


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	77.163	0.31	106.77	74.408	0.32	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	77.562	0.31	104.55	74.475	0.32	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	77.942	0.33	102.41	74.366	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	78.197	0.35	100.38	74.333	0.32	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	78.570	0.34	98.45	74.282	0.32	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	78.847	0.36	96.58	74.320	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	79.038	0.38	94.75	73.952	0.33	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	79.176	0.34	93.05	73.873	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	79.551	0.35	91.35	73.483	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	79.729	0.36	89.68	73.424	0.36	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	79.700	0.40	88.03	73.085	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	80.638	0.39	86.42	72.642	0.40	273.36
24	75.628	0.31	167.16	75.329	0.31	193.01	70	81.025	0.42	84.82	72.230	0.42	274.99
26	76.108	0.32	151.05	75.017	0.31	209.06	72	81.286	0.45	83.18	71.991	0.45	276.60
28	75.682	0.33	140.91	74.898	0.31	218.07	74	81.841	0.49	81.61	71.496	0.49	278.20
30	75.885	0.31	134.42	74.904	0.29	224.61	76	82.521	0.54	79.99	71.129	0.55	279.83
32	76.001	0.30	129.21	74.898	0.32	230.02	78	83.601	0.61	78.39	71.136	N/A	281.44
34	76.290	0.31	124.83	74.819	0.32	234.61	80	86.858	N/A	76.74	71.688	N/A	283.09
36	76.327	0.31	121.06	74.664	0.31	238.40	82	N/A	N/A	N/A	73.812	N/A	284.73
38	76.355	0.31	117.65	74.724	0.31	241.82	84	N/A	N/A	N/A	77.895	N/A	286.39
40	76.675	0.32	114.46	74.651	0.33	244.99	86	N/A	N/A	N/A	N/A	N/A	N/A
42	76.815	0.31	111.82	74.413	0.33	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	76.999	0.30	109.15	74.538	0.36	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

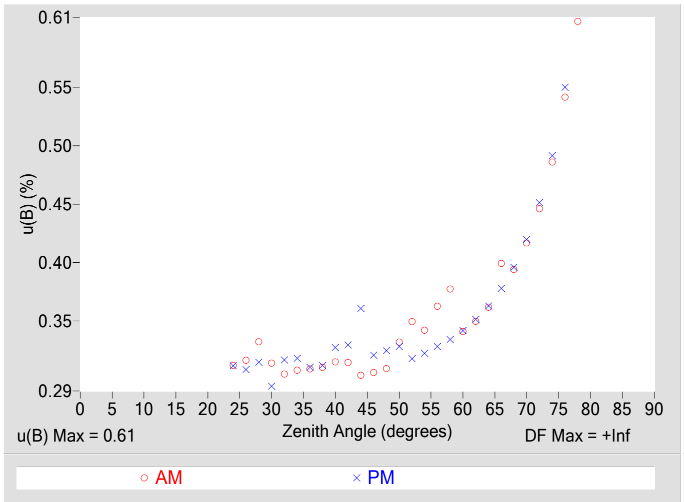


Figure 4. Residuals from Spline Interpolation

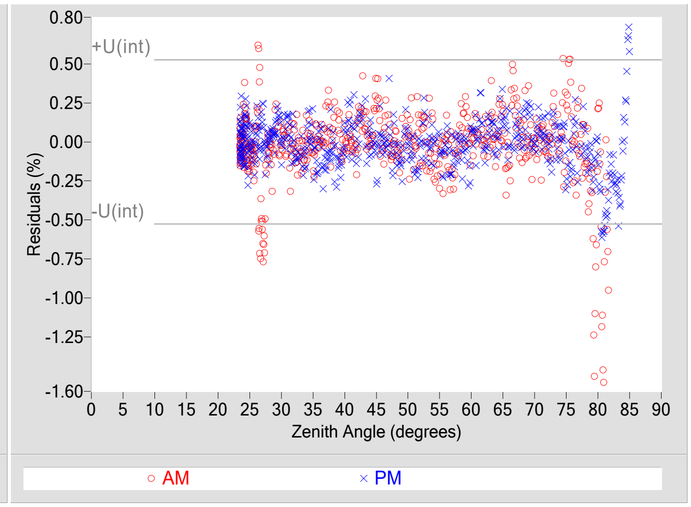


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	45857
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

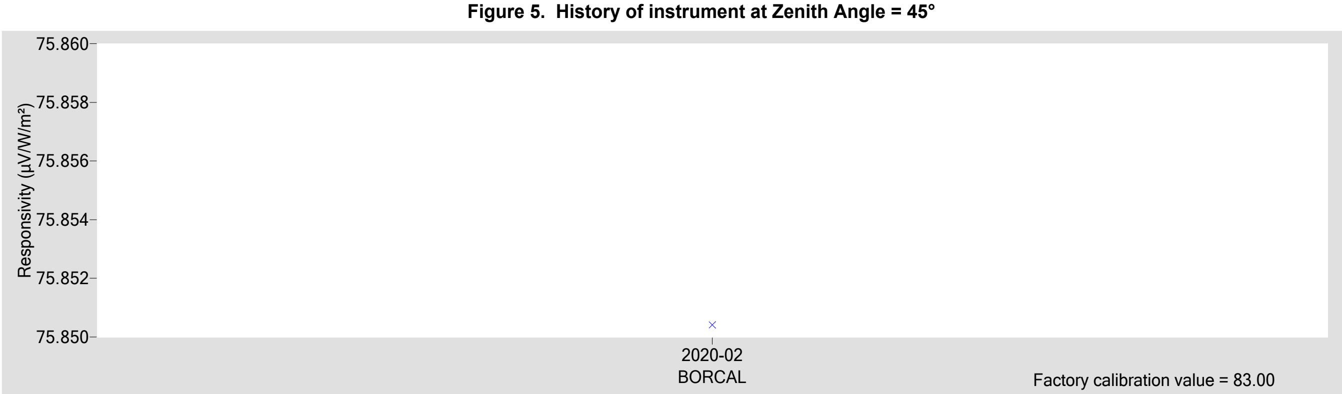
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
75.850	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.74
Offset Uncertainty, U(off) (%)	+4.4 / -2.6
Expanded Uncertainty, U (%)	+5.1 / -3.3
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

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM3	**Serial Number:**	014261
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

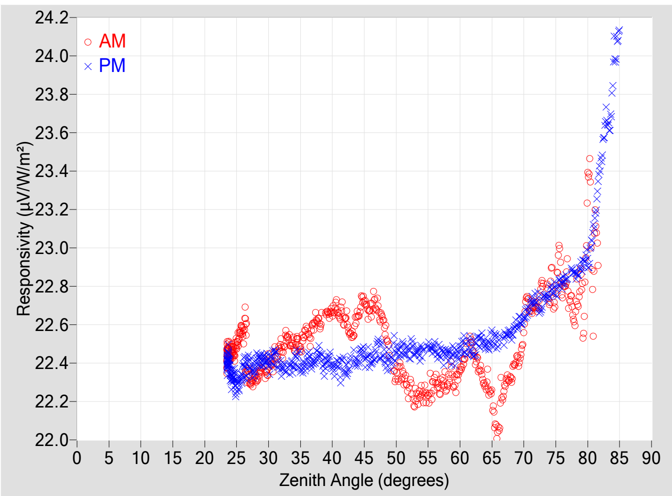


Figure 2. Responsivity vs Local Standard Time

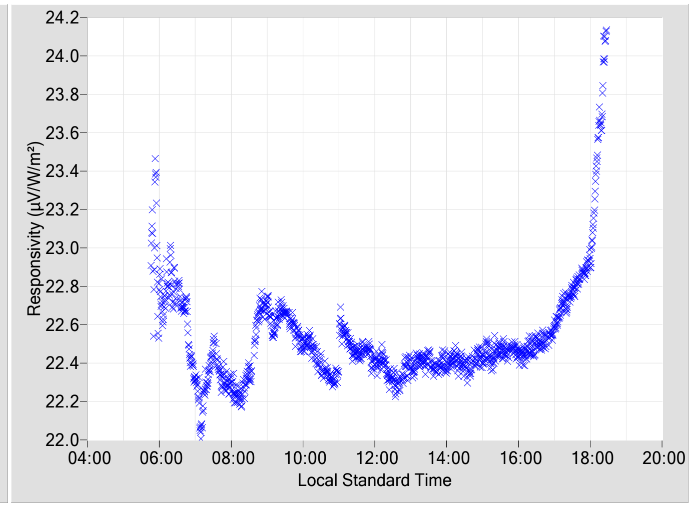


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	22.681	0.33	106.78	22.403	0.31	252.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	22.612	0.33	104.56	22.453	0.31	255.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	22.338	0.33	102.42	22.459	0.32	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	22.264	0.37	100.42	22.459	0.32	259.25
8	N/A	N/A	N/A	N/A	N/A	N/A	54	22.236	0.34	98.46	22.458	0.33	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	22.305	0.35	96.59	22.481	0.33	263.11
12	N/A	N/A	N/A	N/A	N/A	N/A	58	22.285	0.34	94.81	22.440	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	22.361	0.37	93.06	22.472	0.35	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	22.478	0.36	91.36	22.452	0.36	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	22.285	0.42	89.69	22.498	0.37	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	22.045	0.41	88.04	22.507	0.39	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	22.328	0.40	86.39	22.549	0.40	273.37
24	22.459	0.31	167.00	22.366	0.31	193.21	70	22.589	0.45	84.79	22.641	0.43	275.00
26	22.571	0.30	150.94	22.362	0.32	209.12	72	22.691	0.55	83.19	22.731	0.46	276.61
28	22.322	0.30	140.94	22.392	0.33	217.97	74	22.754	0.58	81.62	22.766	0.51	278.21
30	22.382	0.32	134.56	22.399	0.35	224.64	76	22.809	0.56	80.00	22.822	0.57	279.80
32	22.473	0.32	129.13	22.375	0.31	230.09	78	22.645	0.63	78.40	22.864	N/A	281.41
34	22.490	0.31	124.85	22.393	0.33	234.55	80	23.223	N/A	76.80	22.935	N/A	283.06
36	22.568	0.31	121.04	22.411	0.32	238.43	82	N/A	N/A	N/A	23.435	N/A	284.70
38	22.607	0.33	117.59	22.446	0.31	241.92	84	N/A	N/A	N/A	23.898	N/A	286.35
40	22.670	0.34	114.59	22.381	0.30	244.94	86	N/A	N/A	N/A	N/A	N/A	N/A
42	22.629	0.32	111.76	22.370	0.32	247.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	22.642	0.32	109.23	22.412	0.32	250.40	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

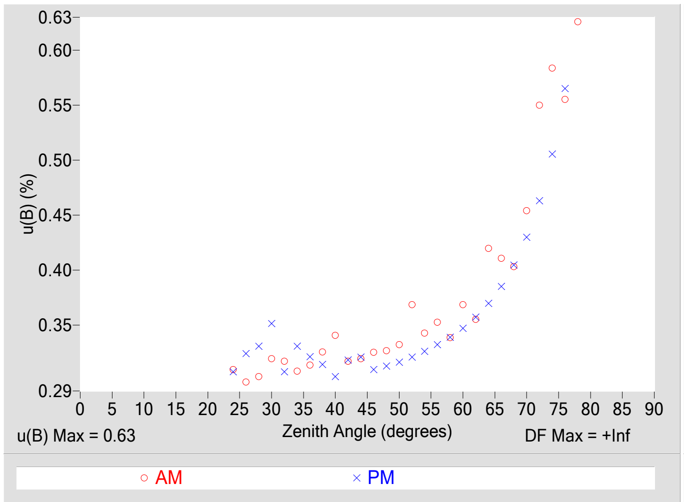


Figure 4. Residuals from Spline Interpolation

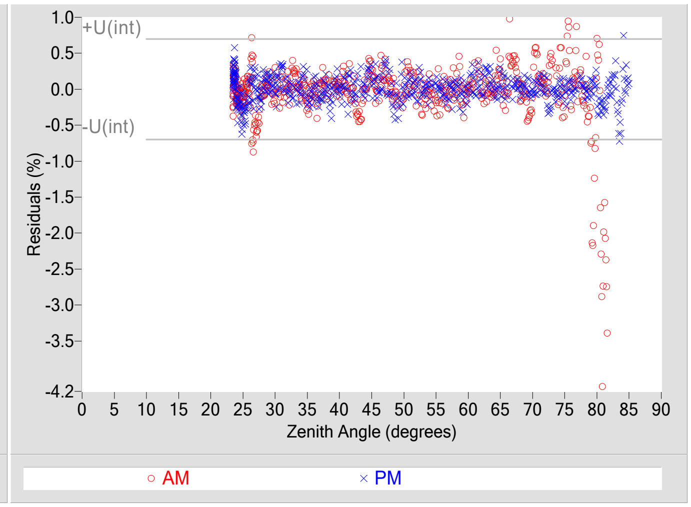


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.35
Combined Standard Uncertainty, u(c) (%)	±0.72
Effective degrees of freedom, DF(c)	20128
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

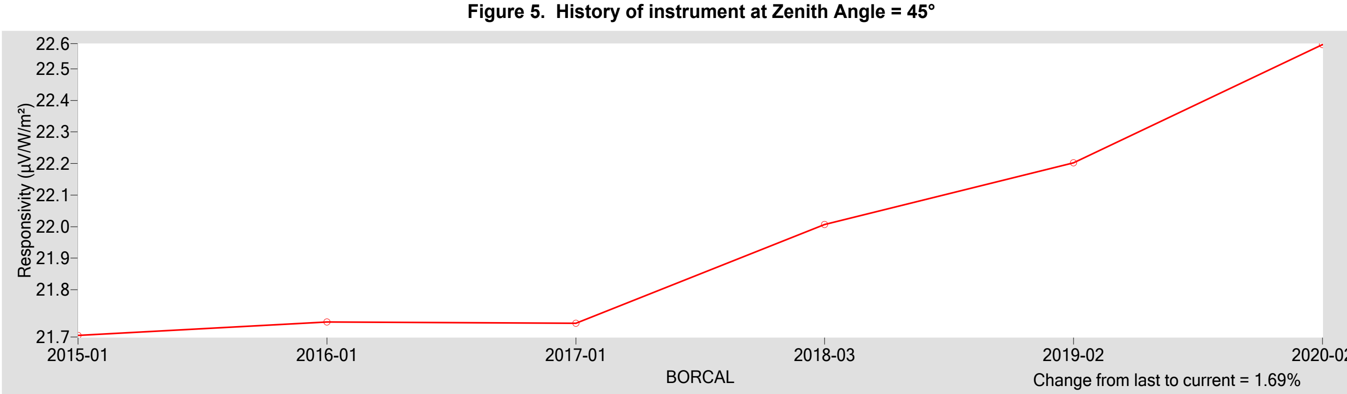
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
22.577	0.40000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.46 / -1.5
Expanded Uncertainty, U (%)	+1.2 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CM6B	**Serial Number:**	015189
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

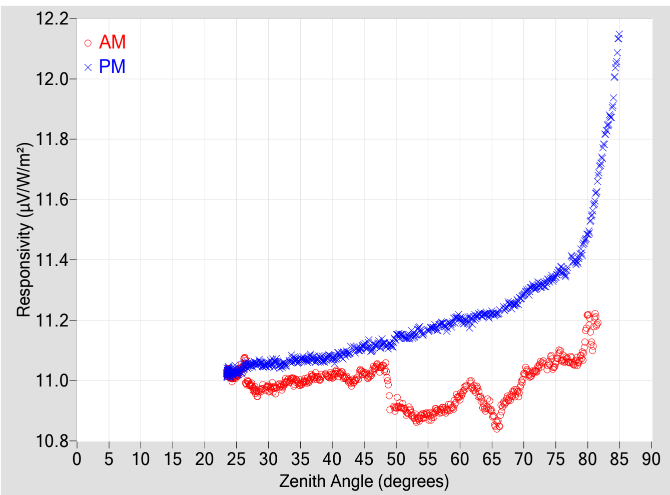


Figure 2. Responsivity vs Local Standard Time

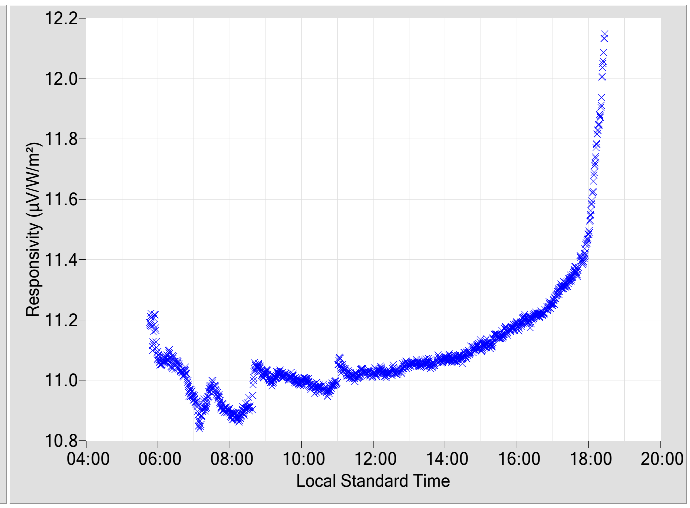


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	11.021	0.31	106.78	11.103	0.33	252.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.044	0.33	104.57	11.127	0.33	255.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.908	0.38	102.46	11.146	0.32	257.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.900	0.36	100.39	11.144	0.34	259.26
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.881	0.33	98.47	11.159	0.35	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.896	0.36	96.60	11.177	0.36	263.12
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.904	0.39	94.81	11.179	0.35	264.93
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.947	0.35	93.06	11.207	0.35	266.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.980	0.36	91.36	11.201	0.37	268.41
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.908	0.43	89.69	11.221	0.38	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.853	0.39	88.05	11.225	0.40	271.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.948	0.44	86.39	11.253	0.42	273.37
24	11.023	0.32	167.23	11.026	0.32	193.22	70	11.018	0.47	84.79	11.286	0.44	275.00
26	11.051	0.31	150.95	11.039	0.32	209.17	72	11.035	0.47	83.20	11.312	0.48	276.61
28	10.963	0.32	140.82	11.058	0.31	217.98	74	11.060	0.52	81.62	11.335	0.52	278.17
30	10.976	0.32	134.42	11.056	0.33	224.65	76	11.075	0.58	80.00	11.367	0.59	279.80
32	10.980	0.33	129.14	11.049	0.30	230.09	78	11.057	0.65	78.40	11.393	N/A	281.42
34	10.999	0.33	124.86	11.068	0.31	234.55	80	11.202	N/A	76.76	11.485	N/A	283.06
36	10.998	0.31	121.03	11.069	0.32	238.43	82	N/A	N/A	N/A	11.719	N/A	284.70
38	11.007	0.32	117.60	11.072	0.32	241.92	84	N/A	N/A	N/A	11.940	N/A	286.36
40	11.016	0.33	114.60	11.074	0.35	244.95	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.010	0.31	111.77	11.091	0.31	247.76	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.008	0.31	109.25	11.104	0.32	250.40	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

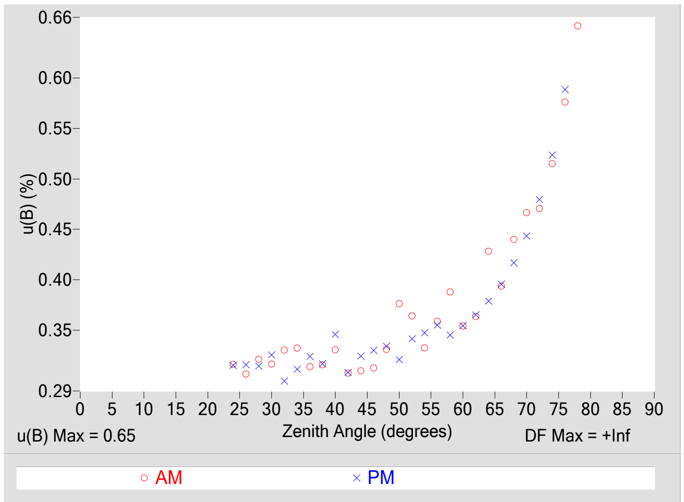


Figure 4. Residuals from Spline Interpolation

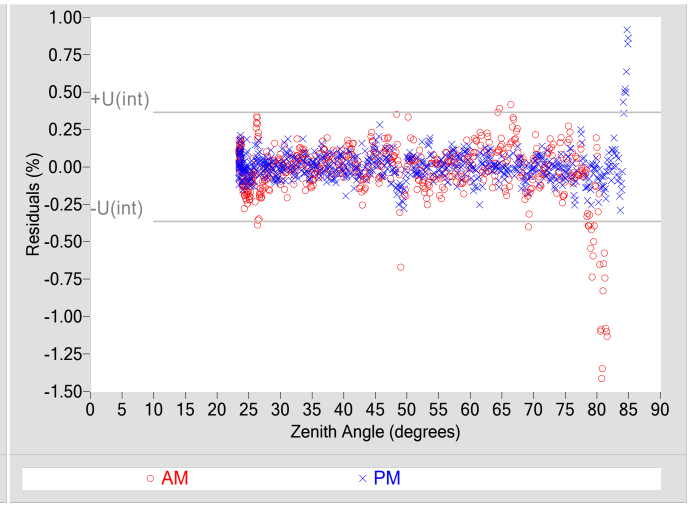


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	218287
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

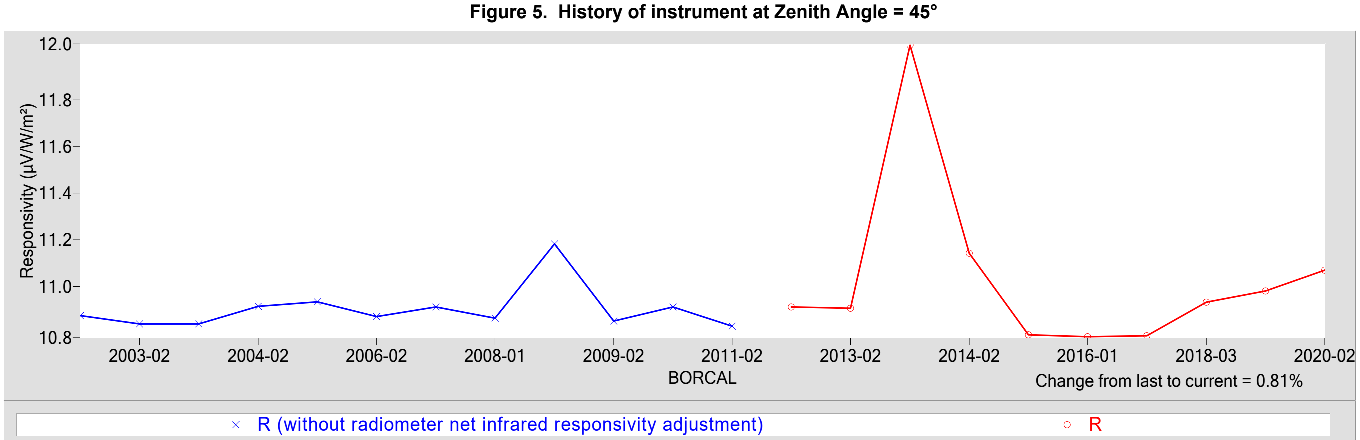
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.069	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.76
Offset Uncertainty, U(off) (%)	+1.2 / -1.7
Expanded Uncertainty, U (%)	+2.0 / -2.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

[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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

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* [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

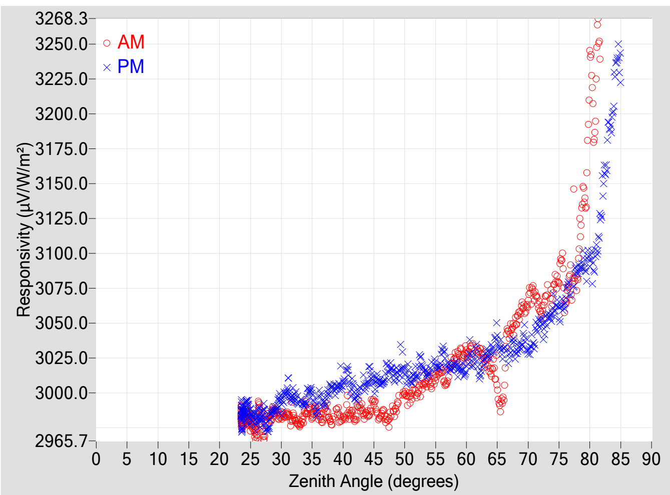


Figure 2. Responsivity vs Local Standard Time

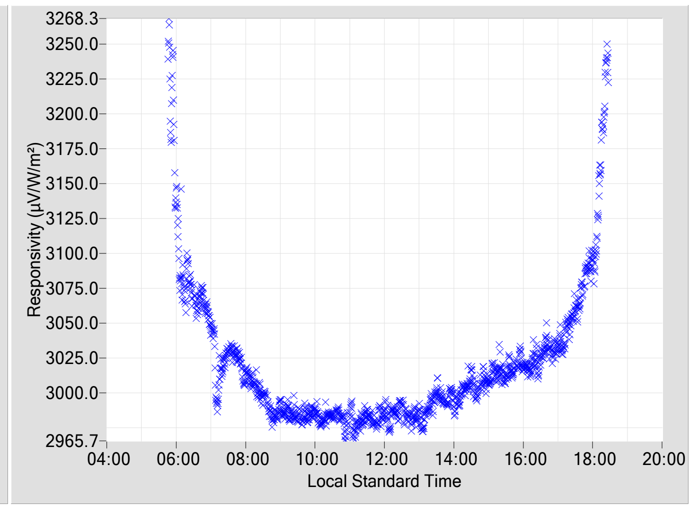


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	2982.9	0.31	106.78	3007.2	0.31	252.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	2986.9	0.31	104.53	3015.9	0.31	255.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	2999.7	0.33	102.42	3014.3	0.33	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	2999.8	0.35	100.39	3014.2	0.32	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	3009.2	0.34	98.46	3015.5	0.34	261.23
10	N/A	N/A	N/A	N/A	N/A	N/A	56	3014.8	0.34	96.59	3028.9	0.33	263.11
12	N/A	N/A	N/A	N/A	N/A	N/A	58	3024.3	0.39	94.80	3020.2	0.33	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	3029.4	0.34	93.06	3019.5	0.34	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	3031.2	0.35	91.36	3015.3	0.35	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	3015.6	0.36	89.69	3030.9	0.36	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	3000.7	0.42	88.04	3029.8	0.38	271.73
22	N/A	N/A	N/A	N/A	N/A	N/A	68	3049.5	0.39	86.43	3028.3	0.40	273.37
24	2982.4	0.31	167.09	2986.7	0.30	193.04	70	3067.4	0.42	84.79	3029.8	0.42	274.99
26	2974.9	0.30	151.05	2981.9	0.31	209.11	72	3060.4	0.45	83.19	3051.0	0.49	276.61
28	2983.1	0.33	140.76	2977.1	0.31	217.97	74	3071.8	0.49	81.61	3059.0	0.49	278.20
30	2984.1	0.33	134.40	2992.1	0.30	224.64	76	3065.7	0.54	80.00	3066.3	0.55	279.80
32	2981.9	0.31	129.23	2997.6	0.33	229.98	78	3086.8	0.75	78.39	3088.5	N/A	281.45
34	2987.3	0.32	124.85	2994.5	0.34	234.45	80	3226.4	N/A	76.75	3095.6	N/A	283.05
36	2984.4	0.31	121.02	2992.7	0.31	238.34	82	N/A	N/A	N/A	3140.0	N/A	284.70
38	2979.8	0.33	117.58	3004.0	0.31	241.76	84	N/A	N/A	N/A	3222.8	N/A	286.39
40	2981.8	0.33	114.47	3007.0	0.31	245.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	2981.1	0.33	111.76	2997.0	0.32	247.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	2984.8	0.32	109.17	3011.0	0.33	250.46	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

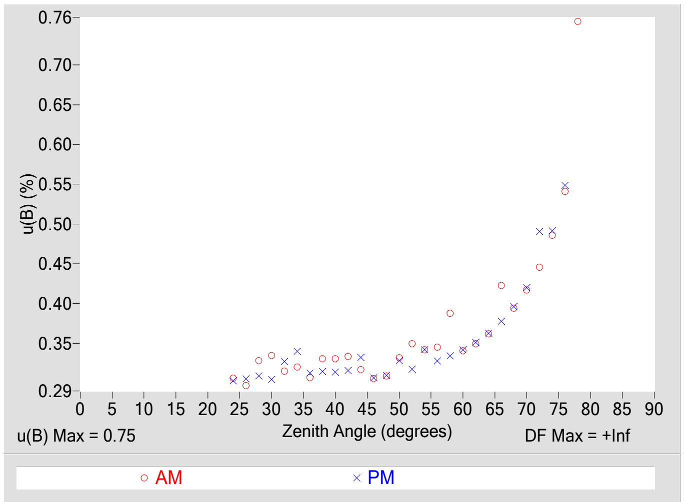


Figure 4. Residuals from Spline Interpolation

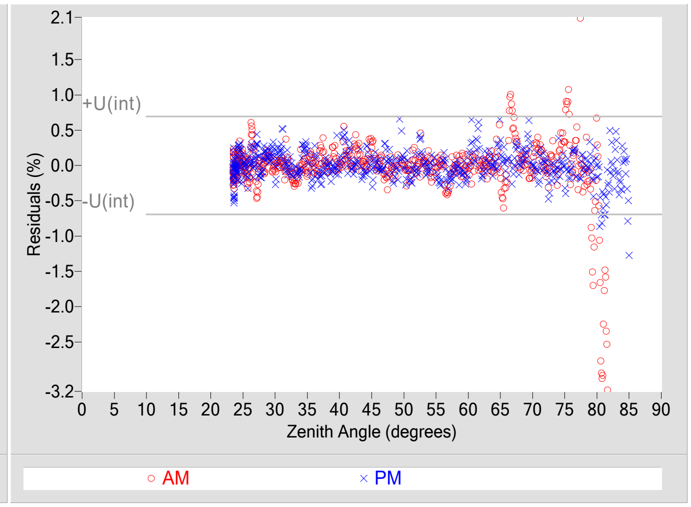


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.75
Type-A Interpolating Function, u(int) (%)	±0.35
Combined Standard Uncertainty, u(c) (%)	±0.83
Effective degrees of freedom, DF(c)	37479
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

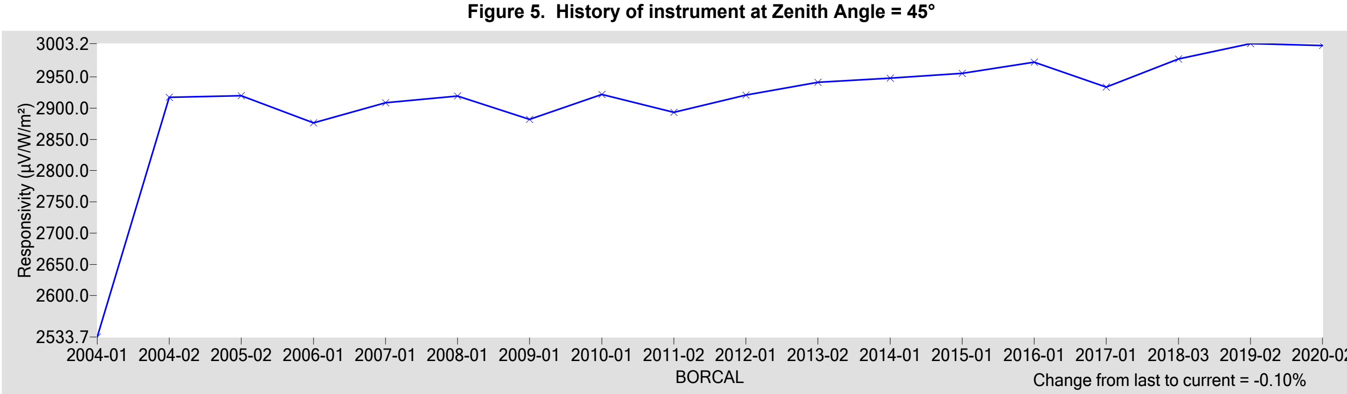
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
3000.1	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.76
Offset Uncertainty, U(off) (%)	+0.98 / -0.68
Expanded Uncertainty, U (%)	+1.7 / -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:**	080009
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

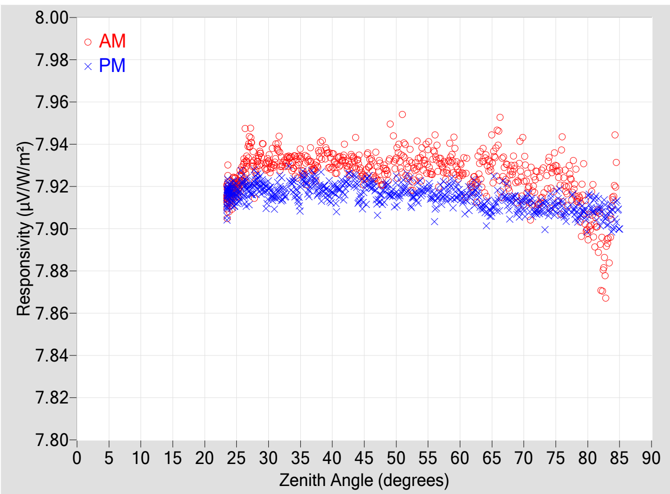


Figure 2. Responsivity vs Local Standard Time

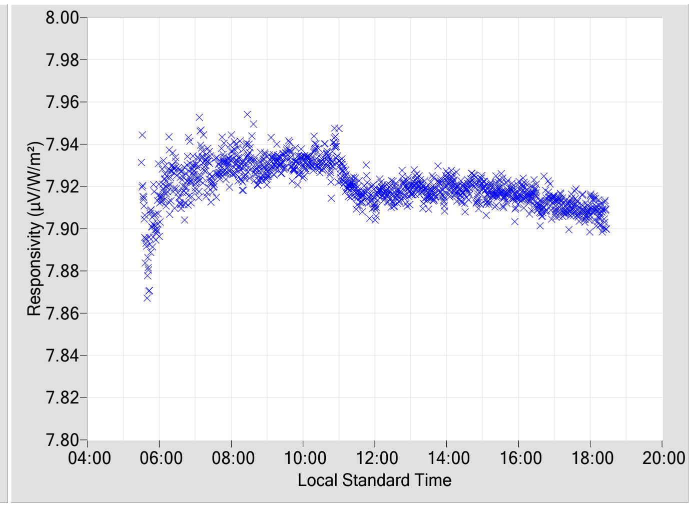


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9308	0.29	106.76	7.9211	0.29	252.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9252	0.30	104.54	7.9162	0.29	255.07
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9314	0.30	102.41	7.9167	0.29	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9276	0.31	100.37	7.9196	0.29	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9311	0.32	98.50	7.9183	0.30	261.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9362	0.30	96.58	7.9114	0.29	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9280	0.30	94.79	7.9166	0.29	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9271	0.30	93.05	7.9162	0.30	266.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9214	0.31	91.35	7.9175	0.30	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9271	0.30	89.68	7.9089	0.30	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9388	0.32	88.03	7.9126	0.30	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.9255	0.31	86.42	7.9121	0.30	273.36
24	7.9152	0.30	167.15	7.9170	0.30	192.94	70	7.9261	0.30	84.82	7.9109	0.30	274.98
26	7.9267	0.31	151.04	7.9198	0.29	209.08	72	7.9197	0.30	83.18	7.9084	0.31	276.59
28	7.9270	0.31	140.90	7.9225	0.31	218.19	74	7.9237	0.33	81.60	7.9103	0.31	278.20
30	7.9311	0.30	134.49	7.9179	0.32	224.72	76	7.9249	0.31	79.99	7.9092	0.31	279.83
32	7.9312	0.29	129.20	7.9185	0.29	230.05	78	7.9215	0.32	78.38	7.9079	N/A	281.44
34	7.9304	0.30	124.82	7.9195	0.30	234.61	80	7.8998	N/A	76.74	7.9087	N/A	283.09
36	7.9308	0.30	121.03	7.9208	0.31	238.40	82	7.8909	N/A	75.09	7.9080	N/A	284.73
38	7.9356	0.31	117.64	7.9190	0.31	241.90	84	7.9199	N/A	73.42	7.9036	N/A	286.38
40	7.9320	0.31	114.45	7.9172	0.30	244.99	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9337	0.29	111.81	7.9191	0.30	247.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9312	0.30	109.15	7.9156	0.29	250.44	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

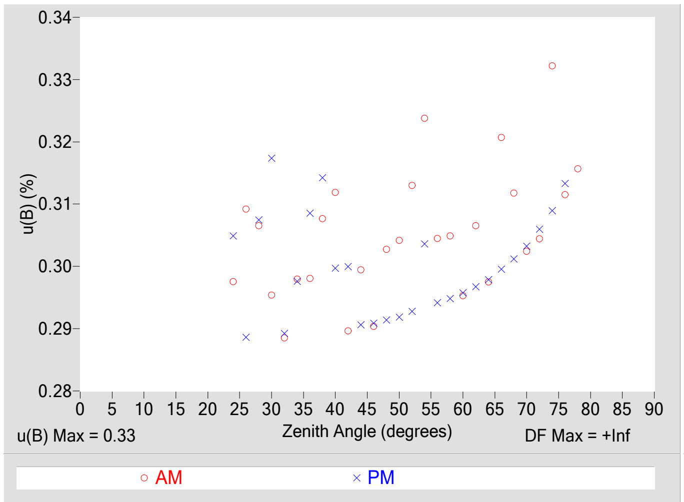


Figure 4. Residuals from Spline Interpolation

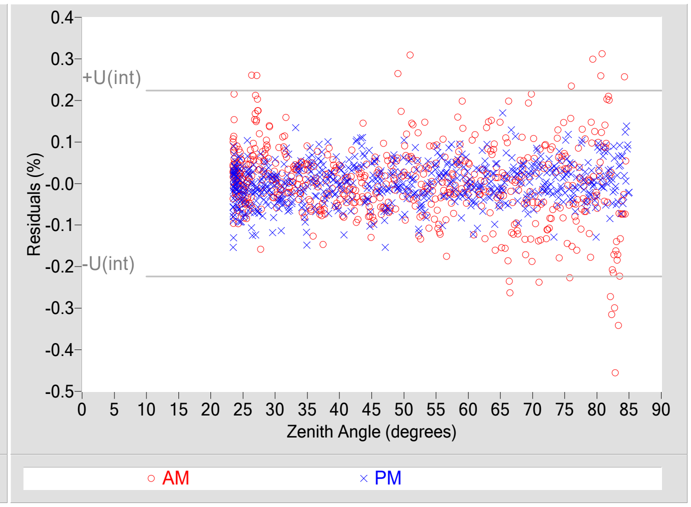


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.11
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	112168
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

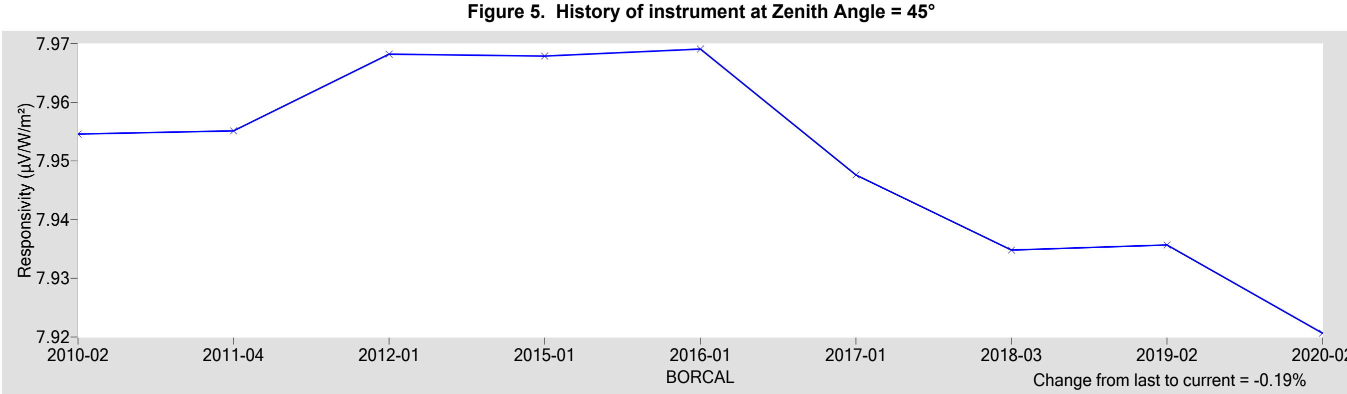
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9207	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.20 / -0.12
Expanded Uncertainty, U (%)	+0.83 / -0.75
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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

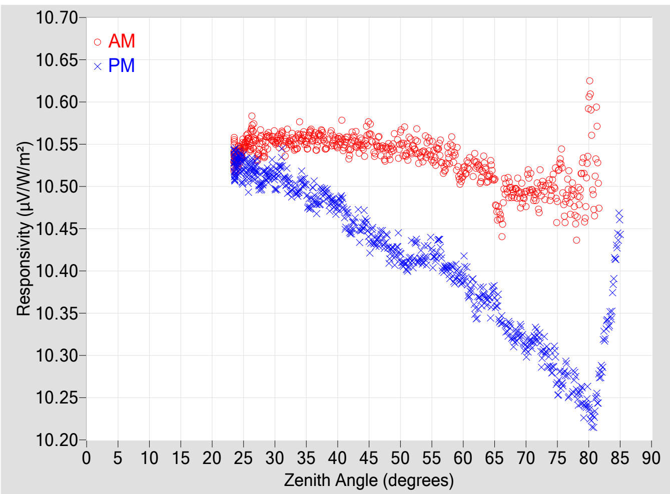


Figure 2. Responsivity vs Local Standard Time

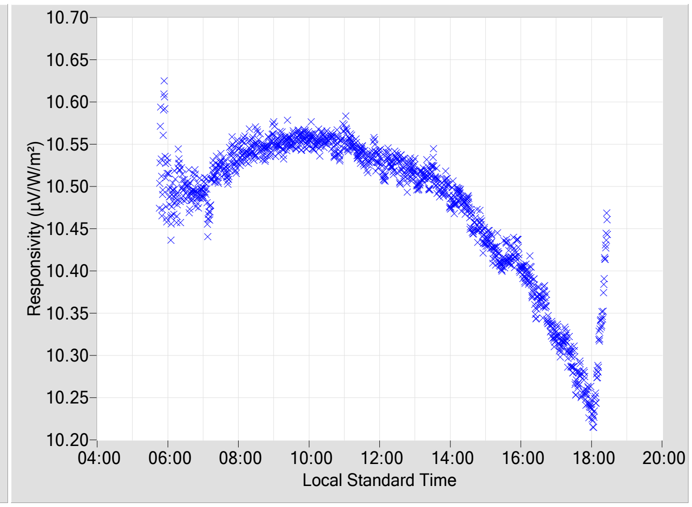


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.544	0.31	106.78	10.434	0.31	252.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.541	0.33	104.51	10.427	0.31	255.09
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.555	0.32	102.43	10.416	0.33	257.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.544	0.32	100.39	10.419	0.32	259.31
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.547	0.35	98.42	10.417	0.32	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.545	0.36	96.60	10.434	0.33	263.12
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.543	0.35	94.81	10.401	0.34	264.93
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.516	0.34	93.07	10.400	0.37	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.529	0.35	91.36	10.354	0.36	268.41
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.510	0.37	89.69	10.366	0.37	270.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.459	0.38	88.05	10.340	0.38	271.73
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.493	0.43	86.39	10.317	0.40	273.37
24	10.534	0.31	166.80	10.529	0.31	192.80	70	10.494	0.42	84.79	10.306	0.43	275.00
26	10.554	0.33	150.95	10.519	0.31	209.24	72	10.492	0.45	83.20	10.321	0.46	276.61
28	10.549	0.33	140.77	10.505	0.31	217.98	74	10.496	0.49	81.62	10.287	0.50	278.21
30	10.555	0.32	134.34	10.504	0.30	224.76	76	10.483	0.55	80.00	10.274	0.56	279.80
32	10.554	0.33	129.28	10.505	0.32	229.99	78	10.464	0.62	78.40	10.263	N/A	281.41
34	10.560	0.33	124.77	10.502	0.33	234.46	80	10.583	N/A	76.76	10.241	N/A	283.06
36	10.560	0.31	121.03	10.492	0.31	238.43	82	N/A	N/A	N/A	10.282	N/A	284.71
38	10.550	0.32	117.59	10.492	0.31	241.85	84	N/A	N/A	N/A	10.399	N/A	286.40
40	10.552	0.31	114.53	10.477	0.34	245.02	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.546	0.32	111.70	10.447	0.32	247.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.546	0.32	109.17	10.456	0.31	250.47	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

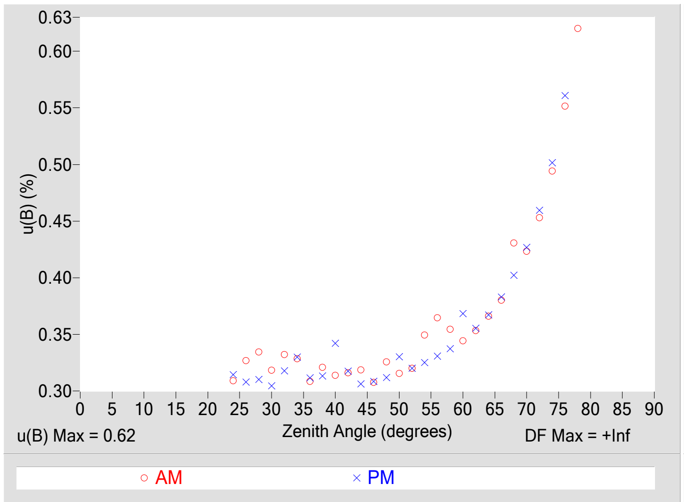


Figure 4. Residuals from Spline Interpolation

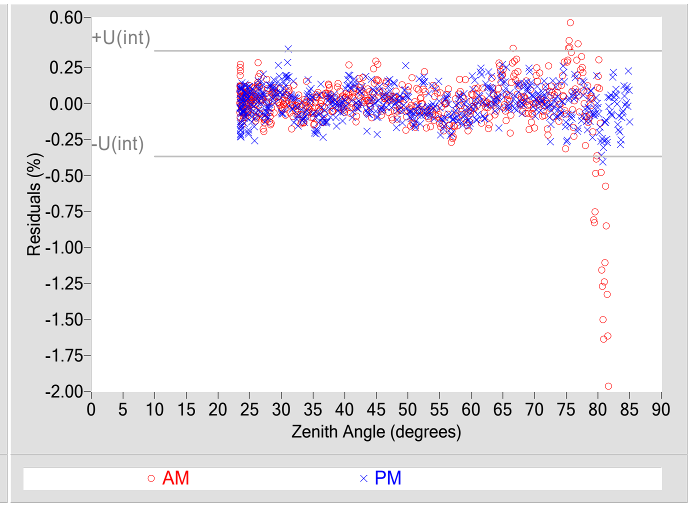


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	177905
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

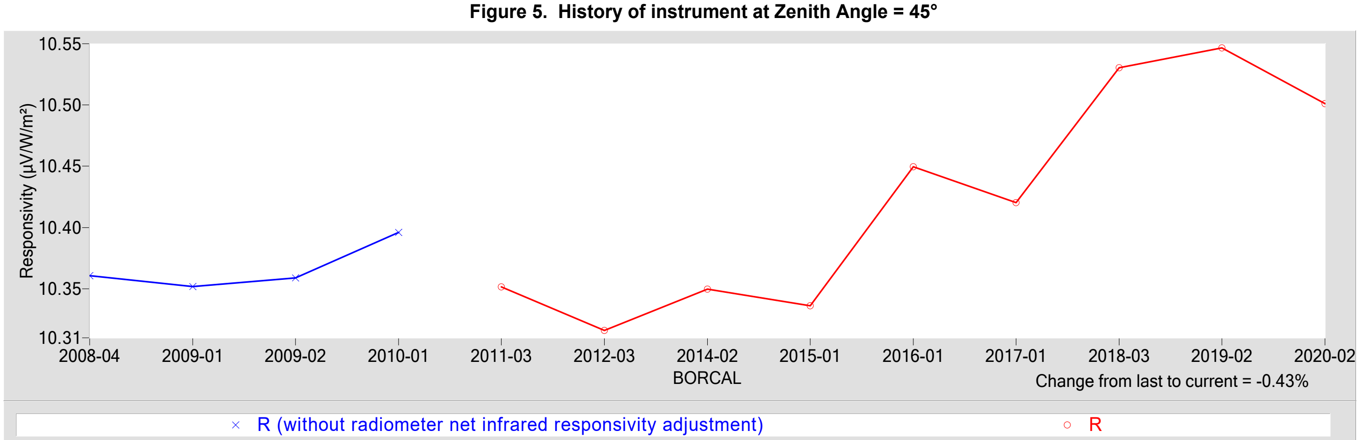
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.501	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+0.56 / -0.96
Expanded Uncertainty, U (%)	+1.3 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	100174
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - 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

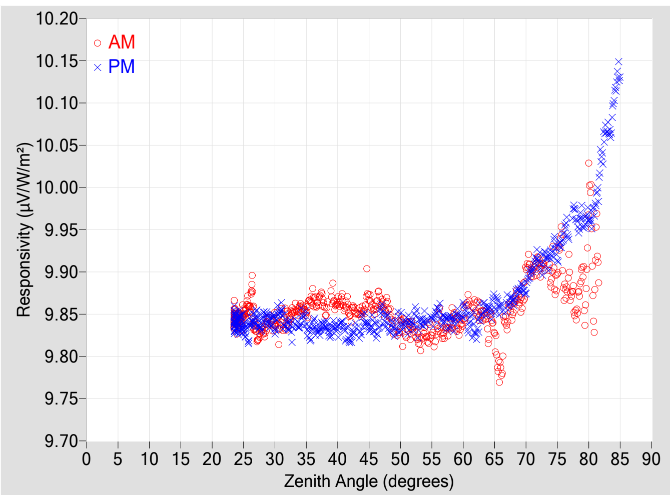


Figure 2. Responsivity vs Local Standard Time

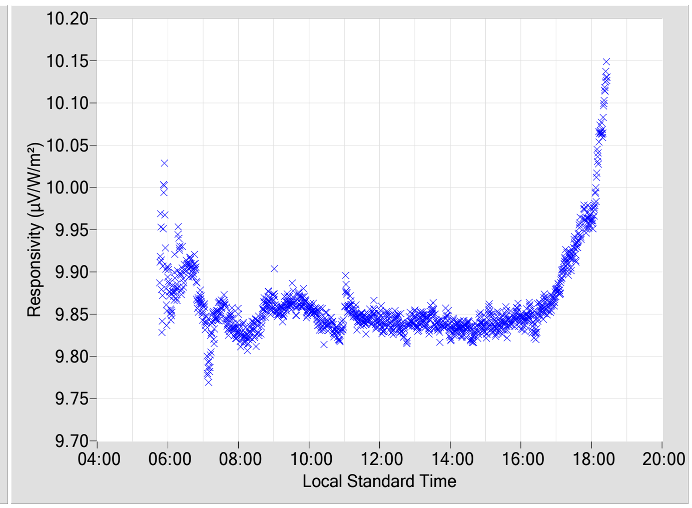


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.8572	0.32	106.77	9.8314	0.31	252.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8592	0.33	104.56	9.8398	0.31	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8364	0.36	102.42	9.8368	0.32	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8328	0.34	100.41	9.8399	0.32	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8256	0.36	98.46	9.8429	0.36	261.23
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8413	0.37	96.59	9.8566	0.35	263.11
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8417	0.34	94.80	9.8415	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8437	0.34	93.06	9.8556	0.35	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8575	0.35	91.36	9.8273	0.36	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.8338	0.39	89.68	9.8565	0.37	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7813	0.41	88.04	9.8563	0.38	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.8542	0.40	86.43	9.8661	0.40	273.37
24	9.8435	0.30	166.91	9.8403	0.32	193.10	70	9.8965	0.42	84.78	9.8801	0.43	274.99
26	9.8626	0.30	150.93	9.8339	0.32	209.14	72	9.9094	0.45	83.19	9.9157	0.46	276.60
28	9.8310	0.35	140.83	9.8430	0.32	218.09	74	9.8939	0.54	81.61	9.9210	0.50	278.21
30	9.8425	0.32	134.32	9.8385	0.31	224.63	76	9.8930	0.55	80.00	9.9456	0.56	279.80
32	9.8429	0.31	129.23	9.8361	0.33	230.08	78	9.8506	0.62	78.39	9.9643	N/A	281.41
34	9.8570	0.30	124.85	9.8404	0.32	234.51	80	9.9707	N/A	76.79	9.9644	N/A	283.05
36	9.8673	0.31	121.02	9.8353	0.33	238.42	82	N/A	N/A	N/A	10.033	N/A	284.70
38	9.8558	0.32	117.58	9.8371	0.34	241.91	84	N/A	N/A	N/A	10.103	N/A	286.35
40	9.8640	0.31	114.59	9.8317	0.33	244.94	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8492	0.32	111.76	9.8192	0.32	247.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8539	0.31	109.22	9.8395	0.32	250.35	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

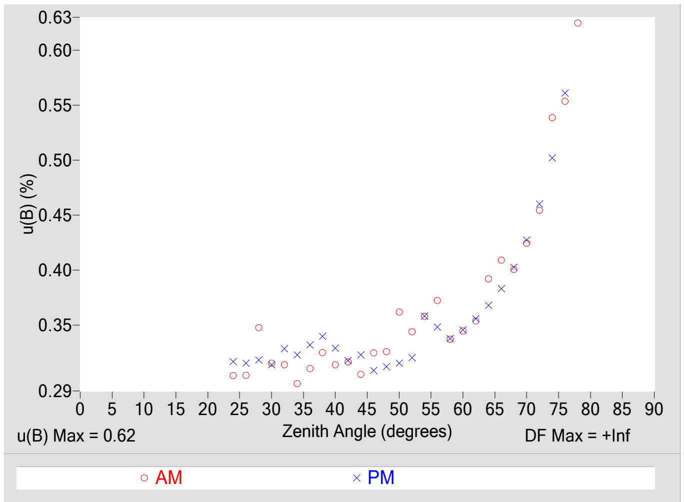


Figure 4. Residuals from Spline Interpolation

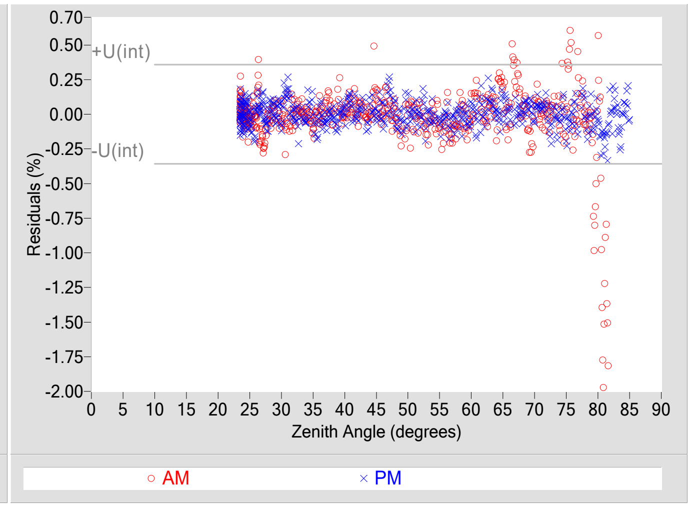


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	197300
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

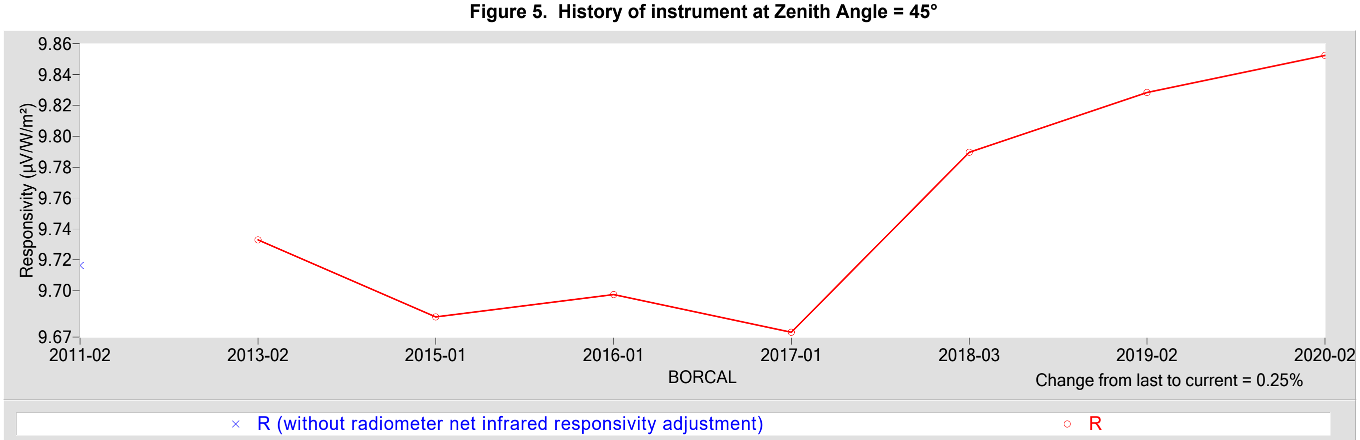
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.8524	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+0.15 / -0.34
Expanded Uncertainty, U (%)	+0.88 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Thermopile Pyranometer	**Manufacturer:**	Apogee
Model:	SP-510	**Serial Number:**	1171
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

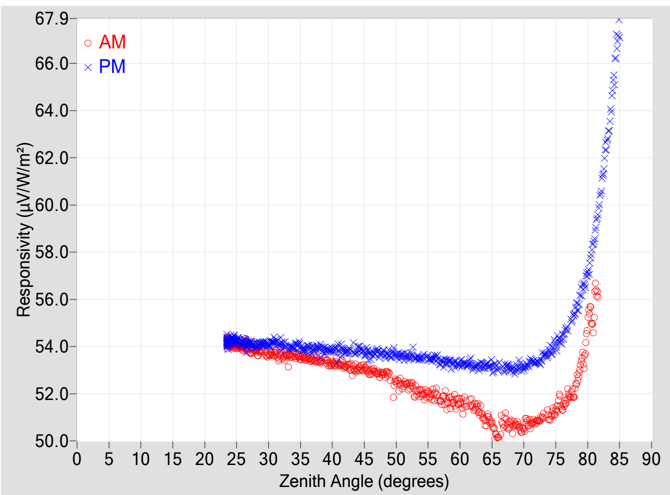


Figure 2. Responsivity vs Local Standard Time

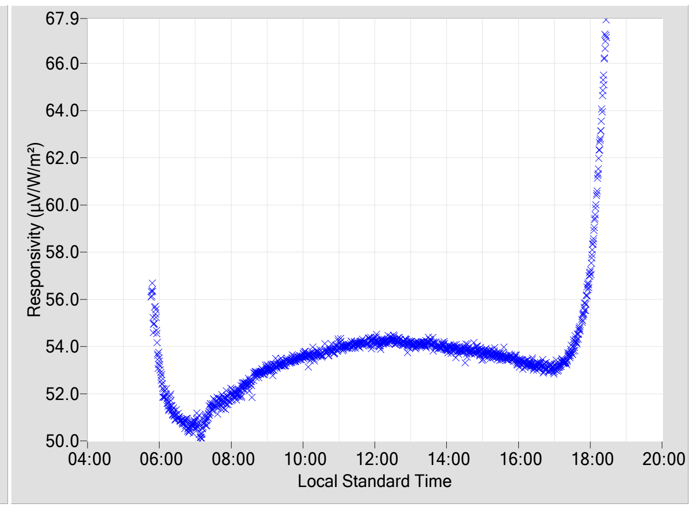


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	52.913	0.32	106.80	53.670	0.34	252.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	52.811	0.36	104.52	53.724	0.36	255.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	52.536	0.34	102.44	53.646	0.33	257.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	52.339	0.37	100.40	53.572	0.35	259.32
8	N/A	N/A	N/A	N/A	N/A	N/A	54	52.019	0.40	98.43	53.501	0.36	261.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	52.024	0.38	96.61	53.516	0.35	263.13
12	N/A	N/A	N/A	N/A	N/A	N/A	58	51.727	0.39	94.82	53.371	0.36	264.94
14	N/A	N/A	N/A	N/A	N/A	N/A	60	51.654	0.42	93.07	53.295	0.37	266.70
16	N/A	N/A	N/A	N/A	N/A	N/A	62	51.520	0.41	91.33	53.141	0.39	268.42
18	N/A	N/A	N/A	N/A	N/A	N/A	64	50.821	0.43	89.65	53.204	0.40	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	50.116	0.43	88.06	53.104	0.42	271.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	50.654	0.46	86.40	53.053	0.45	273.38
24	54.129	0.32	166.82	54.240	0.33	192.94	70	50.594	0.48	84.80	53.112	0.48	275.01
26	53.986	0.33	150.84	54.179	0.32	209.17	72	50.810	0.52	83.21	53.332	0.52	276.58
28	53.860	0.34	140.76	54.040	0.31	218.11	74	50.975	0.57	81.59	53.798	0.61	278.22
30	53.667	0.33	134.45	54.072	0.33	224.79	76	51.406	0.63	80.01	54.348	0.65	279.81
32	53.703	0.32	129.26	54.098	0.32	230.01	78	52.100	0.72	78.41	55.524	N/A	281.43
34	53.668	0.33	124.79	53.994	0.33	234.48	80	54.926	N/A	76.77	57.096	N/A	283.02
36	53.513	0.32	120.97	53.939	0.31	238.45	82	N/A	N/A	N/A	60.417	N/A	284.67
38	53.370	0.32	117.61	53.946	0.31	241.85	84	N/A	N/A	N/A	65.262	N/A	286.41
40	53.270	0.33	114.54	53.834	0.33	244.96	86	N/A	N/A	N/A	N/A	N/A	N/A
42	53.194	0.33	111.71	53.780	0.32	247.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	53.020	0.32	109.19	53.873	0.34	250.39	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

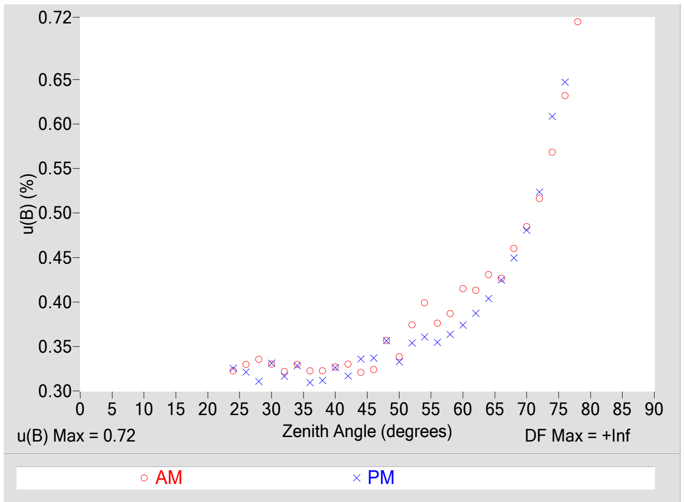


Figure 4. Residuals from Spline Interpolation

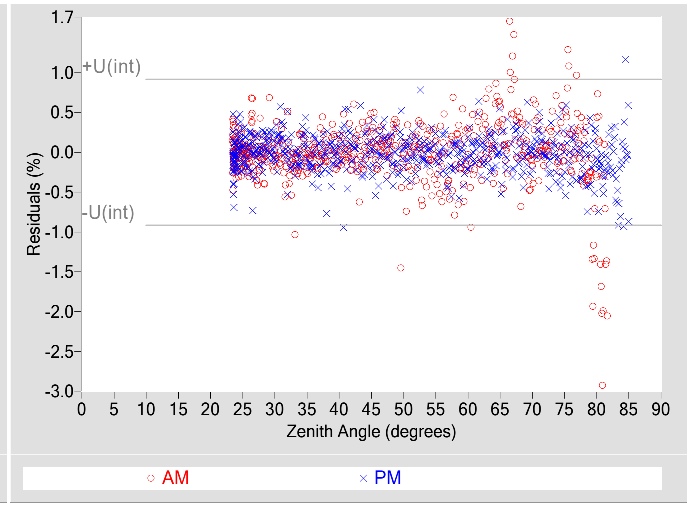


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.72
Type-A Interpolating Function, u(int) (%)	±0.46
Combined Standard Uncertainty, u(c) (%)	±0.85
Effective degrees of freedom, DF(c)	13593
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.7
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

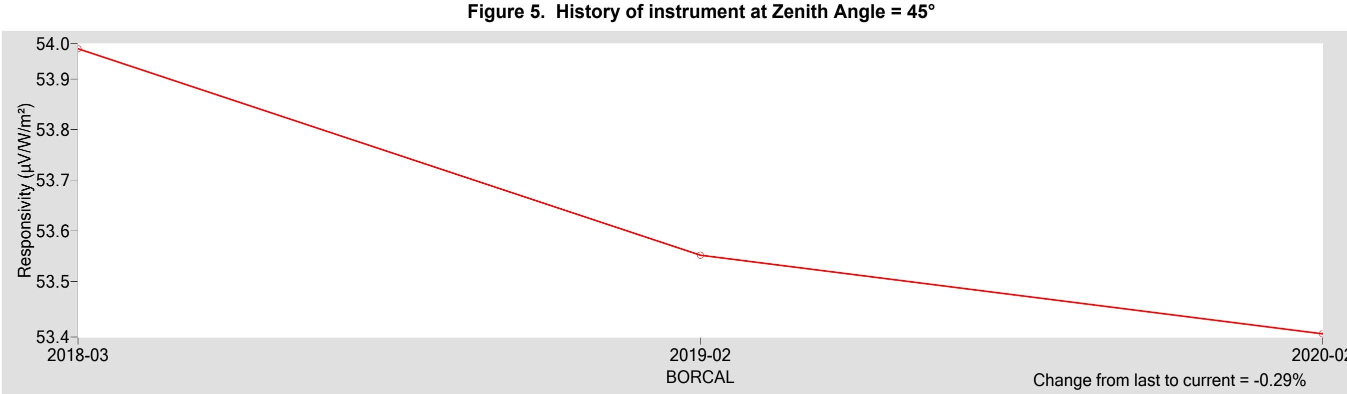
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
53.397	2.5000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.81
Offset Uncertainty, U(off) (%)	+1.3 / -3.3
Expanded Uncertainty, U (%)	+2.1 / -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:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	140043
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

140043 Kipp & Zonen CMP22

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

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

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

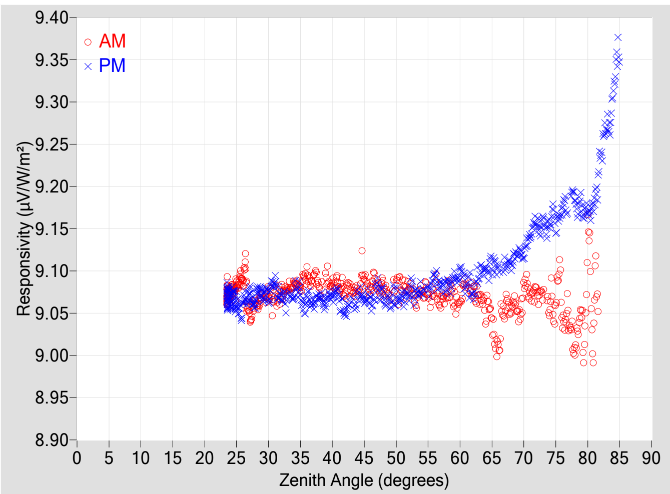


Figure 2. Responsivity vs Local Standard Time

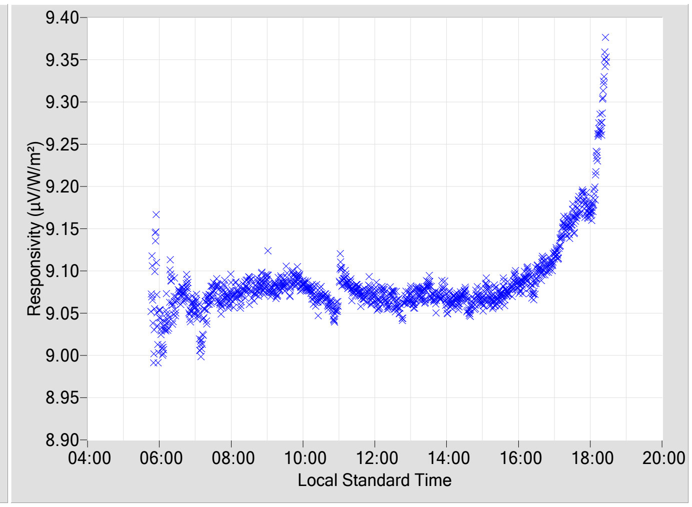


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.0791	0.32	106.77	9.0621	0.31	252.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0827	0.33	104.56	9.0711	0.31	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0842	0.36	102.42	9.0665	0.32	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0804	0.34	100.41	9.0724	0.32	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0756	0.36	98.46	9.0771	0.36	261.23
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0805	0.37	96.59	9.0949	0.35	263.11
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0737	0.34	94.80	9.0839	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0659	0.35	93.06	9.0984	0.35	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0763	0.35	91.36	9.0720	0.36	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0541	0.39	89.68	9.1020	0.37	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0080	0.41	88.04	9.1017	0.38	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.0533	0.40	86.43	9.1080	0.40	273.37
24	9.0738	0.30	166.91	9.0677	0.32	193.10	70	9.0760	0.43	84.78	9.1201	0.43	274.99
26	9.0922	0.30	150.93	9.0589	0.32	209.14	72	9.0748	0.46	83.19	9.1565	0.46	276.60
28	9.0617	0.35	140.83	9.0692	0.32	218.09	74	9.0570	0.54	81.61	9.1562	0.50	278.21
30	9.0727	0.32	134.32	9.0711	0.31	224.63	76	9.0547	0.56	80.00	9.1742	0.56	279.80
32	9.0721	0.31	129.23	9.0684	0.33	230.08	78	9.0066	0.63	78.39	9.1843	N/A	281.41
34	9.0839	0.30	124.85	9.0725	0.32	234.51	80	9.1134	N/A	76.79	9.1717	N/A	283.05
36	9.0930	0.31	121.02	9.0662	0.33	238.42	82	N/A	N/A	N/A	9.2334	N/A	284.70
38	9.0778	0.33	117.58	9.0697	0.34	241.91	84	N/A	N/A	N/A	9.3090	N/A	286.35
40	9.0848	0.31	114.59	9.0693	0.33	244.94	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0728	0.32	111.76	9.0501	0.32	247.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0770	0.31	109.22	9.0686	0.32	250.35	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

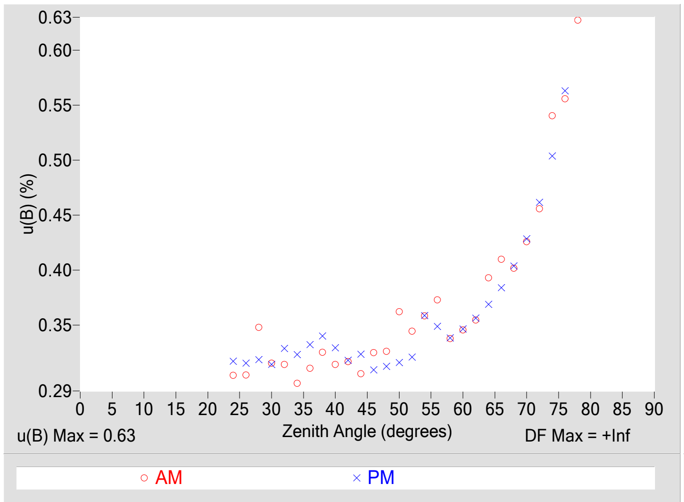


Figure 4. Residuals from Spline Interpolation

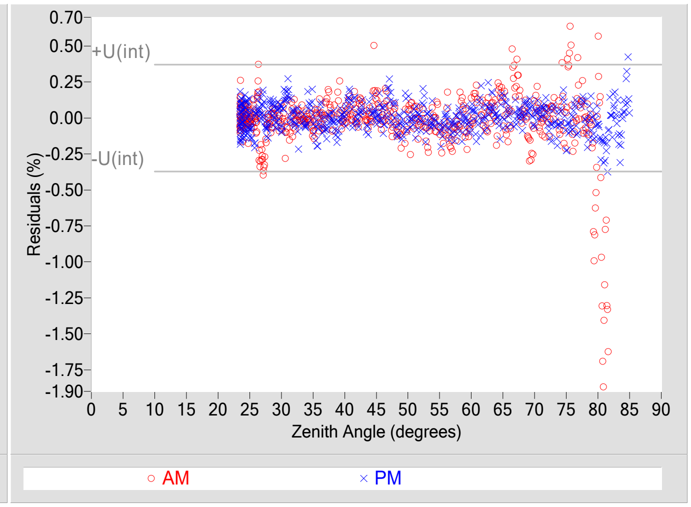


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	173358
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

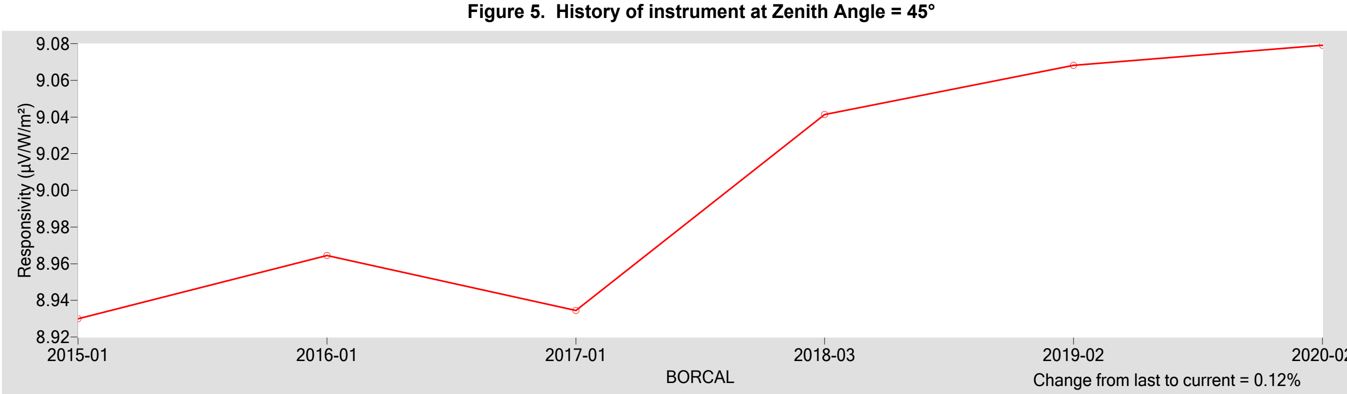
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0791	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+0.21 / -0.32
Expanded Uncertainty, U (%)	+0.94 / -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:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	140108
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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 - 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

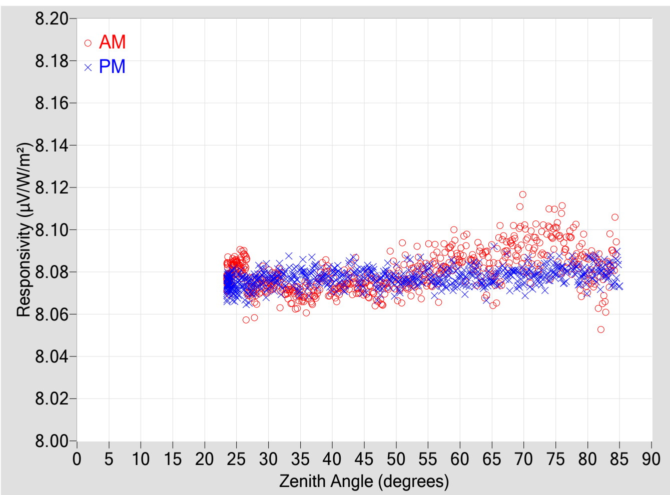


Figure 2. Responsivity vs Local Standard Time

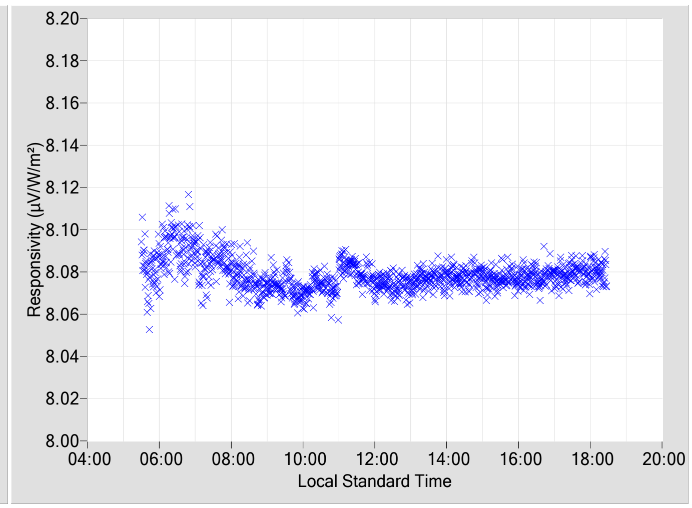


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0730	0.29	106.76	8.0794	0.29	252.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0692	0.30	104.54	8.0767	0.29	255.07
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0745	0.30	102.41	8.0758	0.29	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0753	0.31	100.37	8.0800	0.29	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0783	0.32	98.50	8.0791	0.30	261.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0857	0.30	96.58	8.0743	0.29	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0833	0.30	94.79	8.0764	0.29	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0863	0.30	93.05	8.0775	0.30	266.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0855	0.31	91.35	8.0797	0.30	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0812	0.30	89.68	8.0765	0.30	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0854	0.32	88.03	8.0777	0.30	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.0923	0.31	86.42	8.0779	0.30	273.36
24	8.0778	0.30	167.15	8.0749	0.30	192.94	70	8.0950	0.30	84.82	8.0765	0.30	274.98
26	8.0841	0.31	151.04	8.0752	0.29	209.08	72	8.0916	0.30	83.18	8.0776	0.31	276.59
28	8.0690	0.31	140.90	8.0759	0.31	218.19	74	8.0956	0.33	81.60	8.0805	0.31	278.20
30	8.0746	0.30	134.49	8.0756	0.32	224.72	76	8.0944	0.31	79.99	8.0790	0.31	279.83
32	8.0730	0.29	129.20	8.0775	0.29	230.05	78	8.0915	0.32	78.38	8.0809	N/A	281.44
34	8.0697	0.30	124.82	8.0783	0.30	234.61	80	8.0786	N/A	76.74	8.0794	N/A	283.09
36	8.0724	0.30	121.00	8.0763	0.31	238.40	82	8.0753	N/A	75.09	8.0795	N/A	284.73
38	8.0755	0.31	117.64	8.0773	0.31	241.90	84	8.0898	N/A	73.42	8.0767	N/A	286.38
40	8.0738	0.31	114.45	8.0772	0.30	244.99	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0743	0.29	111.81	8.0743	0.30	247.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0718	0.30	109.15	8.0768	0.29	250.44	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

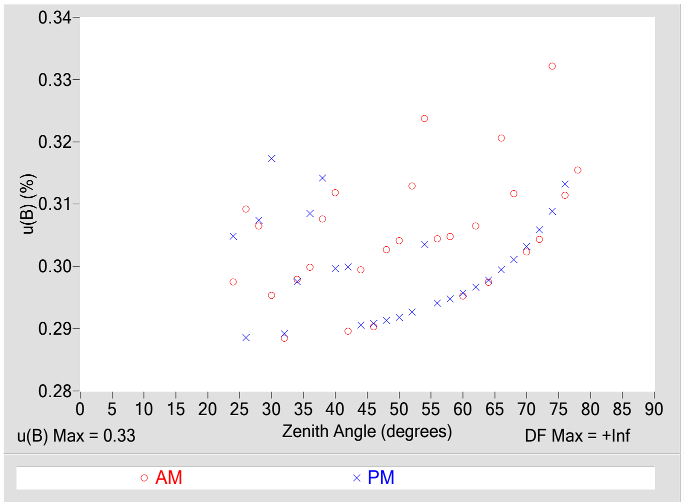


Figure 4. Residuals from Spline Interpolation

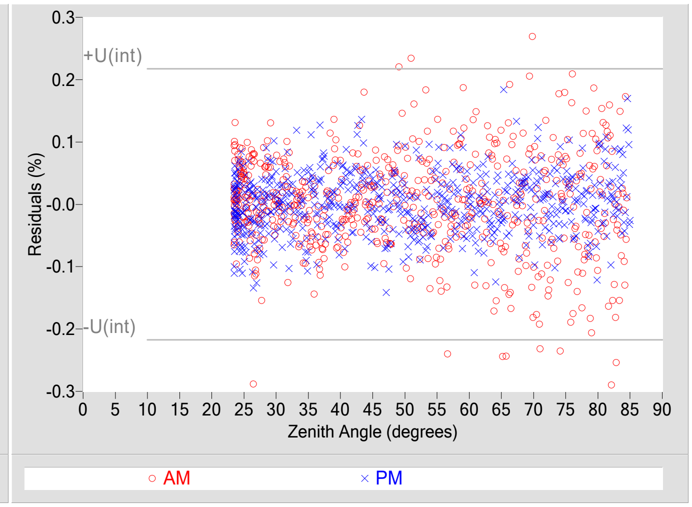


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.11
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	123510
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.68
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

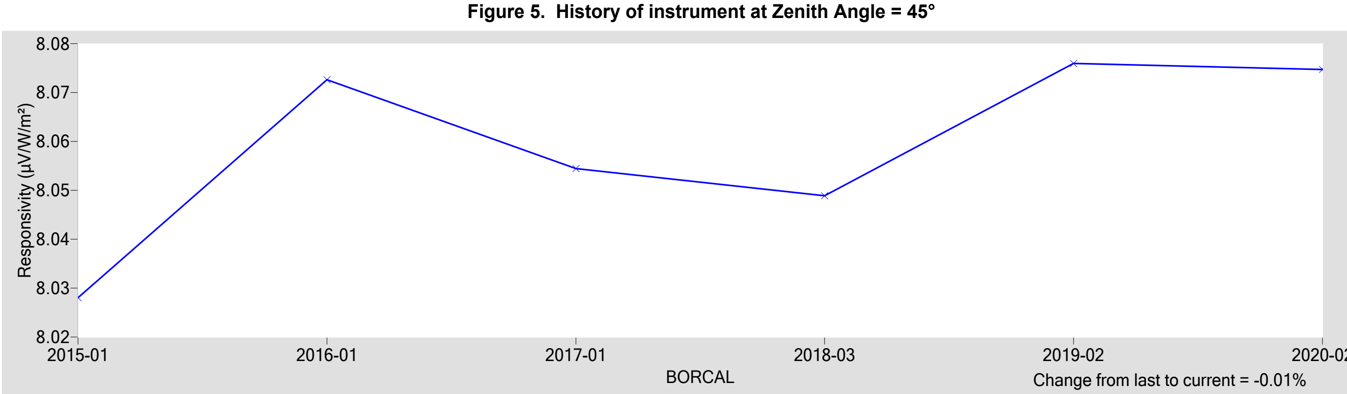
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0747	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.14 / -0.068
Expanded Uncertainty, U (%)	+0.78 / -0.70
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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

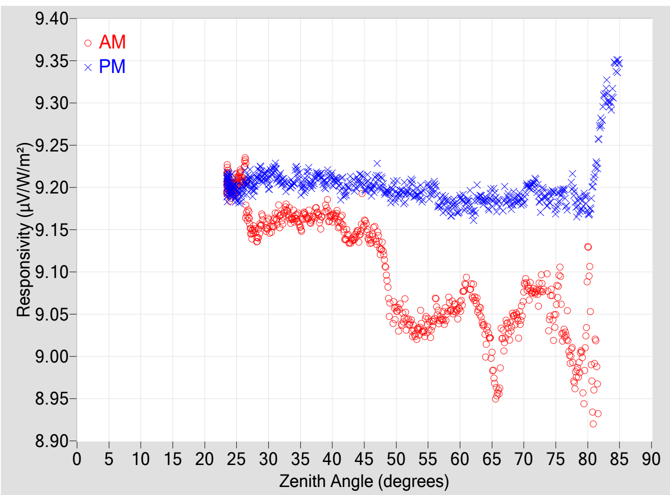


Figure 2. Responsivity vs Local Standard Time

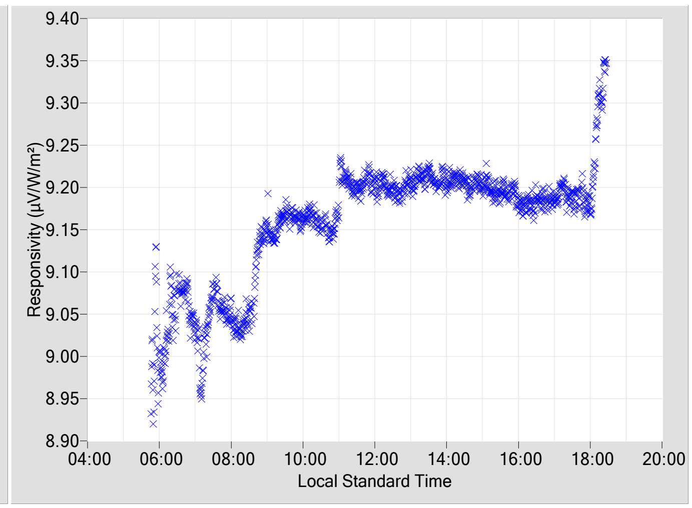


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.1384	0.31	106.83	9.1979	0.31	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1213	0.33	104.55	9.1992	0.32	255.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0540	0.34	102.41	9.1931	0.32	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0400	0.35	100.32	9.1971	0.34	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0360	0.36	98.46	9.1925	0.33	261.23
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0533	0.38	96.58	9.2006	0.34	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0541	0.34	94.77	9.1806	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0598	0.35	93.05	9.1818	0.37	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0754	0.38	91.35	9.1689	0.36	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0217	0.40	89.68	9.1851	0.38	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9577	0.42	88.04	9.1796	0.39	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.0351	0.44	86.42	9.1804	0.41	273.36
24	9.2007	0.31	167.06	9.2020	0.32	193.07	70	9.0754	0.44	84.78	9.1864	0.44	274.99
26	9.2133	0.31	150.99	9.1996	0.30	209.07	72	9.0733	0.47	83.19	9.2009	0.47	276.60
28	9.1429	0.32	140.64	9.2077	0.32	218.08	74	9.0542	0.51	81.61	9.1880	0.52	278.20
30	9.1552	0.32	134.50	9.2082	0.33	224.62	76	9.0436	0.61	79.99	9.1954	0.58	279.79
32	9.1621	0.32	129.23	9.2075	0.32	230.07	78	8.9718	0.65	78.39	9.1850	N/A	281.40
34	9.1648	0.30	124.84	9.2104	0.31	234.50	80	9.0835	N/A	76.79	9.1749	N/A	283.05
36	9.1643	0.30	121.03	9.2117	0.30	238.41	82	N/A	N/A	N/A	9.2728	N/A	284.69
38	9.1619	0.31	117.58	9.2151	0.32	241.95	84	N/A	N/A	N/A	9.3253	N/A	286.39
40	9.1658	0.33	114.58	9.2095	0.31	244.93	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1439	0.35	111.75	9.1938	0.32	247.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1441	0.31	109.22	9.2085	0.34	250.39	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

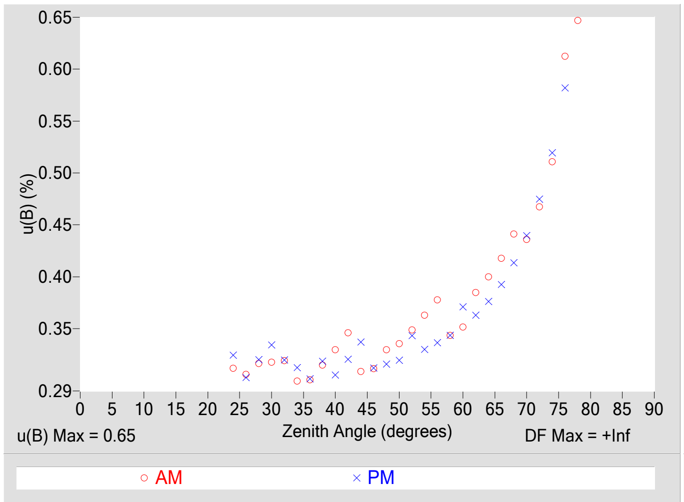


Figure 4. Residuals from Spline Interpolation

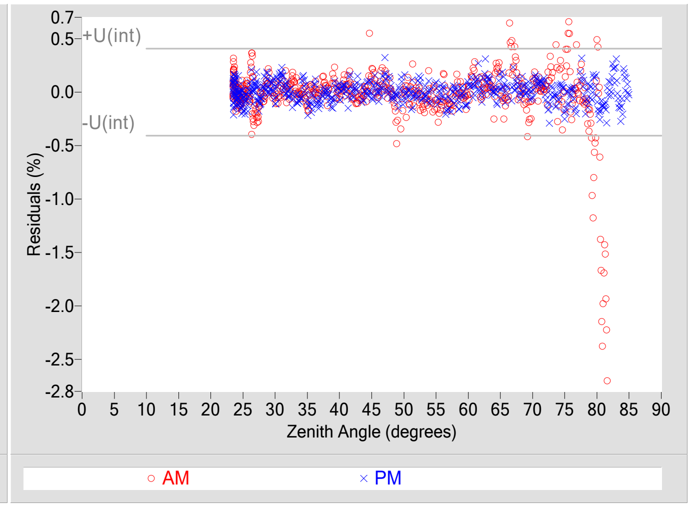


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	139338
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

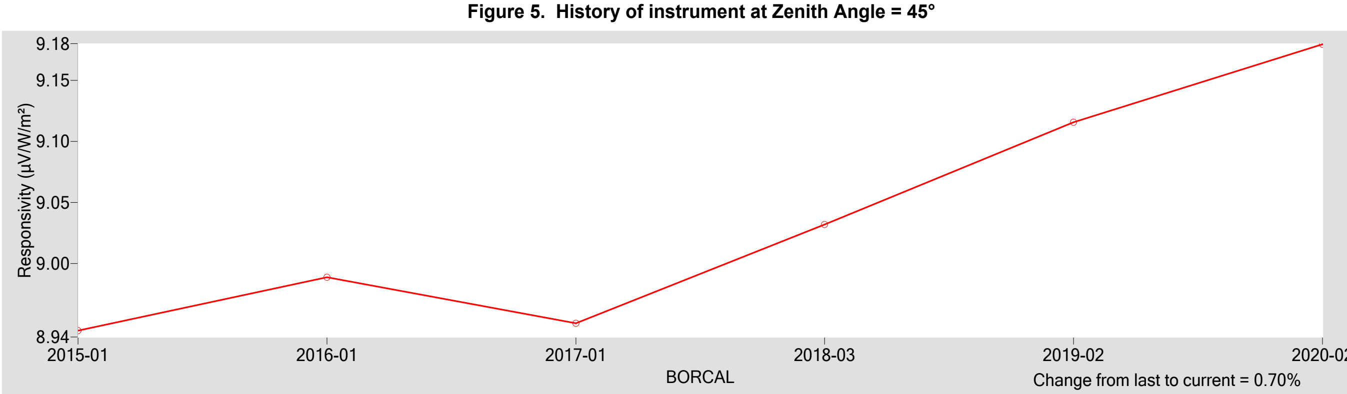
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.1796	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.74
Offset Uncertainty, U(off) (%)	+0.39 / -1.6
Expanded Uncertainty, U (%)	+1.1 / -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

NREL

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	CMP11	**Serial Number:**	140713
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

140713 Kipp & Zonen CMP11

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

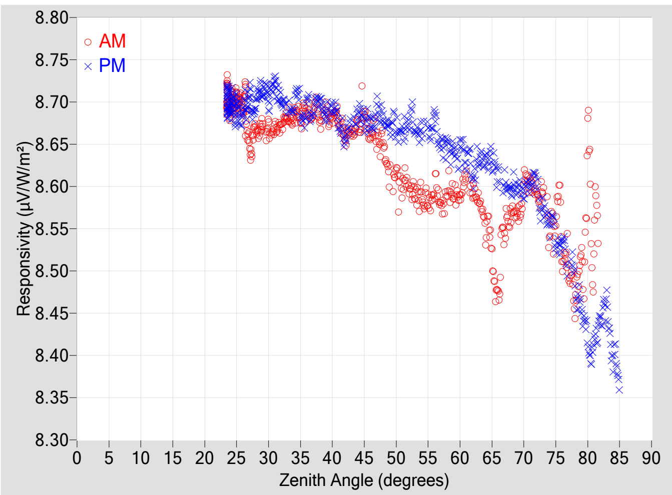


Figure 2. Responsivity vs Local Standard Time

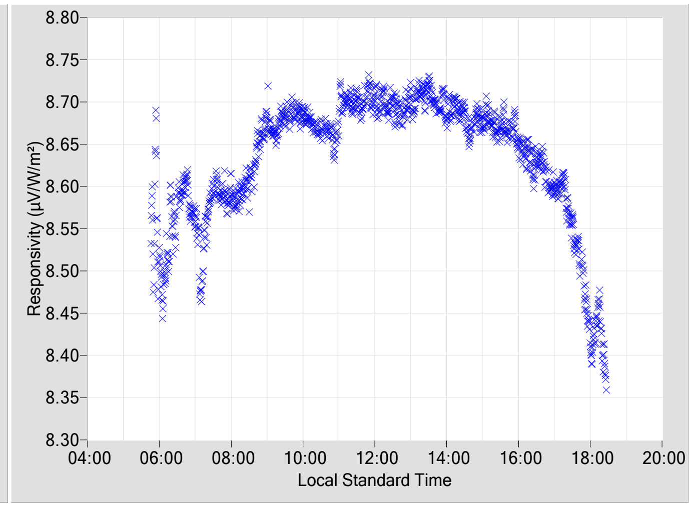


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.6605	0.31	106.83	8.6746	0.31	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6506	0.33	104.55	8.6788	0.32	255.14
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6162	0.34	102.41	8.6662	0.32	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5967	0.35	100.32	8.6741	0.34	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5894	0.36	98.46	8.6679	0.33	261.23
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5992	0.38	96.58	8.6818	0.34	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5975	0.34	94.77	8.6486	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5876	0.35	93.05	8.6410	0.37	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5953	0.39	91.35	8.6085	0.36	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5497	0.40	89.68	8.6316	0.38	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4740	0.42	88.04	8.6106	0.39	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5656	0.44	86.42	8.5950	0.42	273.36
24	8.6975	0.31	167.06	8.6983	0.32	193.07	70	8.6010	0.44	84.78	8.5919	0.44	274.99
26	8.6974	0.31	150.99	8.6897	0.30	209.07	72	8.5907	0.47	83.19	8.6028	0.48	276.60
28	8.6680	0.32	140.64	8.6989	0.32	218.08	74	8.5471	0.51	81.61	8.5572	0.52	278.20
30	8.6683	0.32	134.50	8.7032	0.33	224.62	76	8.5275	0.62	79.99	8.5337	0.59	279.79
32	8.6713	0.32	129.23	8.7001	0.32	230.07	78	8.4601	0.65	78.39	8.4843	N/A	281.40
34	8.6835	0.30	124.84	8.6970	0.31	234.50	80	8.6290	N/A	76.79	8.4167	N/A	283.05
36	8.6849	0.30	121.03	8.6971	0.30	238.41	82	N/A	N/A	N/A	8.4416	N/A	284.69
38	8.6779	0.32	117.58	8.7026	0.32	241.95	84	N/A	N/A	N/A	8.3989	N/A	286.39
40	8.6823	0.33	114.58	8.6932	0.31	244.93	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6575	0.35	111.75	8.6543	0.32	247.74	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6727	0.31	109.22	8.6864	0.34	250.39	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

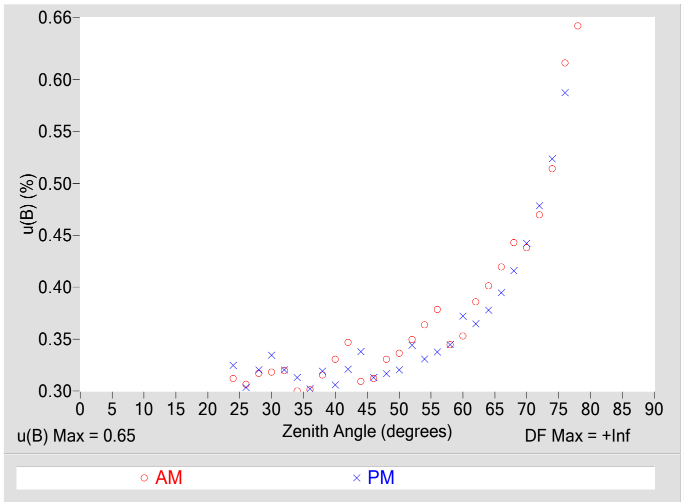


Figure 4. Residuals from Spline Interpolation

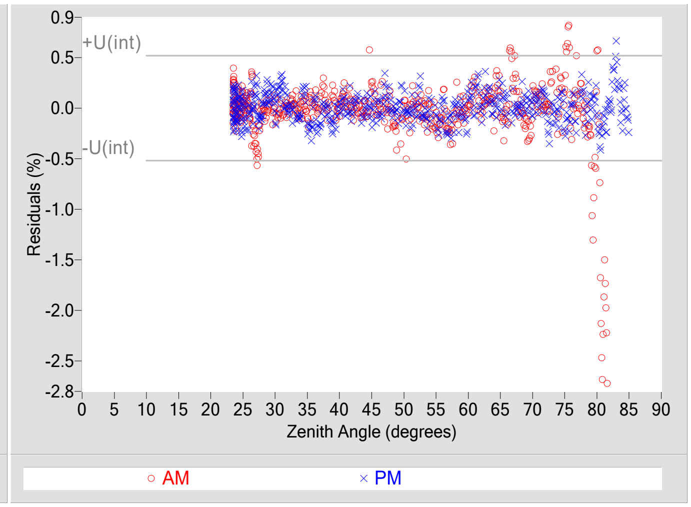


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	60569
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

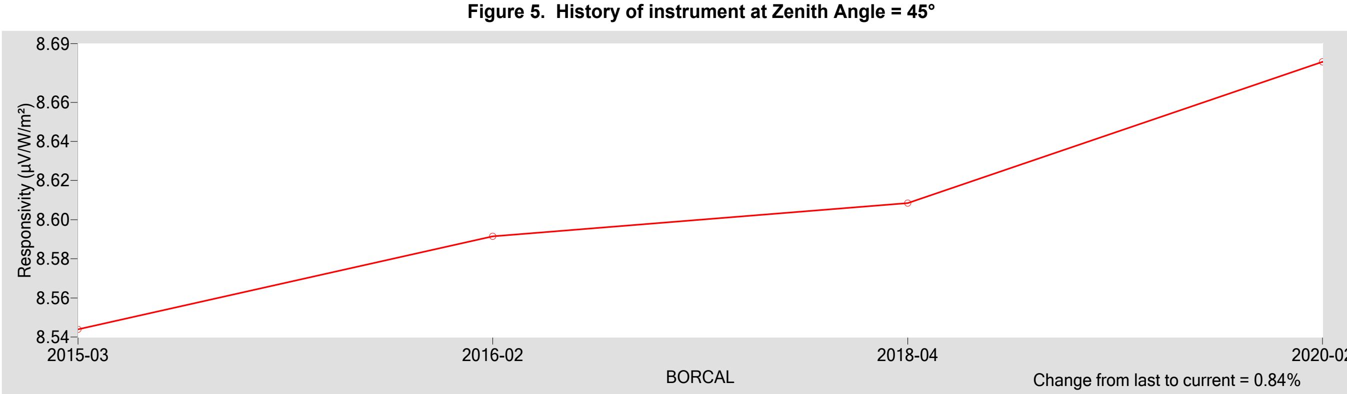
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6806	0.20500

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.74
Offset Uncertainty, U(off) (%)	+0.26 / -1.1
Expanded Uncertainty, U (%)	+1.0 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	151027
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

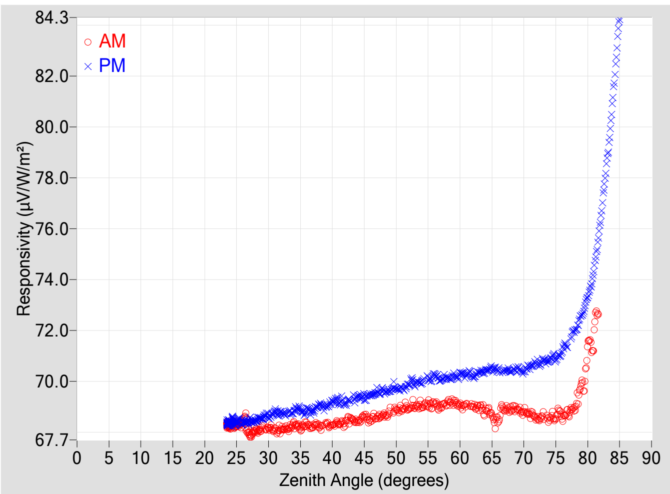


Figure 2. Responsivity vs Local Standard Time

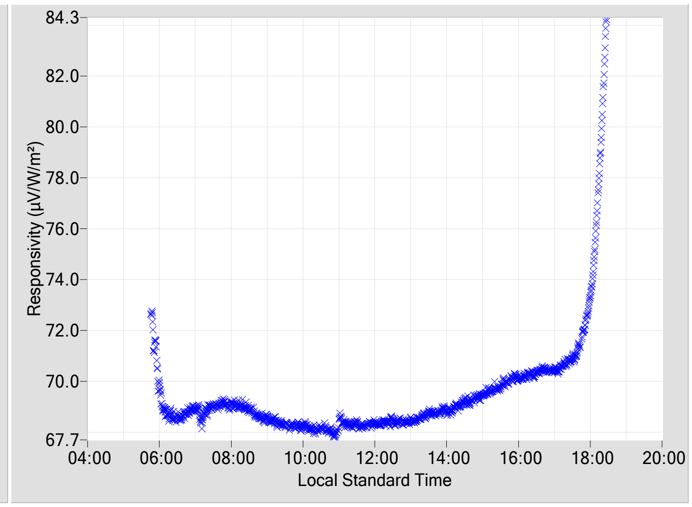


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	68.489	0.31	106.77	69.468	0.32	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	68.673	0.31	104.55	69.632	0.32	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	68.911	0.33	102.41	69.711	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	68.917	0.35	100.38	69.911	0.32	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	68.967	0.32	98.40	69.970	0.32	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	69.158	0.36	96.58	70.254	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	69.159	0.38	94.75	70.143	0.33	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	69.064	0.34	93.05	70.272	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	69.040	0.35	91.35	70.182	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	68.799	0.36	89.68	70.423	0.36	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	68.519	0.40	88.03	70.429	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	68.899	0.39	86.42	70.381	0.40	273.36
24	68.261	0.31	167.32	68.399	0.31	193.01	70	68.809	0.42	84.82	70.398	0.42	274.99
26	68.421	0.32	151.05	68.378	0.31	209.06	72	68.551	0.45	83.18	70.735	0.45	276.60
28	68.082	0.33	140.91	68.458	0.31	218.07	74	68.520	0.49	81.61	70.834	0.49	278.20
30	68.150	0.31	134.42	68.628	0.29	224.61	76	68.588	0.54	79.99	71.226	0.55	279.83
32	68.103	0.30	129.21	68.773	0.32	230.02	78	68.965	0.61	78.39	72.009	N/A	281.44
34	68.293	0.31	124.83	68.853	0.32	234.61	80	71.249	N/A	76.74	73.377	N/A	283.09
36	68.311	0.31	121.06	68.887	0.31	238.40	82	N/A	N/A	N/A	76.425	N/A	284.73
38	68.209	0.31	117.65	69.082	0.31	241.82	84	N/A	N/A	N/A	81.323	N/A	286.39
40	68.292	0.32	114.46	69.207	0.33	244.99	86	N/A	N/A	N/A	N/A	N/A	N/A
42	68.341	0.31	111.82	69.110	0.33	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	68.421	0.30	109.15	69.384	0.36	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

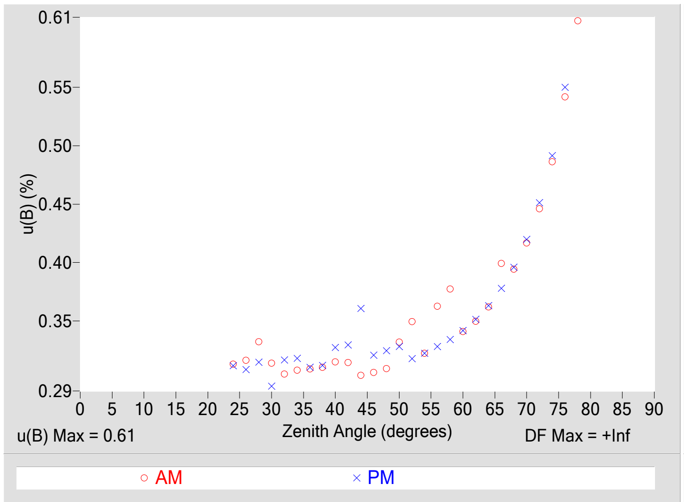


Figure 4. Residuals from Spline Interpolation

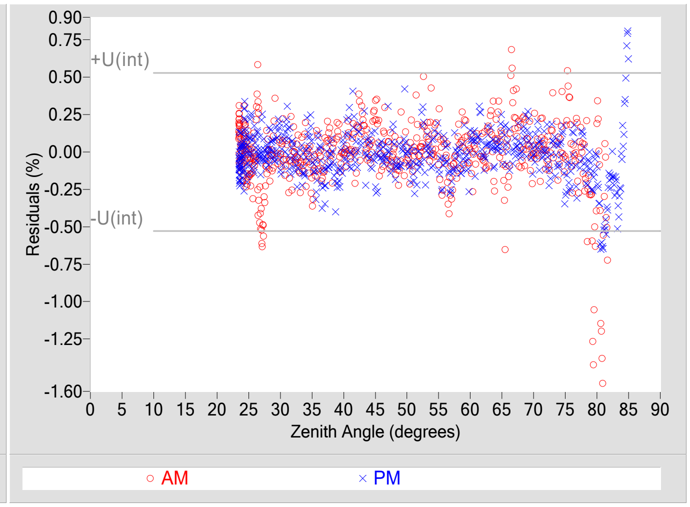


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	45325
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

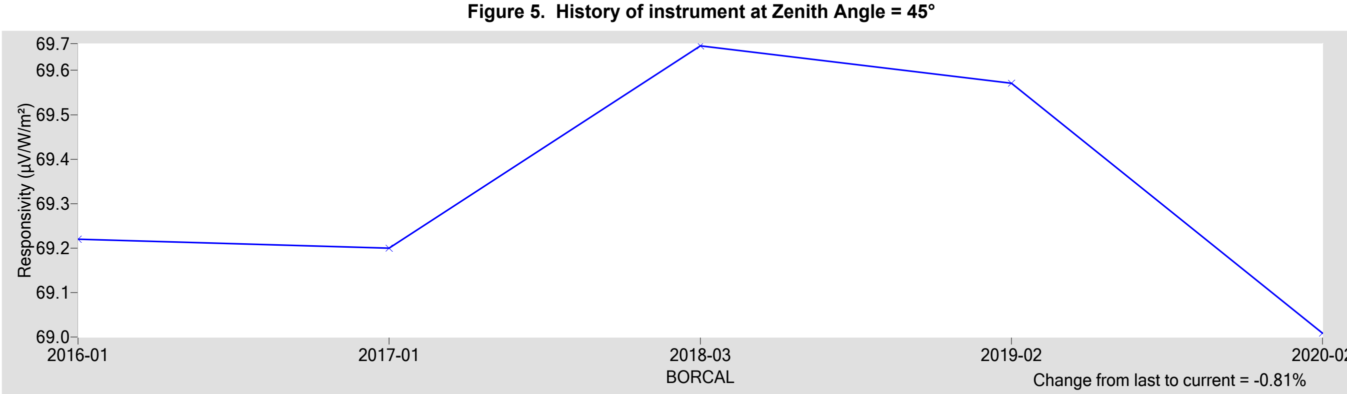
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
69.009	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.74
Offset Uncertainty, U(off) (%)	+1.8 / -1.3
Expanded Uncertainty, U (%)	+2.6 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument: Pyranometer

Manufacturer: Kipp & Zonen

Model: CMP22

Serial Number: 160430

Calibration Date: 5/5/2020

Due Date: 5/5/2021

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/4-5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

160430 Kipp & Zonen CMP22

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

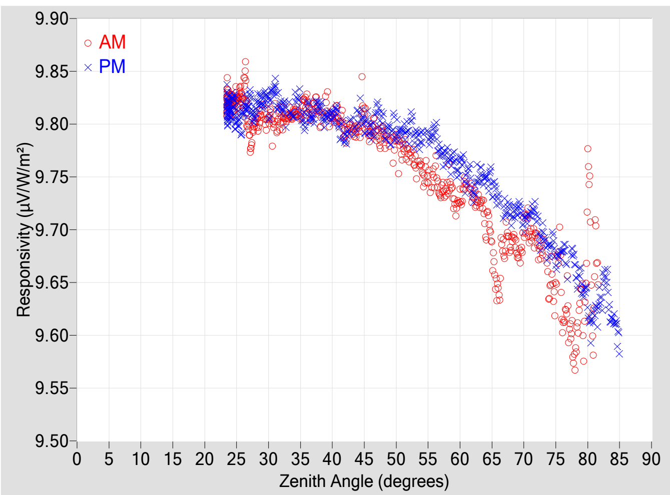


Figure 2. Responsivity vs Local Standard Time

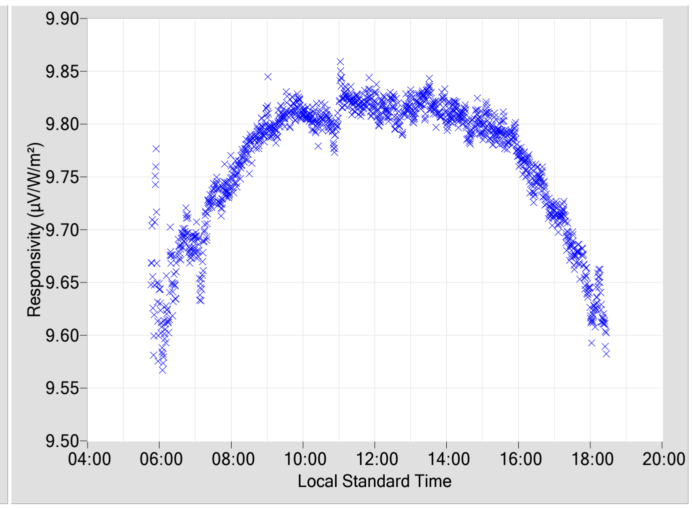


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.7905	0.32	106.77	9.7931	0.31	252.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7900	0.33	104.56	9.7994	0.31	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7841	0.36	102.42	9.7911	0.32	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7707	0.34	100.41	9.7924	0.32	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7560	0.36	98.46	9.7874	0.36	261.23
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7555	0.37	96.59	9.7957	0.35	263.11
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7369	0.34	94.85	9.7691	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7280	0.34	93.06	9.7625	0.35	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7327	0.35	91.36	9.7328	0.36	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7041	0.39	89.68	9.7493	0.37	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.6396	0.41	88.04	9.7283	0.38	271.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.6849	0.40	86.43	9.7132	0.40	273.37
24	9.8191	0.30	166.91	9.8157	0.32	193.10	70	9.6984	0.42	84.78	9.7061	0.43	274.99
26	9.8282	0.30	150.93	9.8076	0.32	209.14	72	9.6895	0.45	83.19	9.7109	0.46	276.60
28	9.8013	0.35	140.83	9.8149	0.32	218.09	74	9.6449	0.54	81.61	9.6811	0.50	278.21
30	9.8085	0.32	134.32	9.8174	0.31	224.63	76	9.6268	0.55	80.00	9.6805	0.56	279.80
32	9.8037	0.31	129.23	9.8158	0.33	230.08	78	9.5790	0.63	78.39	9.6657	N/A	281.41
34	9.8103	0.30	124.85	9.8131	0.32	234.51	80	9.7189	N/A	76.79	9.6272	N/A	283.05
36	9.8183	0.31	121.02	9.8120	0.33	238.42	82	N/A	N/A	N/A	9.6336	N/A	284.70
38	9.8056	0.32	117.58	9.8174	0.34	241.91	84	N/A	N/A	N/A	9.6153	N/A	286.35
40	9.8083	0.31	114.59	9.8063	0.33	244.94	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7903	0.32	111.76	9.7860	0.32	247.75	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7947	0.31	109.22	9.8061	0.32	250.35	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

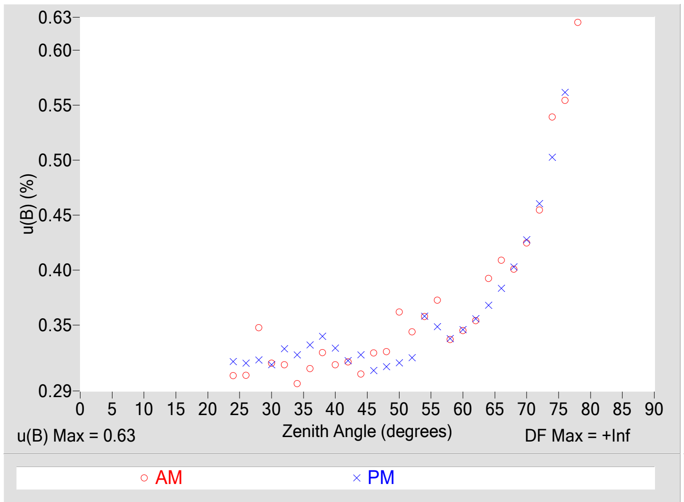


Figure 4. Residuals from Spline Interpolation

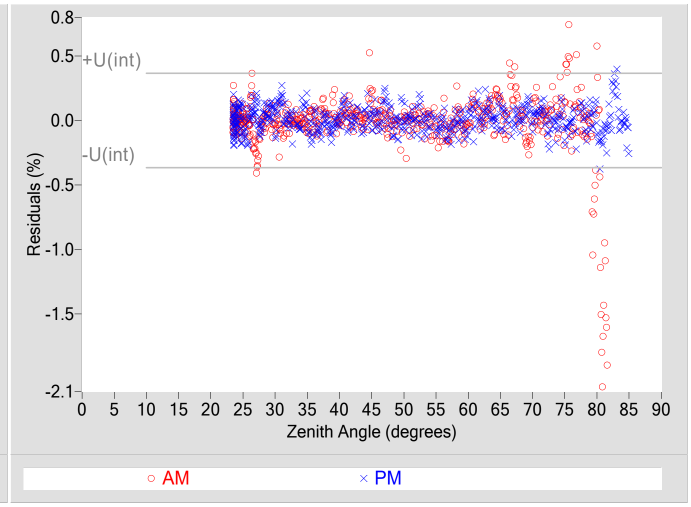


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	183648
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

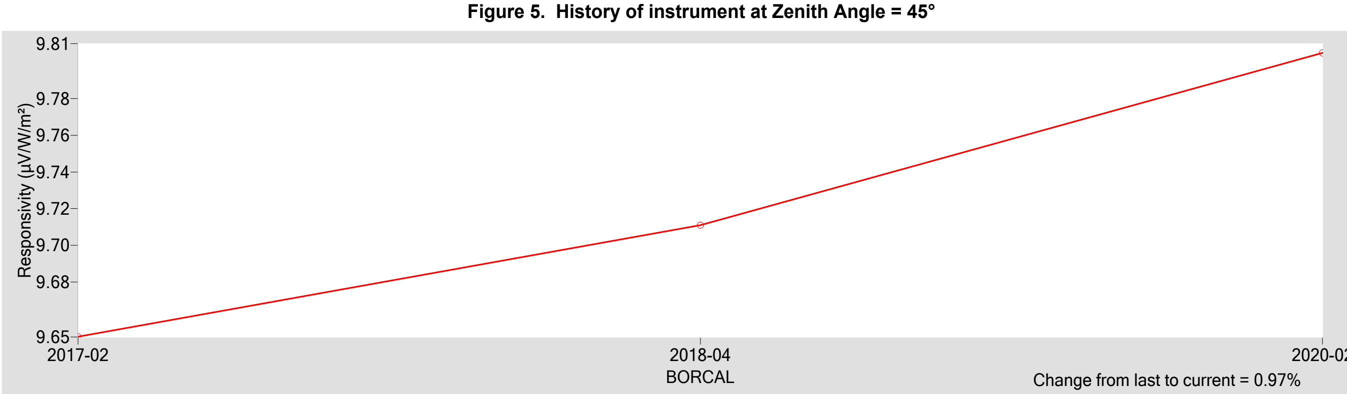
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.8050	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+0.14 / -0.79
Expanded Uncertainty, U (%)	+0.87 / -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:	Silicon Pyranometer	**Manufacturer:**	Kipp & Zonen
Model:	SP-LITE2	**Serial Number:**	194362
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

194362 Kipp & Zonen SP-LITE2

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

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

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

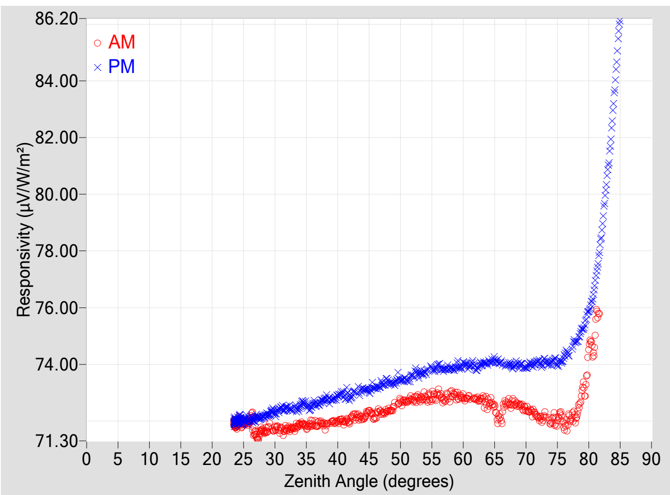


Figure 2. Responsivity vs Local Standard Time

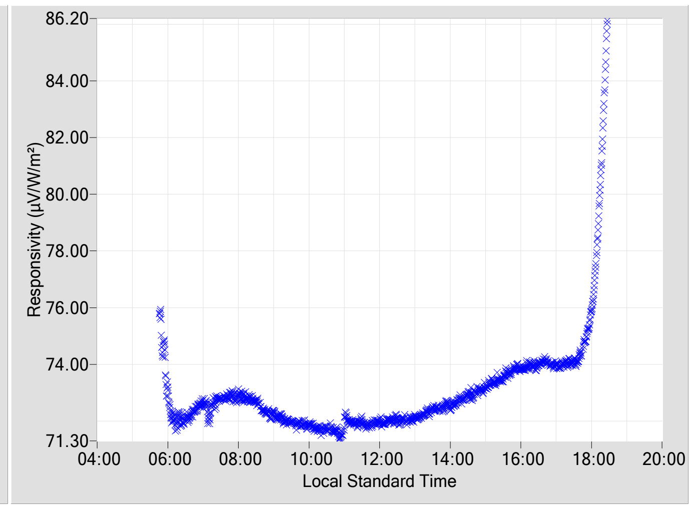


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	72.165	0.31	106.77	73.182	0.32	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	72.364	0.31	104.55	73.400	0.32	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	72.678	0.33	102.41	73.455	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	72.745	0.35	100.38	73.628	0.32	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	72.849	0.34	98.45	73.733	0.32	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	72.969	0.36	96.58	73.973	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	72.902	0.38	94.75	73.852	0.33	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	72.820	0.34	93.05	73.995	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	72.792	0.35	91.35	73.859	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	72.595	0.36	89.68	74.067	0.36	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	72.118	0.40	88.03	74.047	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	72.653	0.39	86.42	73.904	0.40	273.36
24	71.872	0.31	167.32	72.025	0.31	193.01	70	72.441	0.42	84.82	73.887	0.42	274.99
26	72.022	0.32	151.05	72.006	0.31	209.06	72	72.114	0.45	83.18	74.091	0.45	276.60
28	71.674	0.33	140.91	72.142	0.31	218.07	74	71.968	0.49	81.61	74.062	0.49	278.20
30	71.720	0.31	134.42	72.274	0.29	224.61	76	71.868	0.54	79.99	74.245	0.55	279.83
32	71.723	0.30	129.21	72.477	0.32	230.02	78	72.156	0.61	78.39	74.804	N/A	281.44
34	71.895	0.31	124.83	72.540	0.32	234.61	80	74.459	N/A	76.74	75.930	N/A	283.09
36	71.908	0.31	121.06	72.588	0.31	238.40	82	N/A	N/A	N/A	78.677	N/A	284.73
38	71.844	0.31	117.65	72.793	0.31	241.82	84	N/A	N/A	N/A	83.342	N/A	286.39
40	71.987	0.31	114.46	72.884	0.33	244.99	86	N/A	N/A	N/A	N/A	N/A	N/A
42	72.013	0.31	111.82	72.820	0.33	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	72.095	0.30	109.15	73.113	0.36	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

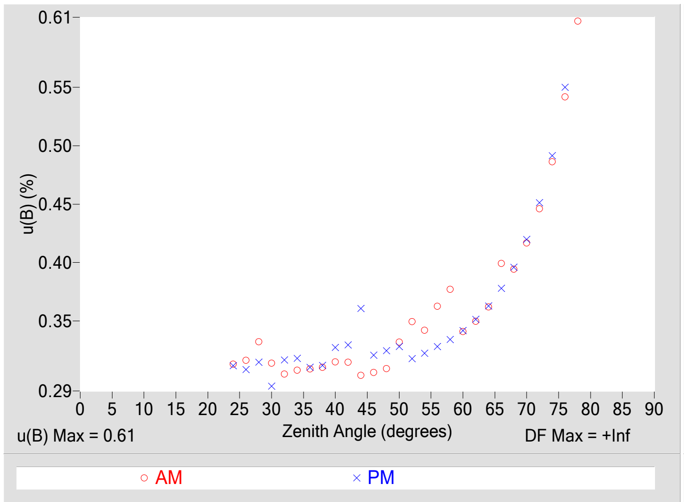


Figure 4. Residuals from Spline Interpolation

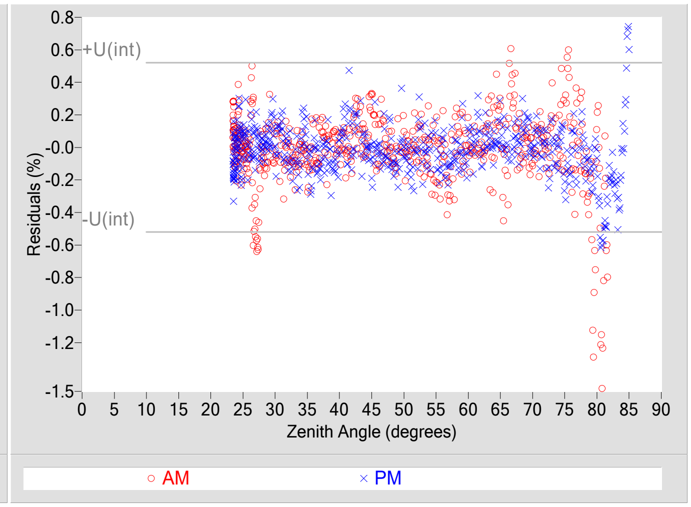


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	47457
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

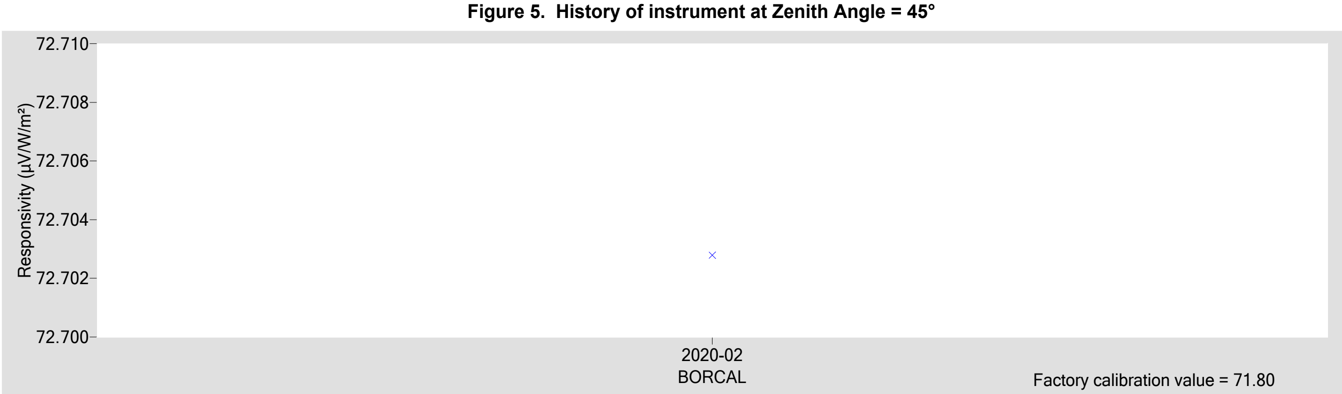
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
72.703	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.74
Offset Uncertainty, U(off) (%)	+1.8 / -1.4
Expanded Uncertainty, U (%)	+2.5 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Black and White Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	21096
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

21096 Eppley 8-48

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

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

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pyrgeometer (W/m²),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  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

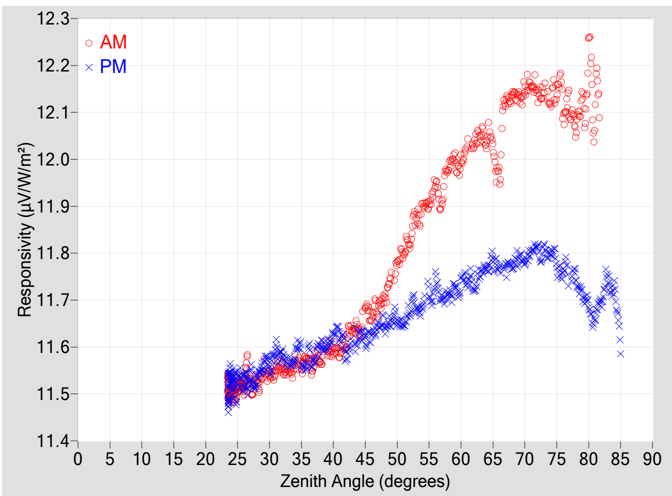


Figure 2. Responsivity vs Local Standard Time

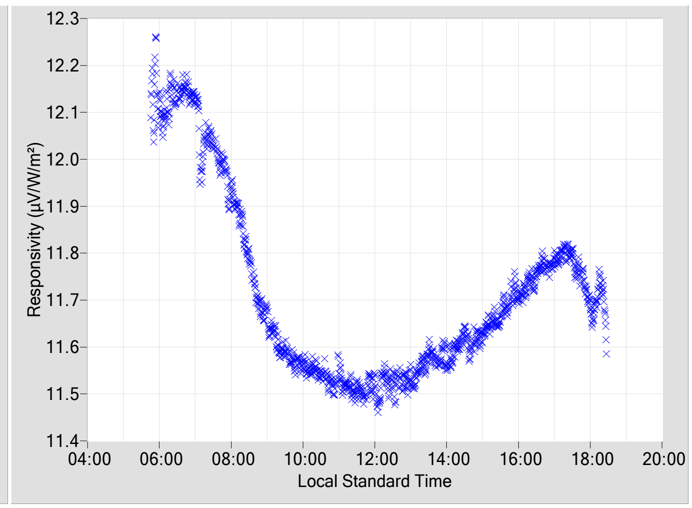


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	11.663	0.31	106.75	11.623	0.31	252.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.705	0.33	104.53	11.649	0.33	255.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.776	0.33	102.45	11.656	0.33	257.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.819	0.36	100.42	11.678	0.35	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.898	0.32	98.48	11.692	0.32	261.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.948	0.35	96.62	11.738	0.35	263.14
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.980	0.34	94.78	11.712	0.34	264.90
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.990	0.36	93.04	11.735	0.36	266.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.034	0.35	91.34	11.725	0.35	268.38
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.042	0.36	89.67	11.767	0.37	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.974	0.40	88.02	11.767	0.38	271.71
22	N/A	N/A	N/A	N/A	N/A	N/A	68	12.134	0.40	86.41	11.772	0.40	273.39
24	11.506	0.30	167.09	11.531	0.31	192.86	70	12.147	0.42	84.81	11.781	0.42	274.97
26	11.517	0.30	151.01	11.528	0.32	209.19	72	12.140	0.45	83.22	11.812	0.46	276.59
28	11.528	0.30	140.77	11.529	0.30	218.16	74	12.123	0.53	81.60	11.800	0.50	278.19
30	11.544	0.32	134.47	11.554	0.31	224.70	76	12.112	0.55	80.02	11.762	0.56	279.82
32	11.556	0.33	129.19	11.584	0.32	230.03	78	12.071	0.76	78.38	11.744	N/A	281.43
34	11.568	0.33	124.80	11.581	0.32	234.59	80	12.218	N/A	76.73	11.687	N/A	283.08
36	11.574	0.32	120.95	11.587	0.31	238.50	82	N/A	N/A	N/A	11.698	N/A	284.72
38	11.565	0.32	117.63	11.602	0.31	241.88	84	N/A	N/A	N/A	11.721	N/A	286.38
40	11.594	0.31	114.48	11.626	0.32	244.93	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.603	0.32	111.80	11.581	0.30	247.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.631	0.30	109.14	11.623	0.31	250.43	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

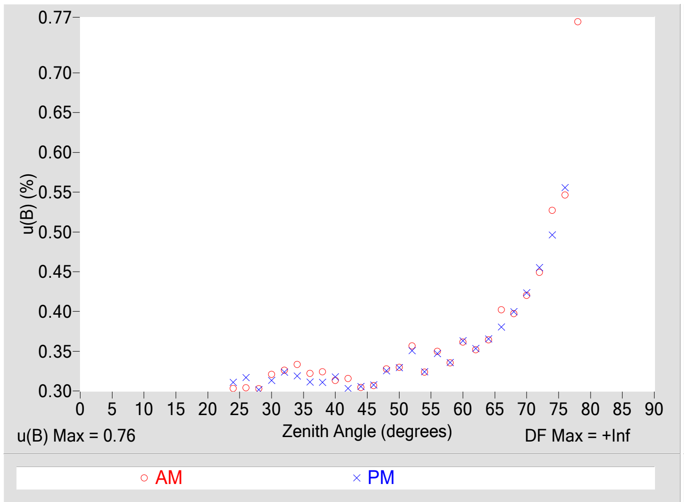


Figure 4. Residuals from Spline Interpolation

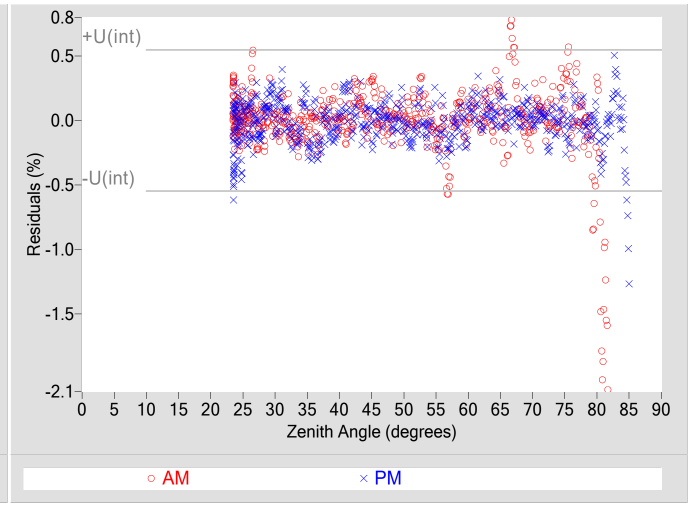


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.76
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.81
Effective degrees of freedom, DF(c)	89560
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

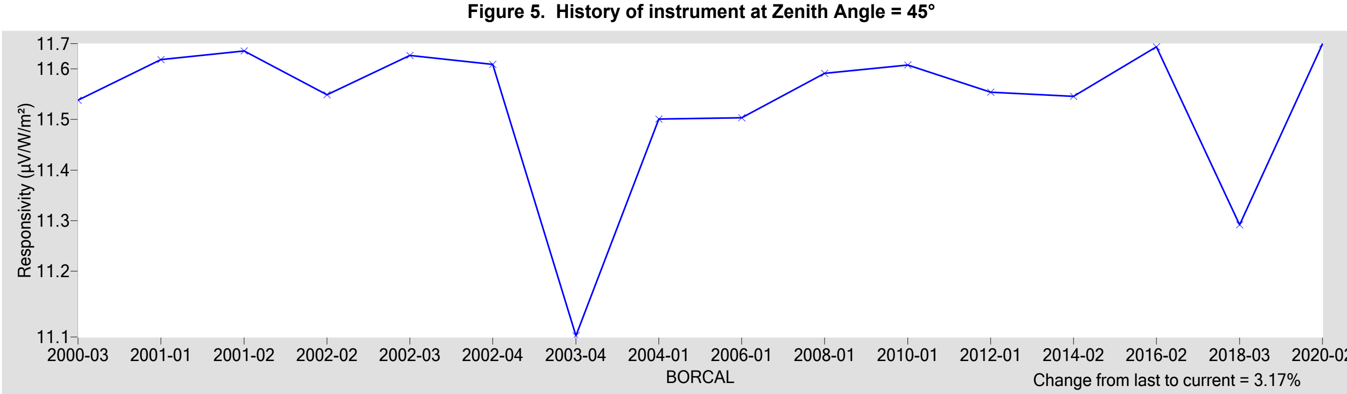
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.649	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+2.9 / -0.90
Expanded Uncertainty, U (%)	+3.6 / -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:**	Hukseflux
Model:	SR25	**Serial Number:**	2530
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

2530 Hukseflux SR25

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

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

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

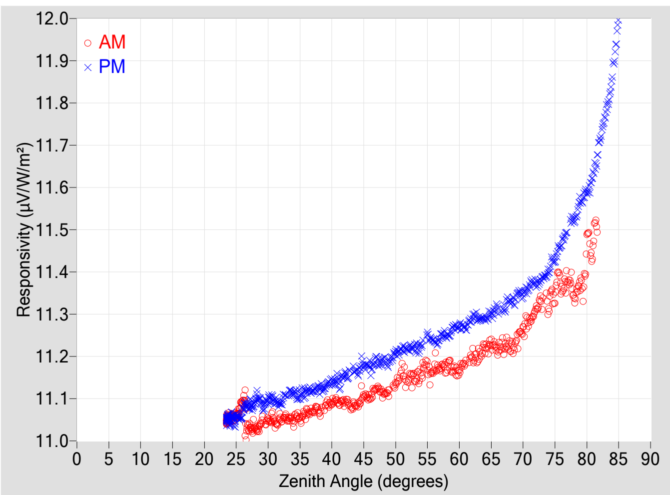


Figure 2. Responsivity vs Local Standard Time

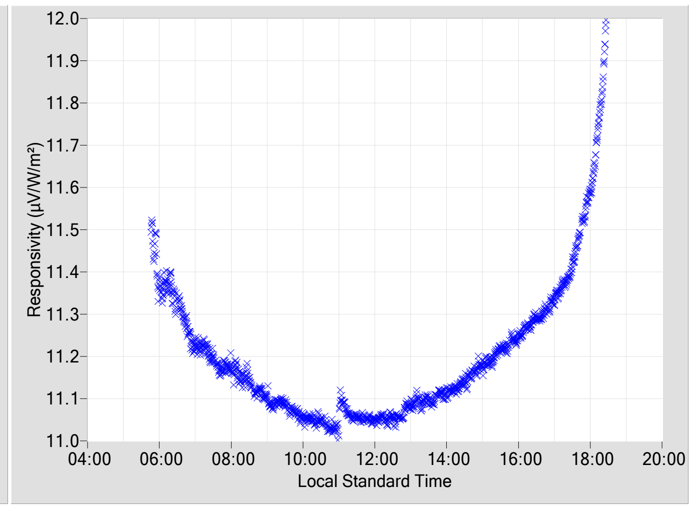


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	11.103	0.31	106.83	11.173	0.31	252.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.113	0.34	104.55	11.192	0.31	255.13
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.135	0.38	102.41	11.209	0.31	257.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.147	0.37	100.32	11.218	0.34	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.160	0.34	98.45	11.226	0.32	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.174	0.36	96.63	11.237	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.172	0.40	94.79	11.248	0.34	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.167	0.34	93.05	11.270	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.201	0.35	91.35	11.289	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.223	0.39	89.68	11.290	0.37	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.216	0.38	88.03	11.313	0.38	271.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	11.224	0.40	86.42	11.329	0.40	273.36
24	11.055	0.31	167.01	11.052	0.30	193.28	70	11.262	0.42	84.78	11.345	0.42	274.99
26	11.092	0.32	151.16	11.066	0.31	208.97	72	11.311	0.45	83.18	11.373	0.46	276.60
28	11.029	0.33	140.65	11.098	0.32	218.07	74	11.318	0.49	81.61	11.401	0.54	278.20
30	11.049	0.32	134.38	11.099	0.32	224.61	76	11.365	0.55	79.99	11.466	0.56	279.79
32	11.052	0.31	129.22	11.089	0.32	230.06	78	11.338	0.62	78.39	11.524	N/A	281.40
34	11.050	0.32	124.83	11.113	0.30	234.52	80	11.450	N/A	76.79	11.591	N/A	283.05
36	11.066	0.32	121.00	11.117	0.31	238.40	82	N/A	N/A	N/A	11.707	N/A	284.69
38	11.069	0.30	117.57	11.124	0.31	241.90	84	N/A	N/A	N/A	11.868	N/A	286.38
40	11.090	0.33	114.58	11.141	0.33	244.93	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.092	0.32	111.74	11.156	0.30	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.085	0.30	109.21	11.164	0.32	250.38	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

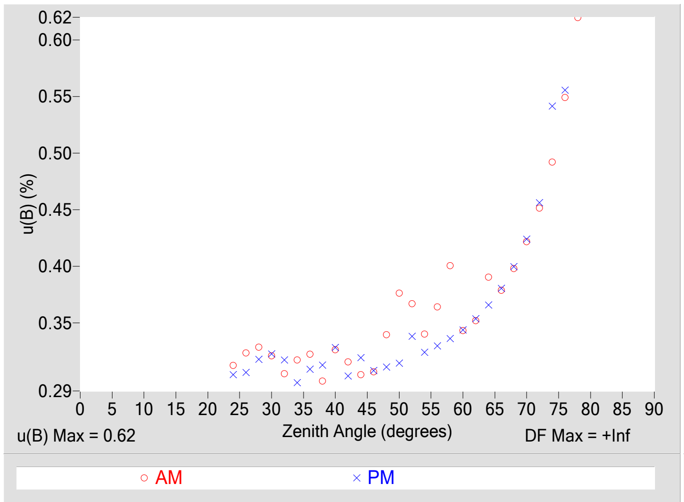


Figure 4. Residuals from Spline Interpolation

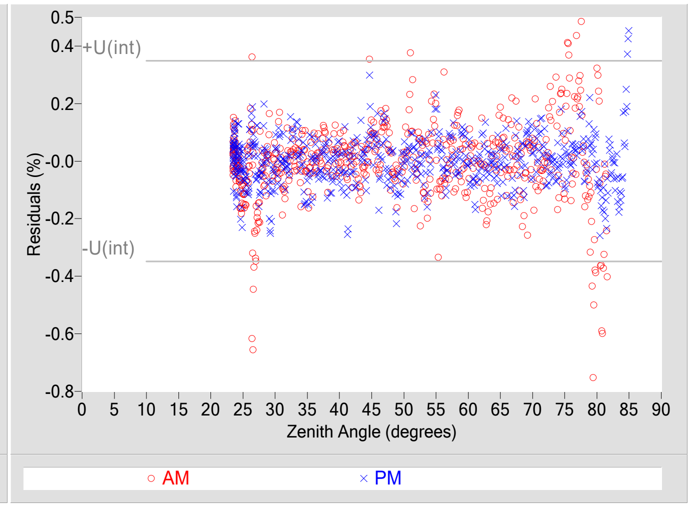


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	211310
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

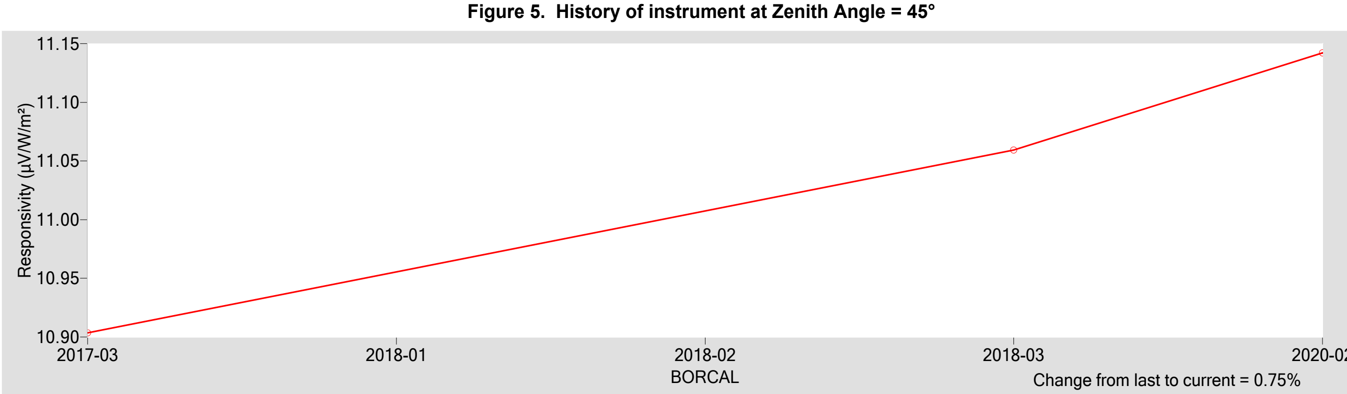
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
11.142	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+1.1 / -0.84
Expanded Uncertainty, U (%)	+1.9 / -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:**	Hukseflux
Model:	SR25	**Serial Number:**	2543
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

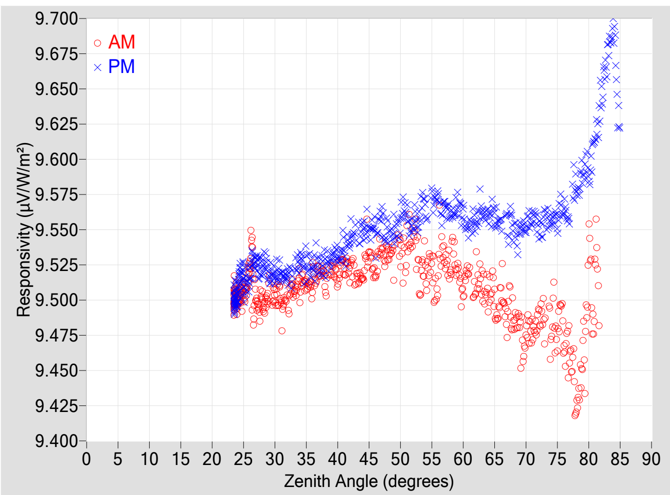


Figure 2. Responsivity vs Local Standard Time

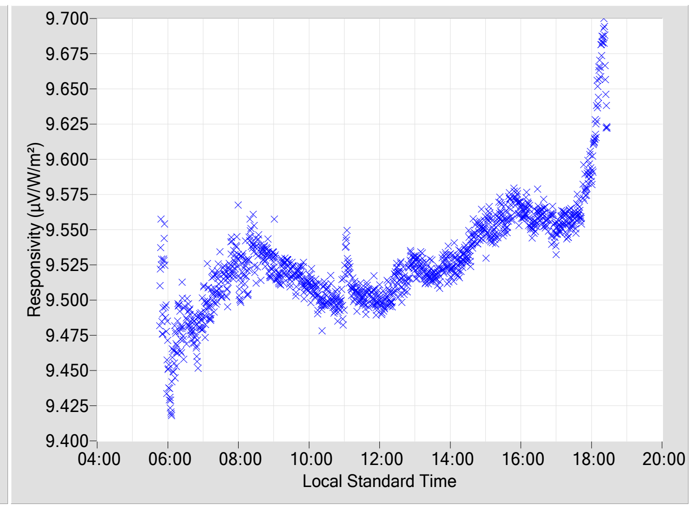


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.5200	0.31	106.83	9.5474	0.31	252.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.5336	0.34	104.55	9.5509	0.31	255.13
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.5355	0.38	102.41	9.5566	0.32	257.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.5458	0.37	100.32	9.5558	0.34	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.5216	0.34	98.45	9.5643	0.32	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.5123	0.35	96.68	9.5723	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5232	0.40	94.79	9.5600	0.34	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5075	0.34	93.05	9.5589	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.5129	0.35	91.35	9.5542	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.5066	0.39	89.68	9.5605	0.37	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.5075	0.38	88.03	9.5547	0.38	271.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.4863	0.40	86.42	9.5505	0.40	273.36
24	9.5021	0.31	167.01	9.5050	0.30	193.28	70	9.4755	0.42	84.78	9.5515	0.43	274.99
26	9.5268	0.32	151.16	9.5171	0.31	208.97	72	9.4864	0.45	83.18	9.5513	0.46	276.60
28	9.4986	0.33	140.65	9.5244	0.32	218.07	74	9.4759	0.49	81.61	9.5560	0.54	278.20
30	9.5032	0.32	134.38	9.5193	0.32	224.61	76	9.4715	0.55	79.99	9.5638	0.56	279.79
32	9.5002	0.31	129.22	9.5169	0.32	230.06	78	9.4220	0.62	78.39	9.5782	N/A	281.40
34	9.5119	0.32	124.83	9.5273	0.30	234.52	80	9.5222	N/A	76.79	9.5910	N/A	283.05
36	9.5143	0.32	121.00	9.5239	0.31	238.40	82	N/A	N/A	N/A	9.6425	N/A	284.69
38	9.5119	0.30	117.57	9.5265	0.31	241.90	84	N/A	N/A	N/A	9.6916	N/A	286.38
40	9.5165	0.33	114.58	9.5317	0.33	244.93	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5223	0.32	111.74	9.5438	0.30	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.5159	0.30	109.21	9.5510	0.32	250.38	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

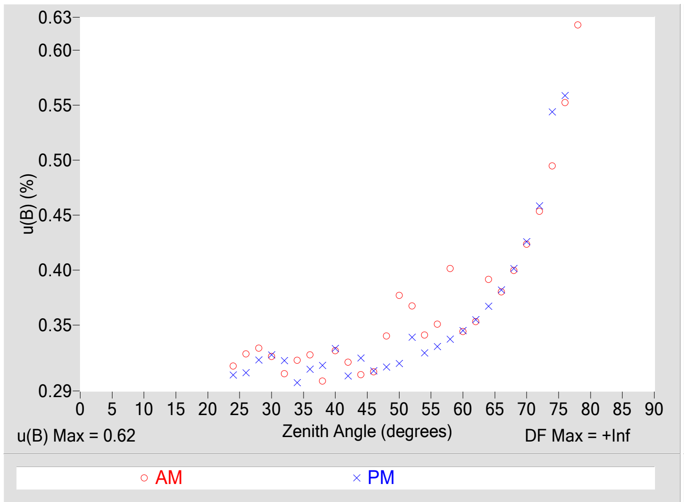


Figure 4. Residuals from Spline Interpolation

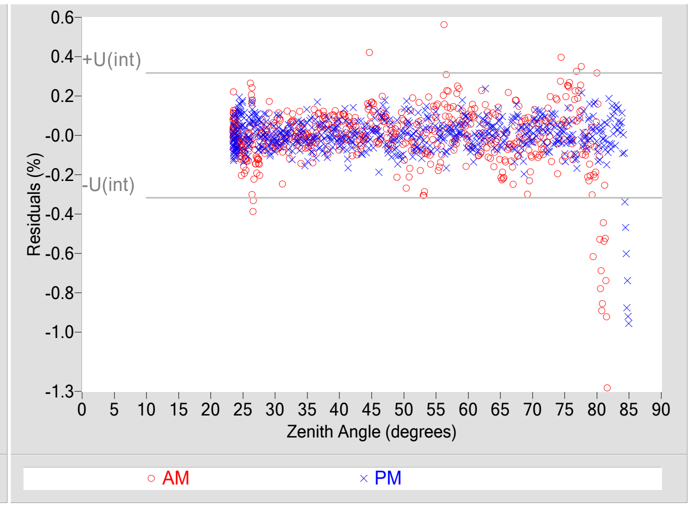


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	308525
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

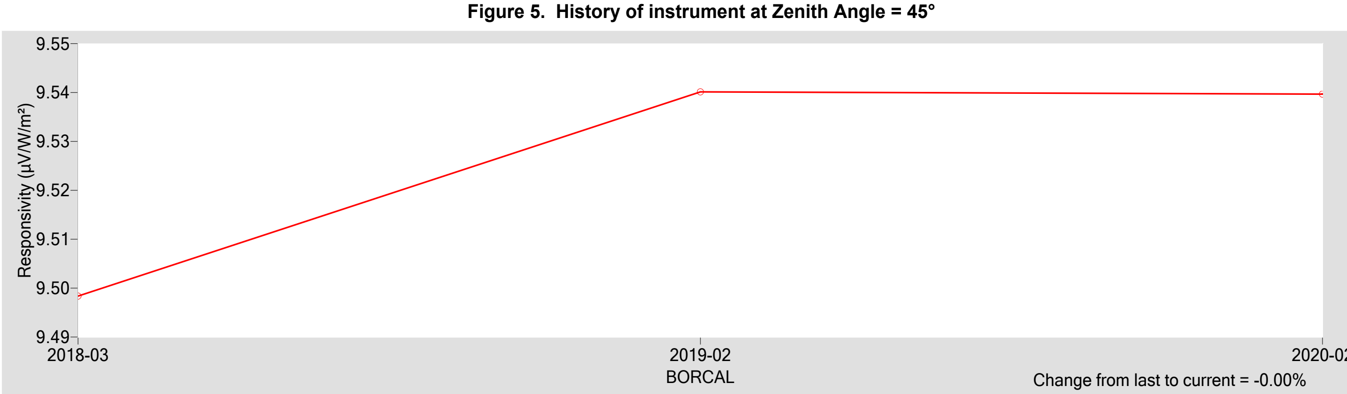
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.5397	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+0.34 / -0.41
Expanded Uncertainty, U (%)	+1.1 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	28402F3
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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 31203F3	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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

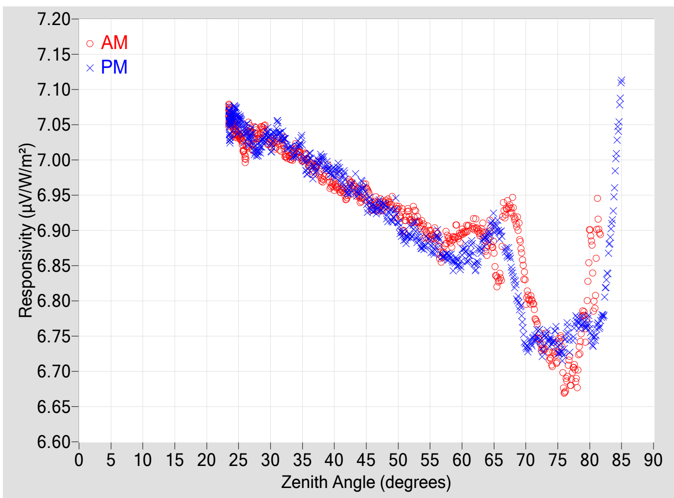


Figure 2. Responsivity vs Local Standard Time

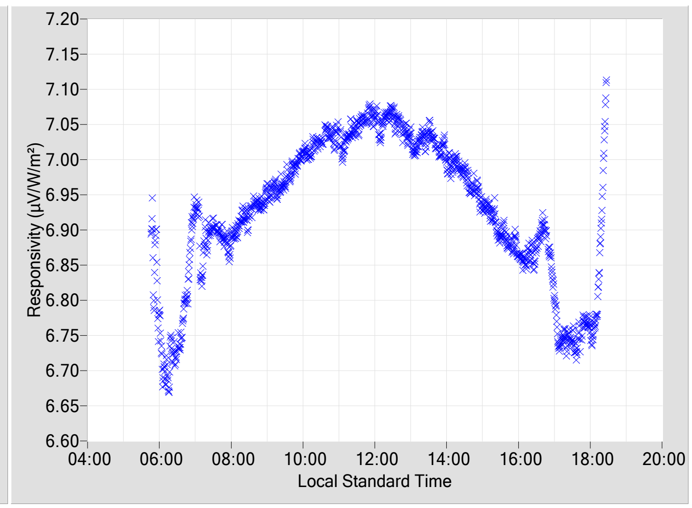


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	6.9340	0.33	106.79	6.9316	0.34	252.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.9377	0.34	104.51	6.9297	0.33	255.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.9302	0.37	102.43	6.9093	0.34	257.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.9146	0.36	100.40	6.8967	0.36	259.31
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.9013	0.35	98.42	6.8780	0.35	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.8924	0.36	96.60	6.8905	0.36	263.12
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.8880	0.38	94.82	6.8624	0.37	264.93
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.8945	0.38	93.07	6.8635	0.40	266.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9077	0.42	91.37	6.8526	0.41	268.41
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.8794	0.42	89.69	6.8932	0.41	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.8390	0.42	88.05	6.8948	0.44	271.74
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.9280	0.45	86.39	6.8331	0.46	273.38
24	7.0529	0.31	166.91	7.0609	0.32	193.13	70	6.8169	0.48	84.79	6.7351	0.50	275.00
26	7.0111	0.33	150.96	7.0407	0.34	209.09	72	6.7523	0.52	83.20	6.7529	0.54	276.57
28	7.0345	0.35	140.78	7.0122	0.31	217.99	74	6.7162	0.57	81.62	6.7415	0.60	278.21
30	7.0246	0.34	134.32	7.0235	0.33	224.77	76	6.6771	0.69	80.01	6.7344	0.68	279.81
32	7.0212	0.32	129.15	7.0312	0.34	230.00	78	6.6966	0.73	78.40	6.7731	N/A	281.42
34	7.0152	0.32	124.77	7.0092	0.32	234.38	80	6.8767	N/A	76.76	6.7611	N/A	283.06
36	6.9947	0.33	121.04	6.9981	0.31	238.43	82	N/A	N/A	N/A	6.7788	N/A	284.71
38	6.9745	0.32	117.60	7.0014	0.31	241.85	84	N/A	N/A	N/A	6.9887	N/A	286.40
40	6.9634	0.33	114.53	6.9814	0.33	245.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.9526	0.35	111.70	6.9552	0.35	247.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.9454	0.35	109.18	6.9600	0.32	250.41	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

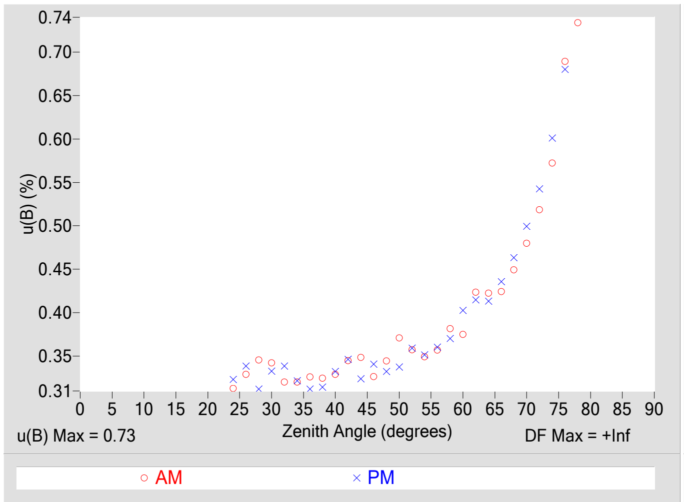


Figure 4. Residuals from Spline Interpolation

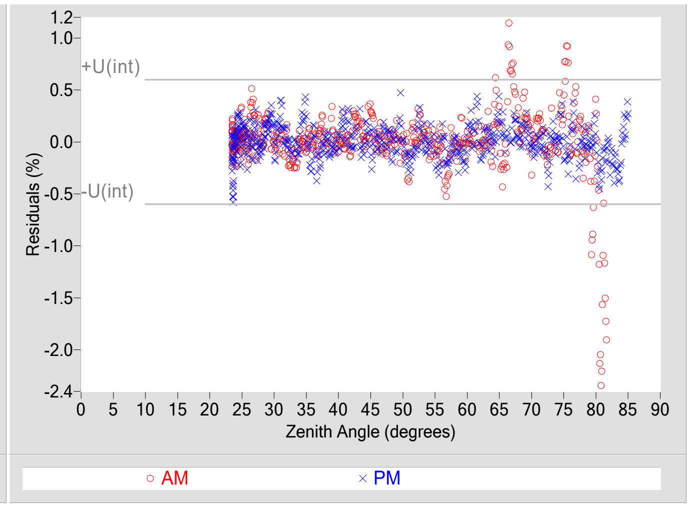


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.73
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.79
Effective degrees of freedom, DF(c)	56097
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

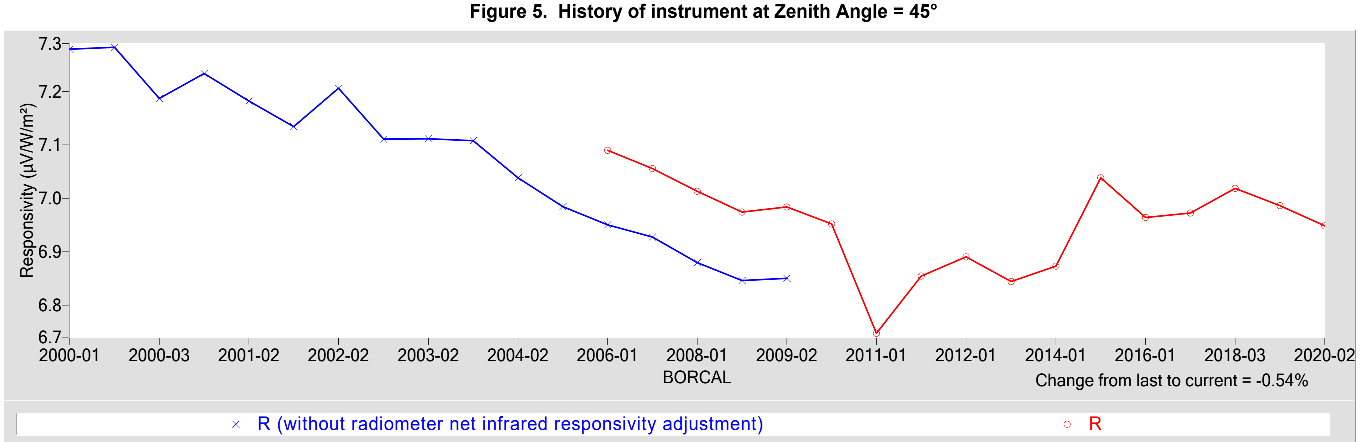
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
6.9486	0.64000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+1.2 / -1.2
Expanded Uncertainty, U (%)	+2.0 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31137E6
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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* [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

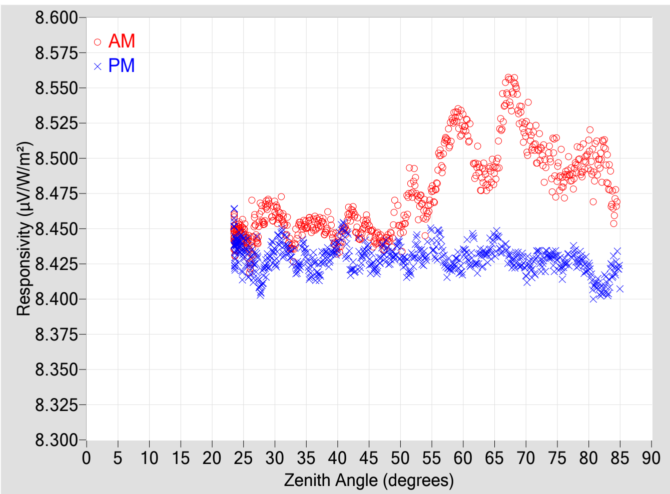


Figure 2. Responsivity vs Local Standard Time

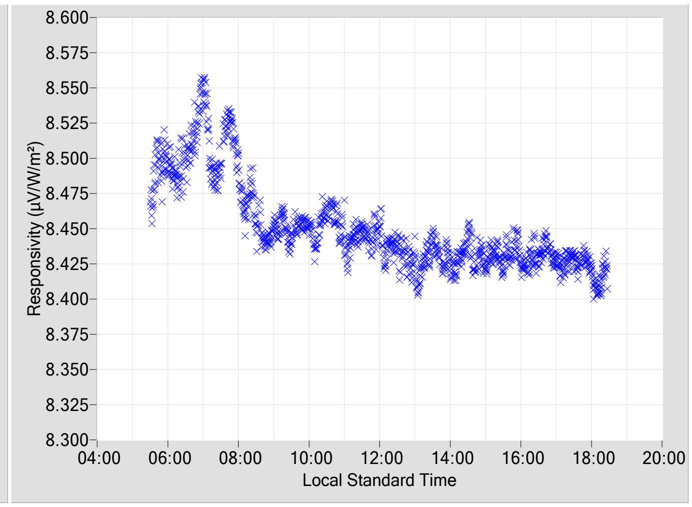


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4418	0.30	106.75	8.4209	0.29	252.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4430	0.30	104.54	8.4341	0.29	255.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4473	0.33	102.42	8.4342	0.31	257.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4799	0.32	100.42	8.4294	0.30	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4594	0.30	98.49	8.4320	0.29	261.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4924	0.29	96.62	8.4434	0.30	263.14
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5182	0.33	94.78	8.4228	0.29	264.90
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5227	0.30	93.04	8.4290	0.31	266.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4947	0.30	91.34	8.4269	0.30	268.38
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4850	0.31	89.67	8.4338	0.30	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5214	0.31	88.03	8.4350	0.30	271.71
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5484	0.30	86.42	8.4260	0.30	273.39
24	8.4469	0.30	166.99	8.4383	0.30	193.03	70	8.5152	0.30	84.81	8.4199	0.30	274.98
26	8.4330	0.31	151.02	8.4265	0.31	209.20	72	8.5035	0.30	83.22	8.4317	0.31	276.59
28	8.4571	0.30	140.63	8.4142	0.31	218.17	74	8.4969	0.32	81.60	8.4305	0.31	278.19
30	8.4635	0.29	134.43	8.4289	0.30	224.70	76	8.4818	0.33	79.98	8.4226	0.31	279.82
32	8.4470	0.30	129.23	8.4368	0.30	230.04	78	8.4964	0.32	78.38	8.4285	N/A	281.43
34	8.4532	0.30	124.79	8.4259	0.30	234.54	80	8.5041	N/A	76.74	8.4216	N/A	283.08
36	8.4518	0.31	120.85	8.4258	0.31	238.50	82	8.4983	N/A	75.12	8.4053	N/A	284.72
38	8.4482	0.31	117.64	8.4308	0.29	241.89	84	8.4672	N/A	73.41	8.4202	N/A	286.38
40	8.4373	0.30	114.49	8.4384	0.31	244.98	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4605	0.29	111.80	8.4239	0.29	247.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4498	0.30	109.14	8.4315	0.31	250.43	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

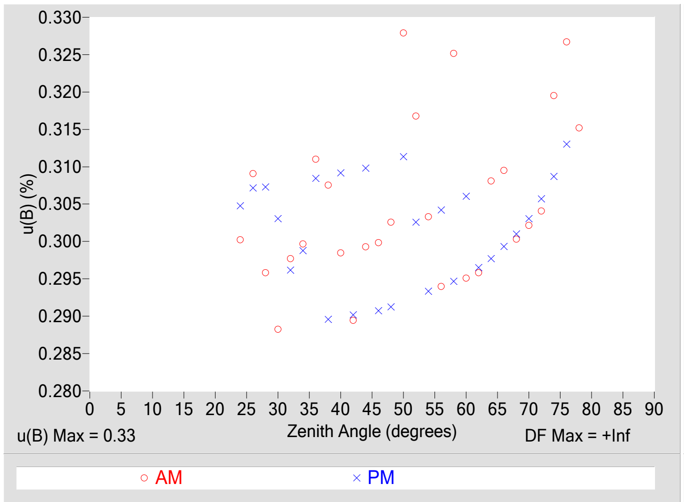


Figure 4. Residuals from Spline Interpolation

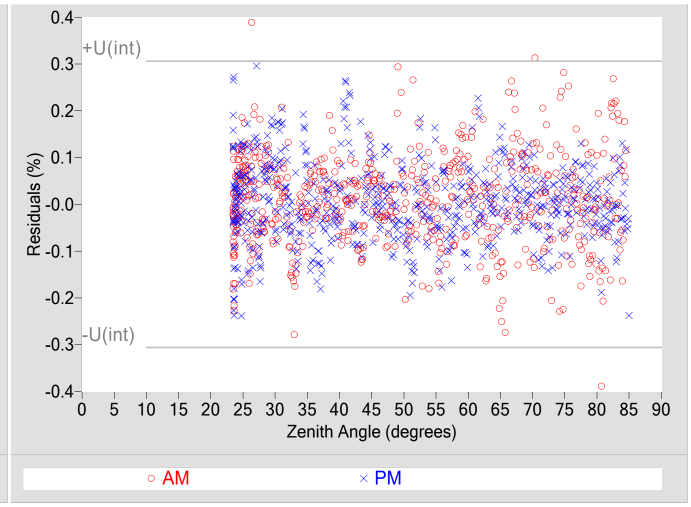


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	35774
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.71
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

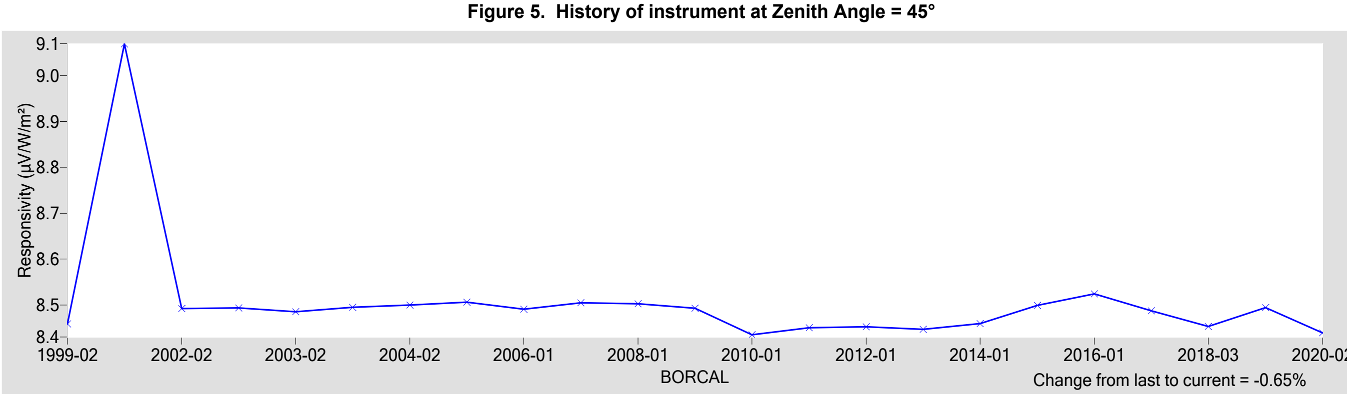
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4394	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.99 / -0.22
Expanded Uncertainty, U (%)	+1.6 / -0.86
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Black and White Pyranometer	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	34722
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

34722 Eppley 8-48

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

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

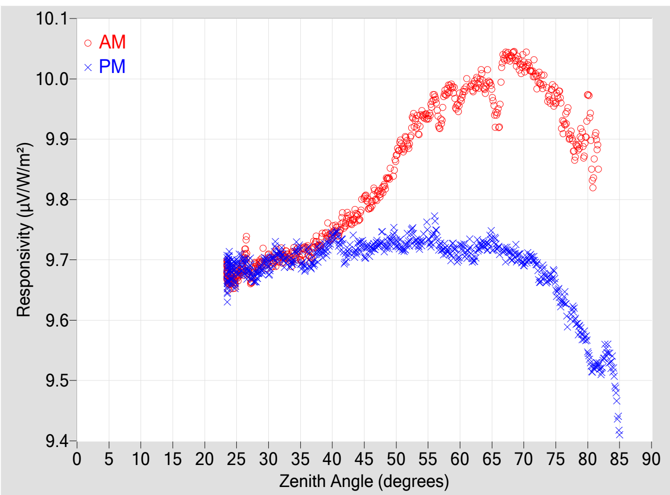


Figure 2. Responsivity vs Local Standard Time

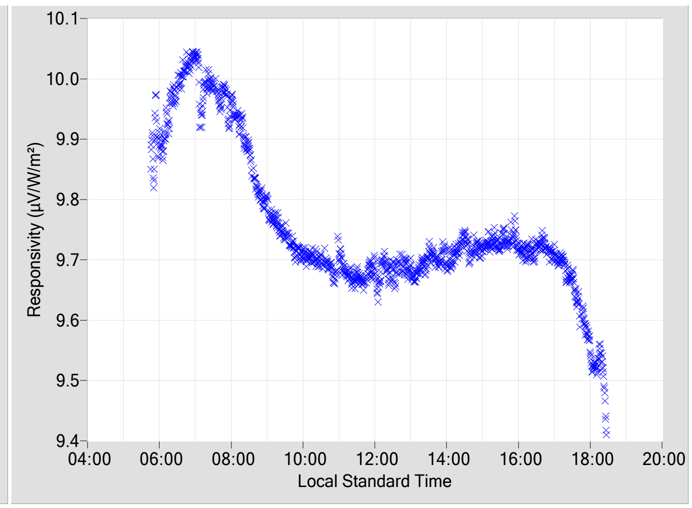


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.7898	0.31	106.75	9.7166	0.31	252.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8199	0.33	104.53	9.7300	0.33	255.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8682	0.33	102.45	9.7301	0.33	257.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8922	0.36	100.42	9.7336	0.35	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.9369	0.32	98.48	9.7318	0.32	261.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.9696	0.35	96.62	9.7536	0.35	263.14
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.9789	0.34	94.78	9.7160	0.34	264.90
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.9625	0.36	93.04	9.7160	0.36	266.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.9879	0.35	91.34	9.7011	0.35	268.38
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.9896	0.37	89.67	9.7232	0.37	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.9386	0.40	88.02	9.7175	0.38	271.71
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.036	0.40	86.41	9.7060	0.40	273.39
24	9.6687	0.30	167.09	9.6878	0.31	192.86	70	10.023	0.42	84.81	9.6945	0.42	274.97
26	9.6909	0.30	151.01	9.6907	0.32	209.19	72	9.9998	0.45	83.22	9.6913	0.46	276.59
28	9.6909	0.30	140.77	9.6708	0.30	218.16	74	9.9689	0.53	81.60	9.6706	0.50	278.19
30	9.7005	0.32	134.47	9.6861	0.31	224.70	76	9.9358	0.55	80.02	9.6307	0.56	279.82
32	9.7047	0.33	129.19	9.7097	0.32	230.03	78	9.8793	0.77	78.38	9.6041	N/A	281.43
34	9.7114	0.33	124.80	9.7037	0.32	234.59	80	9.9480	N/A	76.73	9.5516	N/A	283.08
36	9.7183	0.32	120.95	9.7060	0.31	238.50	82	N/A	N/A	N/A	9.5188	N/A	284.72
38	9.7234	0.32	117.63	9.7139	0.31	241.88	84	N/A	N/A	N/A	9.5176	N/A	286.38
40	9.7441	0.31	114.48	9.7387	0.32	244.93	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7592	0.32	111.80	9.7021	0.30	247.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7701	0.30	109.14	9.7214	0.31	250.43	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

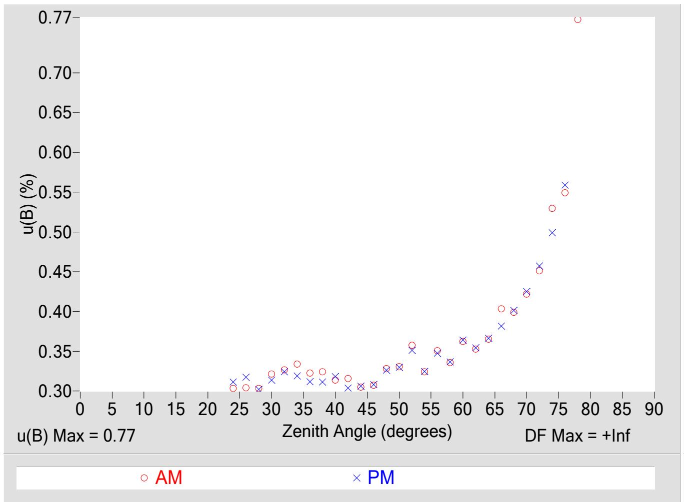


Figure 4. Residuals from Spline Interpolation

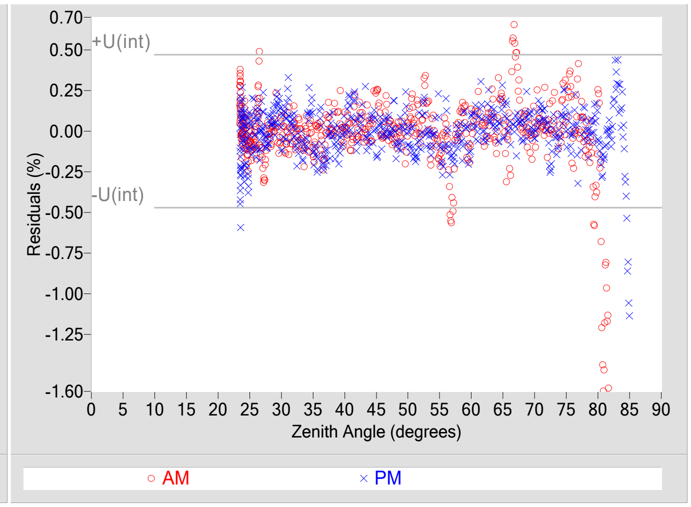


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.77
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.80
Effective degrees of freedom, DF(c)	155388
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

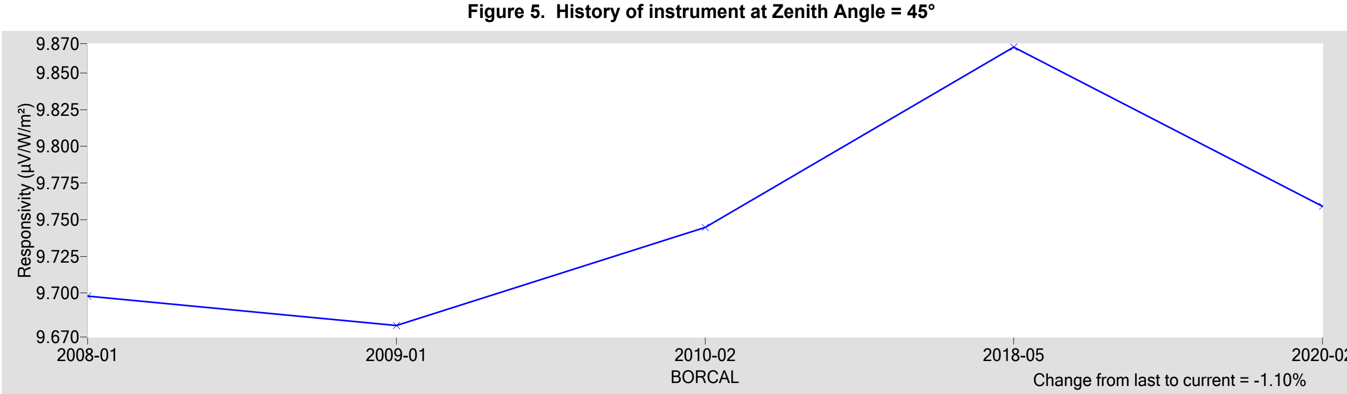
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.7590	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+2.3 / -0.75
Expanded Uncertainty, U (%)	+3.0 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

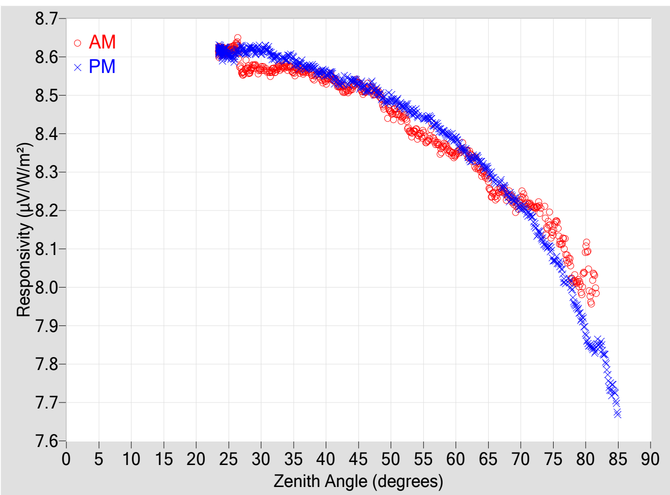


Figure 2. Responsivity vs Local Standard Time

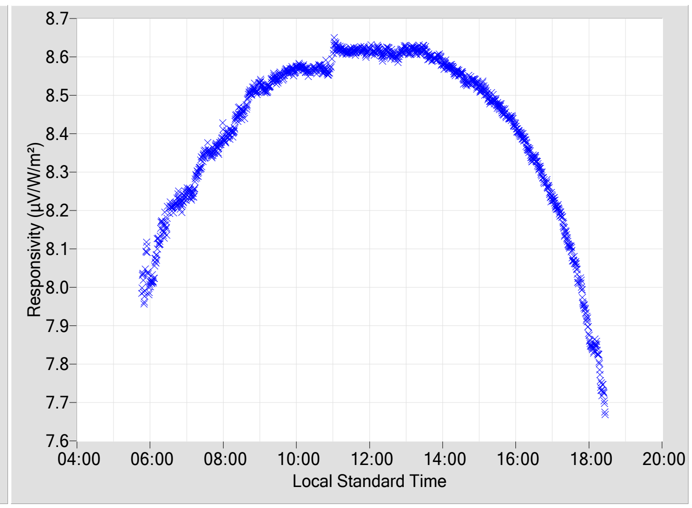


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5089	0.32	106.82	8.5162	0.31	252.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5066	0.33	104.54	8.5079	0.31	255.13
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4564	0.35	102.40	8.4888	0.33	257.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4449	0.32	100.42	8.4687	0.32	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4009	0.36	98.45	8.4508	0.34	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3974	0.33	96.63	8.4403	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3648	0.34	94.79	8.4052	0.34	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3462	0.35	93.05	8.3855	0.37	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3469	0.38	91.34	8.3356	0.36	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2989	0.40	89.67	8.3221	0.37	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2386	0.39	88.03	8.2788	0.39	271.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.2384	0.41	86.42	8.2368	0.41	273.35
24	8.6167	0.32	166.95	8.6114	0.32	193.02	70	8.2313	0.47	84.82	8.2079	0.44	274.98
26	8.6237	0.32	151.04	8.6051	0.34	209.01	72	8.2057	0.46	83.18	8.1691	0.47	276.59
28	8.5654	0.32	140.77	8.6175	0.34	218.06	74	8.1589	0.51	81.60	8.1059	0.56	278.19
30	8.5694	0.31	134.49	8.6164	0.33	224.61	76	8.1238	0.61	79.98	8.0589	0.62	279.79
32	8.5650	0.32	129.30	8.6008	0.30	230.05	78	8.0178	0.64	78.38	7.9797	N/A	281.40
34	8.5750	0.33	124.82	8.5958	0.30	234.42	80	8.0807	N/A	76.78	7.8784	N/A	283.04
36	8.5653	0.32	121.00	8.5820	0.34	238.40	82	N/A	N/A	N/A	7.8525	N/A	284.69
38	8.5476	0.30	117.58	8.5732	0.30	241.89	84	N/A	N/A	N/A	7.7369	N/A	286.43
40	8.5397	0.33	114.57	8.5549	0.33	244.99	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5234	0.32	111.74	8.5325	0.31	247.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5197	0.31	109.21	8.5385	0.31	250.38	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

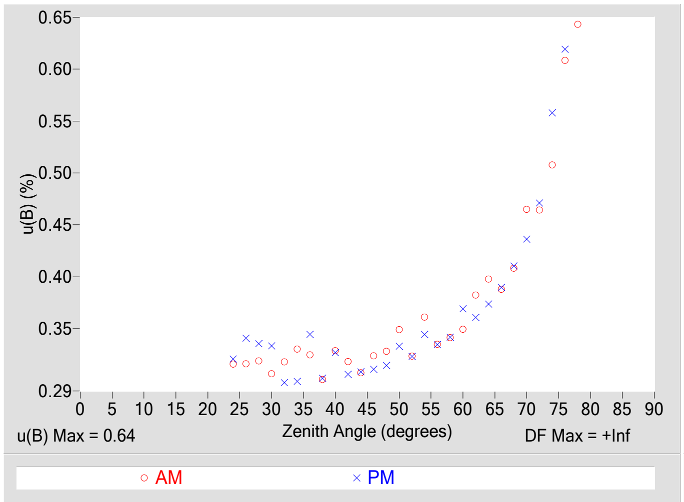


Figure 4. Residuals from Spline Interpolation

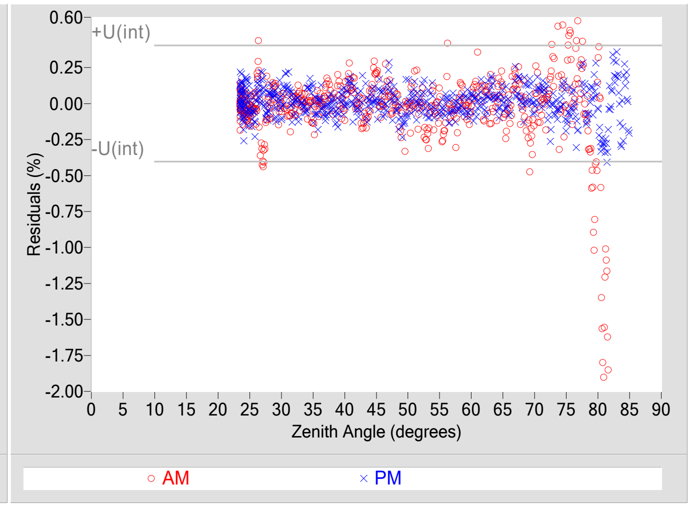


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	142055
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

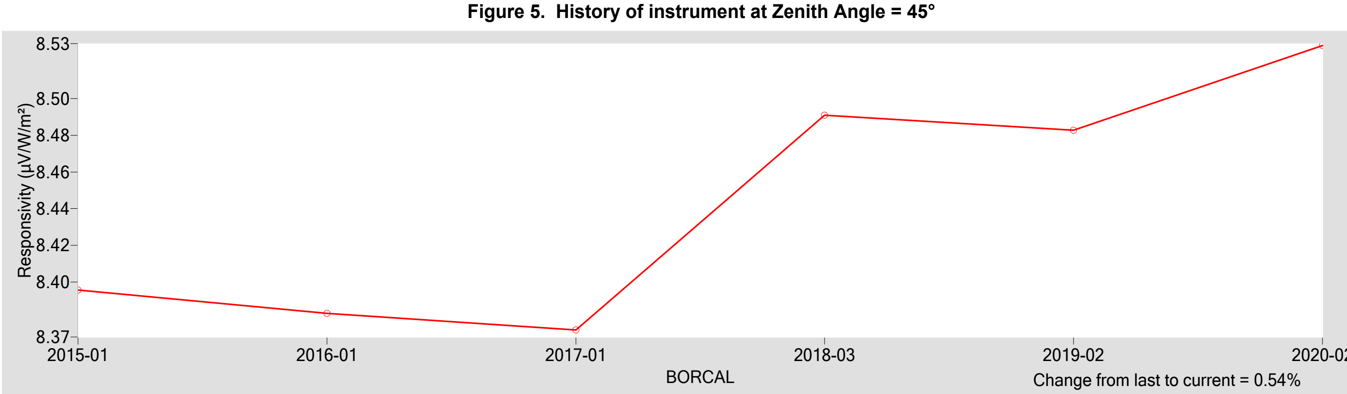
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5290	0.15000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+1.0 / -2.1
Expanded Uncertainty, U (%)	+1.7 / -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

ACCREDITED
Calibration CERT #1239.02

Test Instrument:	Standard Precision Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	SPP	**Serial Number:**	37839F3
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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 31203F3	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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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 - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

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

Figure 1. Responsivity vs Zenith Angle

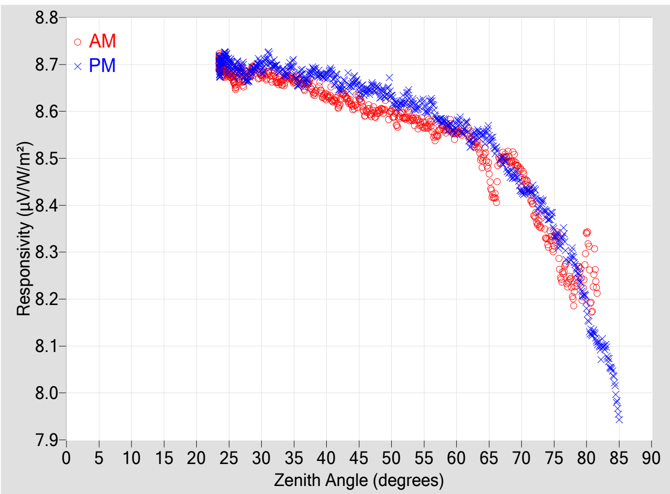


Figure 2. Responsivity vs Local Standard Time

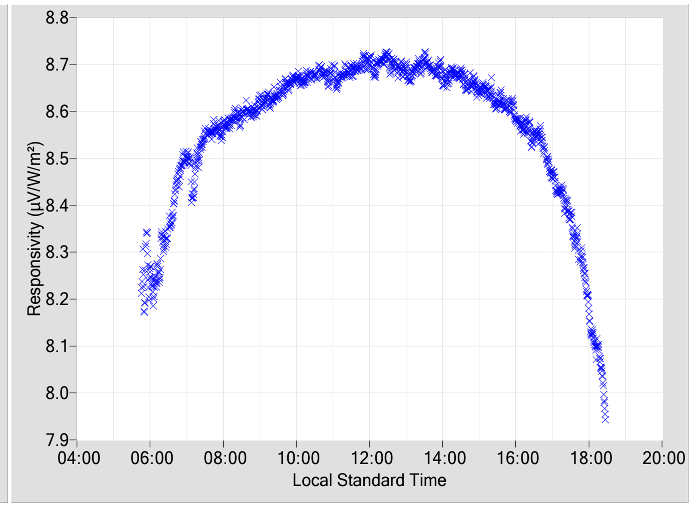


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5968	0.32	106.79	8.6418	0.33	252.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5988	0.34	104.51	8.6443	0.32	255.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5986	0.36	102.43	8.6313	0.33	257.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5857	0.35	100.40	8.6245	0.35	259.31
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5774	0.34	98.42	8.6085	0.34	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5729	0.34	96.60	8.6203	0.35	263.12
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5656	0.37	94.82	8.5794	0.35	264.93
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5531	0.36	93.07	8.5706	0.39	266.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5509	0.41	91.37	8.5362	0.40	268.41
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4972	0.41	89.69	8.5513	0.39	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4213	0.40	88.05	8.5186	0.41	271.74
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.4993	0.43	86.39	8.4682	0.44	273.38
24	8.6917	0.31	166.91	8.7083	0.32	193.13	70	8.4644	0.45	84.79	8.4282	0.47	275.00
26	8.6613	0.33	150.96	8.6902	0.33	209.09	72	8.3831	0.49	83.20	8.4287	0.50	276.57
28	8.6790	0.34	140.78	8.6706	0.31	217.99	74	8.3239	0.54	81.62	8.3748	0.56	278.21
30	8.6770	0.34	134.32	8.6911	0.33	224.77	76	8.2549	0.65	80.01	8.3226	0.63	279.81
32	8.6758	0.31	129.15	8.6982	0.33	230.00	78	8.2100	0.68	78.40	8.2882	N/A	281.42
34	8.6748	0.31	124.77	8.6818	0.32	234.38	80	8.3188	N/A	76.76	8.1808	N/A	283.06
36	8.6611	0.32	121.04	8.6763	0.31	238.43	82	N/A	N/A	N/A	8.0937	N/A	284.71
38	8.6412	0.32	117.60	8.6880	0.31	241.85	84	N/A	N/A	N/A	8.0410	N/A	286.40
40	8.6316	0.32	114.53	8.6767	0.33	245.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6180	0.34	111.70	8.6480	0.34	247.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6102	0.34	109.18	8.6618	0.32	250.41	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

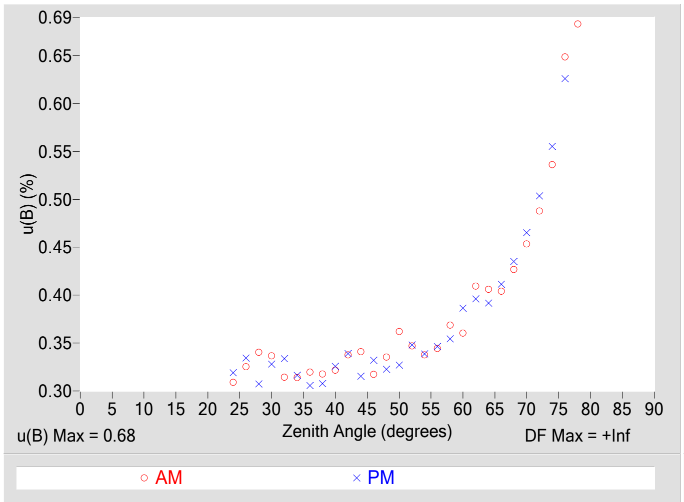


Figure 4. Residuals from Spline Interpolation

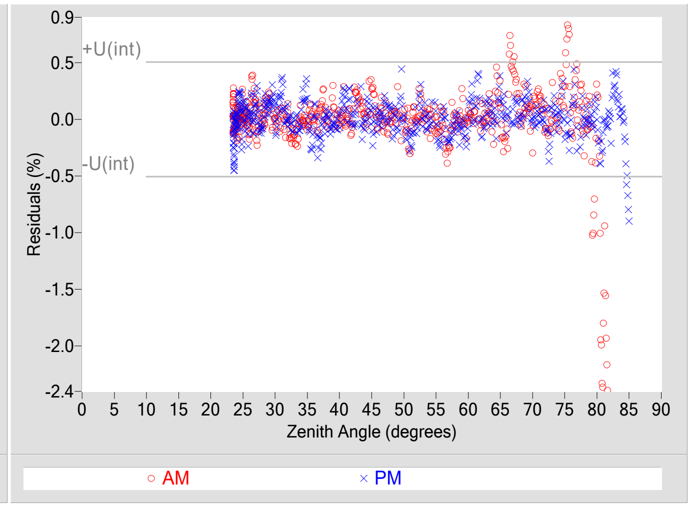


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.68
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.73
Effective degrees of freedom, DF(c)	79169
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

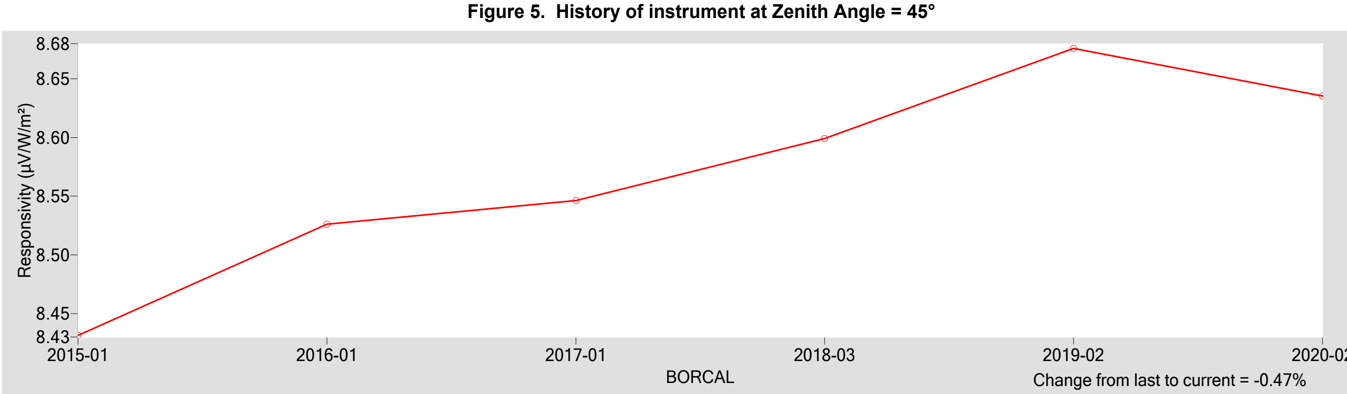
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6353	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.76
Offset Uncertainty, U(off) (%)	+0.73 / -0.95
Expanded Uncertainty, U (%)	+1.5 / -1.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Short Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37882E6
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

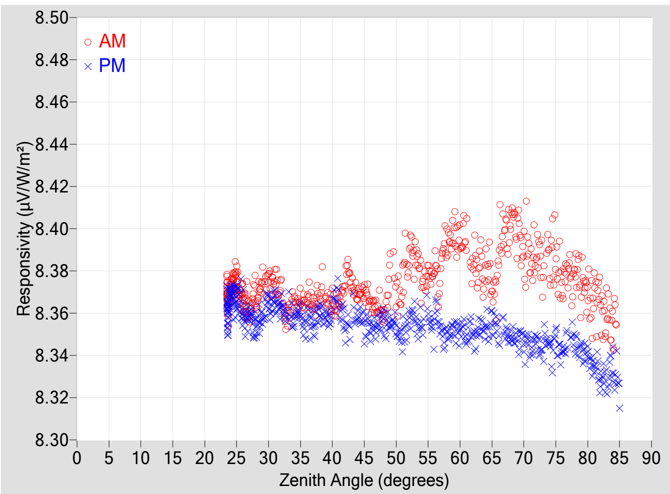


Figure 2. Responsivity vs Local Standard Time

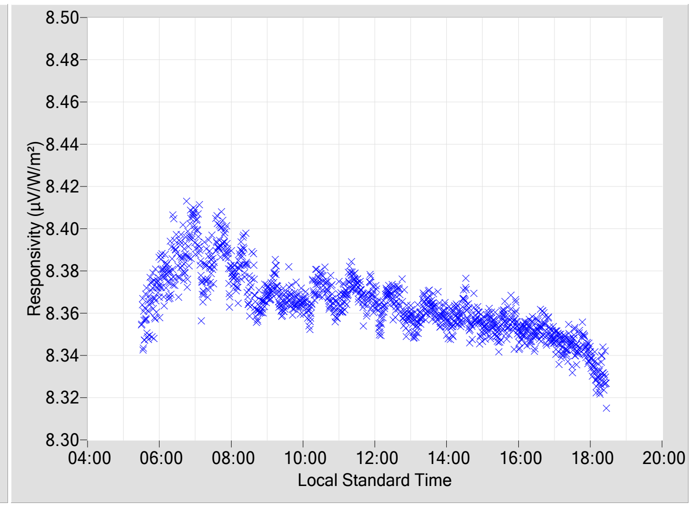


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3643	0.30	106.75	8.3521	0.29	252.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3584	0.30	104.54	8.3577	0.29	255.06
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3690	0.33	102.42	8.3530	0.31	257.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3852	0.32	100.42	8.3571	0.30	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3758	0.30	98.49	8.3553	0.29	261.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3815	0.29	96.62	8.3611	0.29	263.17
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3923	0.33	94.78	8.3506	0.29	264.90
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3932	0.30	93.04	8.3507	0.31	266.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3837	0.30	91.34	8.3501	0.30	268.38
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3796	0.31	89.67	8.3537	0.30	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3838	0.31	88.03	8.3493	0.30	271.71
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.4031	0.30	86.42	8.3493	0.30	273.39
24	8.3700	0.30	166.85	8.3671	0.30	193.03	70	8.3853	0.30	84.81	8.3451	0.30	274.98
26	8.3670	0.31	151.02	8.3592	0.31	209.20	72	8.3854	0.30	83.22	8.3467	0.31	276.59
28	8.3672	0.30	140.63	8.3543	0.31	218.17	74	8.3869	0.32	81.60	8.3455	0.31	278.19
30	8.3755	0.29	134.43	8.3636	0.30	224.70	76	8.3741	0.33	79.98	8.3410	0.31	279.82
32	8.3701	0.30	129.23	8.3633	0.30	230.04	78	8.3796	0.32	78.38	8.3461	N/A	281.43
34	8.3672	0.30	124.79	8.3564	0.30	234.54	80	8.3686	N/A	76.74	8.3399	N/A	283.08
36	8.3657	0.31	120.85	8.3574	0.31	238.50	82	8.3650	N/A	75.12	8.3278	N/A	284.72
38	8.3669	0.31	117.64	8.3600	0.29	241.89	84	8.3558	N/A	73.41	8.3313	N/A	286.38
40	8.3638	0.30	114.49	8.3642	0.31	244.98	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3748	0.29	111.80	8.3535	0.29	247.79	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3680	0.30	109.14	8.3579	0.31	250.43	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

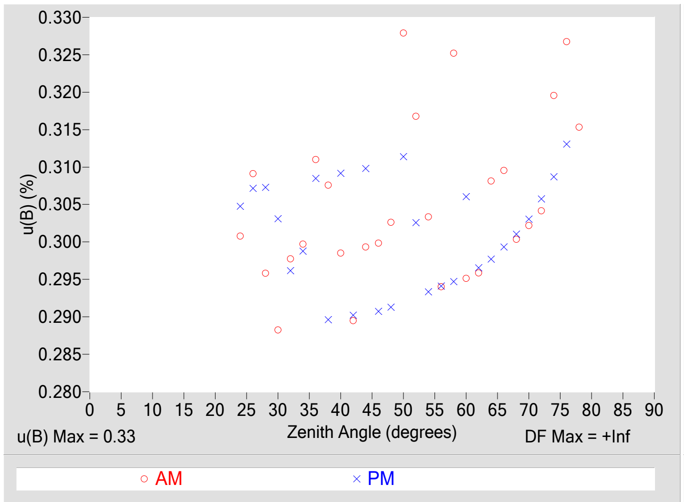


Figure 4. Residuals from Spline Interpolation

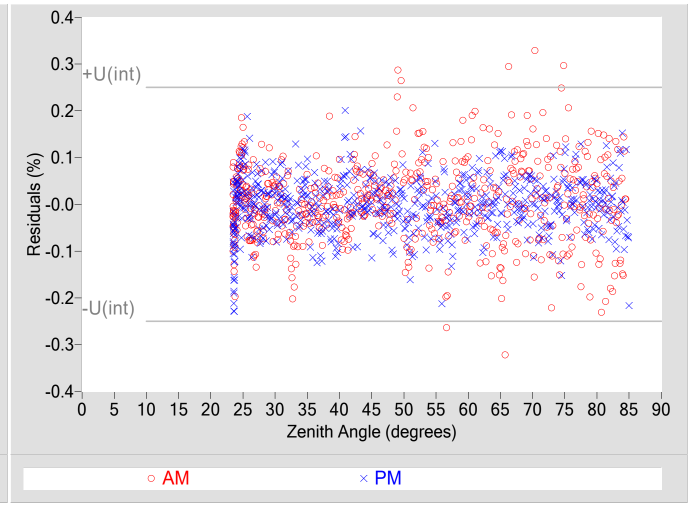


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.12
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	71018
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

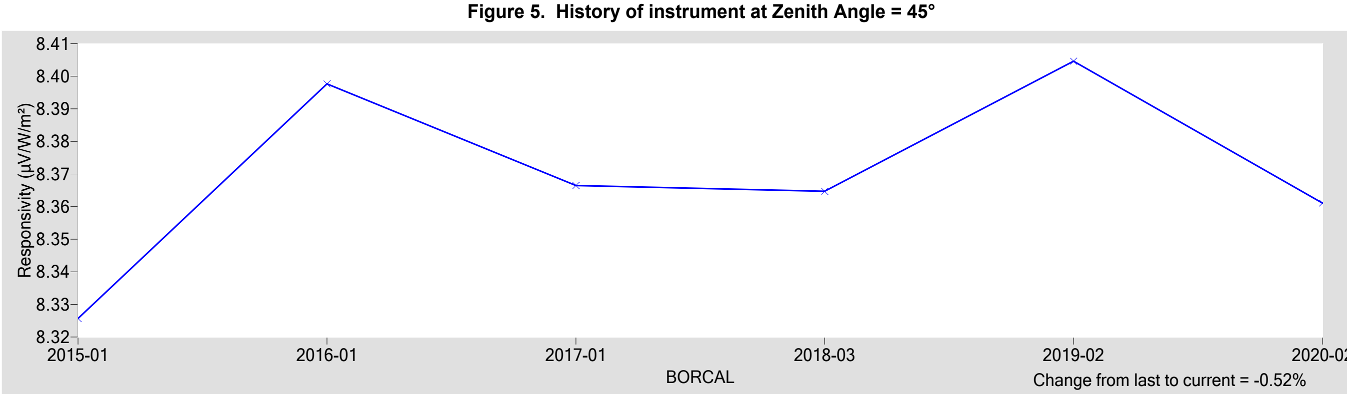
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3611	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.38 / -0.12
Expanded Uncertainty, U (%)	+1.0 / -0.77
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Standard Precision Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	SPP	**Serial Number:**	38924F3
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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 31203F3	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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

38924F3 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

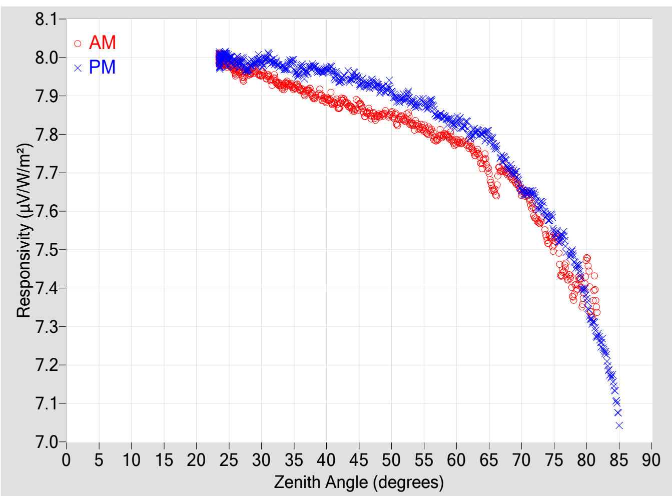


Figure 2. Responsivity vs Local Standard Time

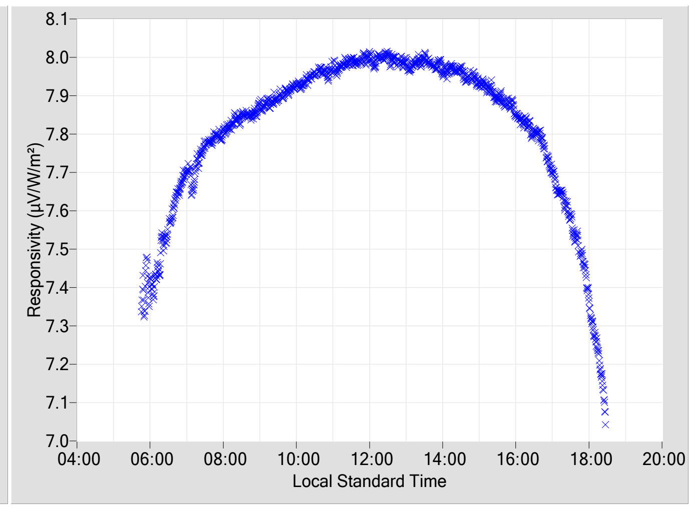


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.8527	0.31	106.79	7.9286	0.33	252.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8478	0.33	104.51	7.9229	0.32	255.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8524	0.36	102.43	7.9089	0.32	257.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8373	0.34	100.40	7.8957	0.34	259.31
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8205	0.33	98.42	7.8770	0.33	261.24
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8095	0.34	96.60	7.8858	0.34	263.12
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7973	0.36	94.82	7.8451	0.35	264.93
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7788	0.36	93.07	7.8338	0.38	266.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7728	0.40	91.37	7.7988	0.39	268.41
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7252	0.40	89.69	7.8026	0.38	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.6525	0.40	88.05	7.7661	0.40	271.74
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.6978	0.42	86.39	7.7086	0.42	273.38
24	7.9893	0.31	166.91	8.0009	0.32	193.13	70	7.6506	0.45	84.79	7.6541	0.45	275.00
26	7.9656	0.32	150.96	7.9887	0.33	209.09	72	7.5936	0.48	83.20	7.6415	0.49	276.57
28	7.9627	0.34	140.78	7.9718	0.31	217.99	74	7.5274	0.52	81.62	7.5824	0.54	278.21
30	7.9560	0.33	134.32	7.9836	0.33	224.77	76	7.4500	0.64	80.01	7.5287	0.61	279.81
32	7.9437	0.31	129.15	7.9876	0.33	230.00	78	7.3862	0.67	78.40	7.4813	N/A	281.42
34	7.9320	0.31	124.77	7.9747	0.31	234.38	80	7.4544	N/A	76.76	7.3730	N/A	283.06
36	7.9175	0.32	121.04	7.9718	0.30	238.43	82	N/A	N/A	N/A	7.2652	N/A	284.71
38	7.8974	0.32	117.60	7.9765	0.31	241.85	84	N/A	N/A	N/A	7.1576	N/A	286.40
40	7.8898	0.32	114.53	7.9691	0.32	245.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8745	0.34	111.70	7.9384	0.34	247.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8660	0.34	109.18	7.9501	0.31	250.41	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

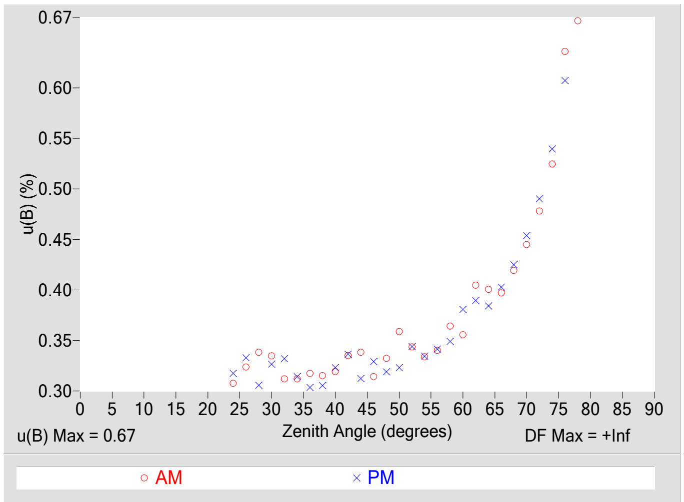


Figure 4. Residuals from Spline Interpolation

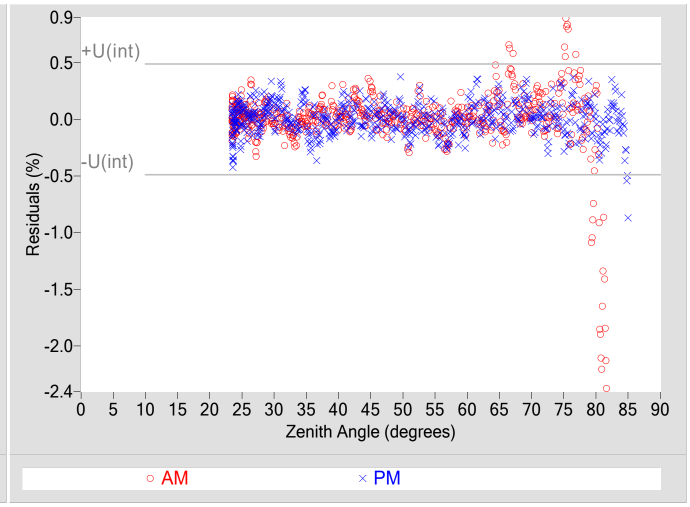


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.67
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.71
Effective degrees of freedom, DF(c)	82232
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

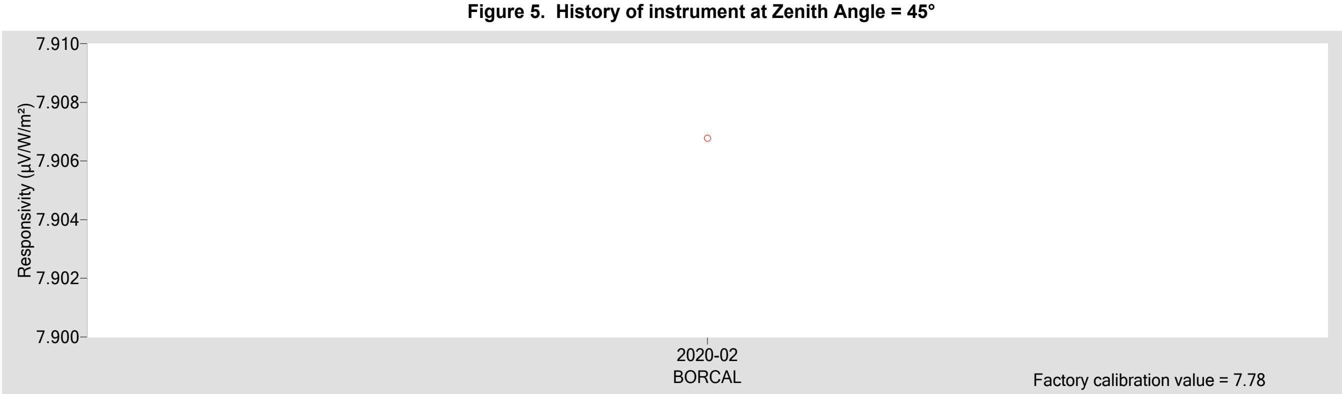
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9068	0.22000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.75
Offset Uncertainty, U(off) (%)	+1.0 / -1.6
Expanded Uncertainty, U (%)	+1.8 / -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:	Si pyranometer	**Manufacturer:**	Apogee
Model:	SP-110	**Serial Number:**	40337
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

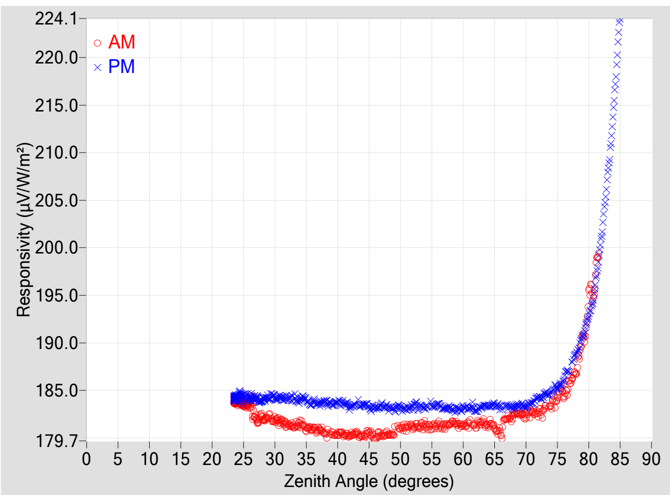


Figure 2. Responsivity vs Local Standard Time

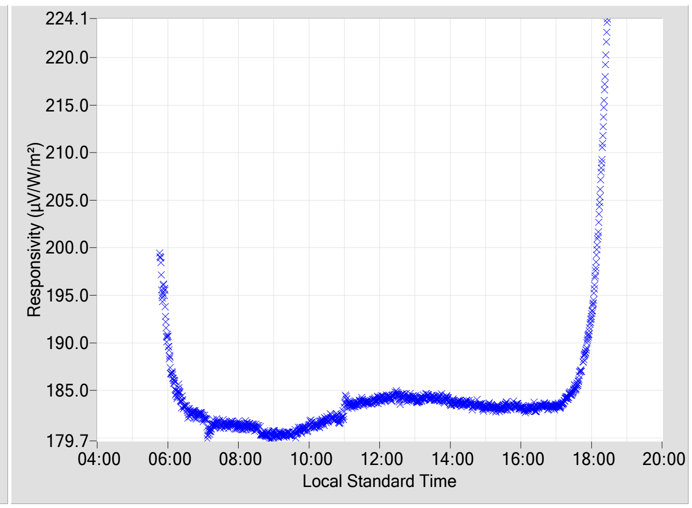


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	179.86	0.31	106.80	183.17	0.31	252.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	180.47	0.31	104.58	183.21	0.35	255.10
4	N/A	N/A	N/A	N/A	N/A	N/A	50	181.08	0.34	102.44	183.24	0.31	257.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	181.14	0.32	100.40	183.35	0.32	259.26
8	N/A	N/A	N/A	N/A	N/A	N/A	54	181.35	0.37	98.48	183.24	0.34	261.25
10	N/A	N/A	N/A	N/A	N/A	N/A	56	181.39	0.37	96.61	183.54	0.35	263.12
12	N/A	N/A	N/A	N/A	N/A	N/A	58	181.53	0.35	94.82	183.08	0.33	264.94
14	N/A	N/A	N/A	N/A	N/A	N/A	60	181.38	0.34	93.07	183.14	0.34	266.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	181.36	0.35	91.32	182.82	0.35	268.42
18	N/A	N/A	N/A	N/A	N/A	N/A	64	181.33	0.36	89.70	183.40	0.36	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	180.59	0.38	88.01	183.20	0.38	271.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	182.41	0.39	86.40	183.20	0.40	273.38
24	183.78	0.32	167.05	184.30	0.31	192.79	70	182.42	0.45	84.80	183.28	0.42	274.97
26	183.66	0.30	150.98	184.20	0.30	209.16	72	182.75	0.45	83.21	184.30	0.45	276.62
28	182.13	0.31	140.72	184.03	0.31	218.13	74	183.52	0.49	81.58	184.81	0.49	278.18
30	181.89	0.33	134.44	184.26	0.32	224.67	76	184.55	0.54	80.01	186.23	0.55	279.81
32	181.30	0.29	129.20	184.16	0.30	230.00	78	187.18	0.61	78.37	188.94	N/A	281.42
34	181.51	0.30	124.88	184.02	0.30	234.57	80	194.57	N/A	76.77	192.95	N/A	283.07
36	180.99	0.31	120.96	183.78	0.31	238.47	82	N/A	N/A	N/A	201.10	N/A	284.71
38	180.38	0.33	117.63	183.84	0.30	241.86	84	N/A	N/A	N/A	215.09	N/A	286.37
40	180.38	0.31	114.61	183.80	0.30	244.96	86	N/A	N/A	N/A	N/A	N/A	N/A
42	180.27	0.30	111.78	183.24	0.32	247.77	88	N/A	N/A	N/A	N/A	N/A	N/A
44	180.15	0.32	109.18	183.48	0.30	250.42	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

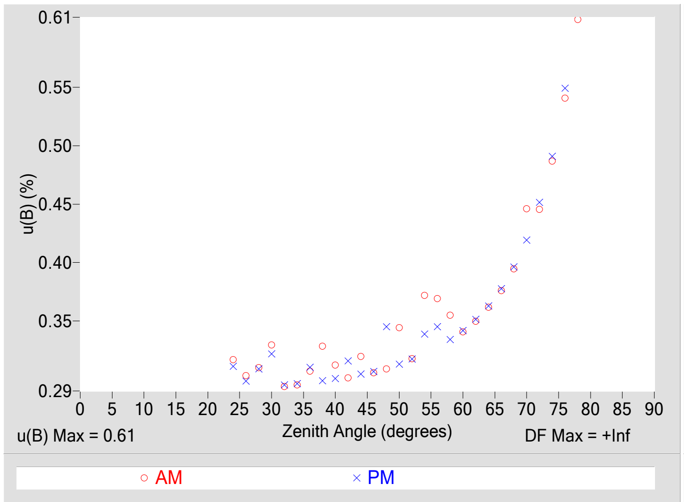


Figure 4. Residuals from Spline Interpolation

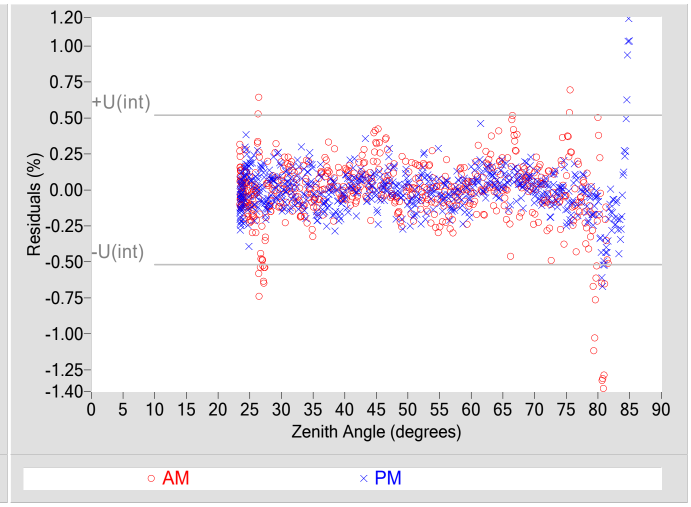


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	48351
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

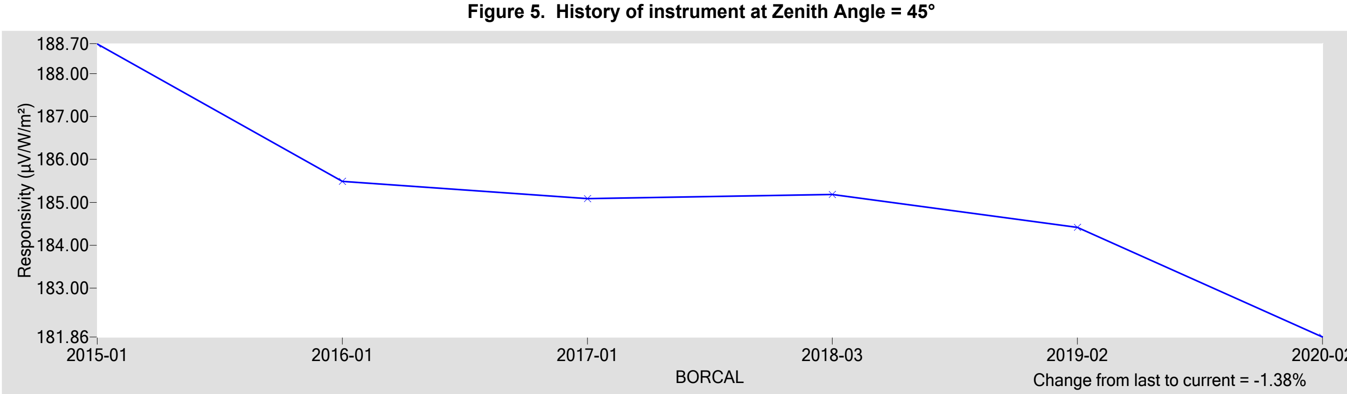
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
181.86	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+1.3 / -1.1
Expanded Uncertainty, U (%)	+2.0 / -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:	Pyrheliometer	**Manufacturer:**	Hukseflux
Model:	DR02	**Serial Number:**	9206
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

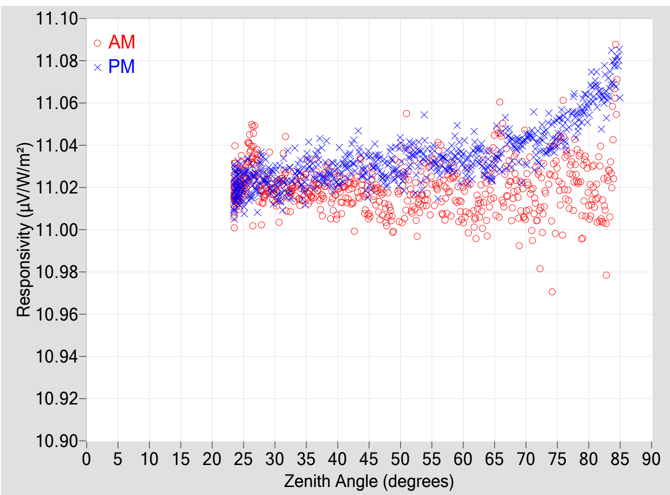


Figure 2. Responsivity vs Local Standard Time

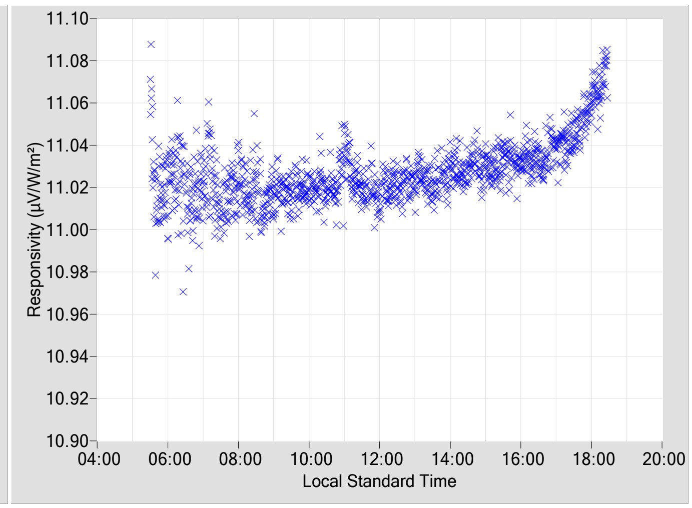


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	11.018	0.29	106.76	11.034	0.29	252.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.009	0.29	104.54	11.026	0.29	255.07
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.019	0.33	102.40	11.034	0.30	257.22
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.014	0.30	100.37	11.038	0.29	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.020	0.31	98.49	11.038	0.29	261.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.028	0.30	96.57	11.027	0.29	263.14
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.022	0.30	94.78	11.032	0.29	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.013	0.29	93.05	11.034	0.29	266.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.006	0.30	91.34	11.038	0.30	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.016	0.30	89.67	11.031	0.30	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	11.037	0.31	88.03	11.035	0.30	271.71
22	N/A	N/A	N/A	N/A	N/A	N/A	68	11.018	0.30	86.42	11.039	0.30	273.35
24	11.018	0.29	166.98	11.020	0.30	192.98	70	11.019	0.31	84.81	11.039	0.30	274.98
26	11.037	0.31	151.03	11.021	0.30	209.21	72	11.009	0.30	83.22	11.039	0.30	276.59
28	11.015	0.29	140.80	11.029	0.30	218.18	74	11.027	0.31	81.63	11.041	0.31	278.19
30	11.017	0.31	134.48	11.022	0.31	224.76	76	11.031	0.31	79.99	11.047	0.31	279.83
32	11.017	0.29	129.23	11.024	0.29	230.12	78	11.030	0.31	78.38	11.051	N/A	281.44
34	11.018	0.31	124.81	11.026	0.30	234.54	80	11.015	N/A	76.74	11.059	N/A	283.08
36	11.018	0.30	120.99	11.028	0.29	238.48	82	11.019	N/A	75.12	11.061	N/A	284.73
38	11.023	0.30	117.64	11.028	0.31	241.91	84	11.057	N/A	73.41	11.076	N/A	286.38
40	11.017	0.29	114.49	11.028	0.30	244.98	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.020	0.30	111.81	11.033	0.29	247.80	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.019	0.29	109.14	11.027	0.31	250.44	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

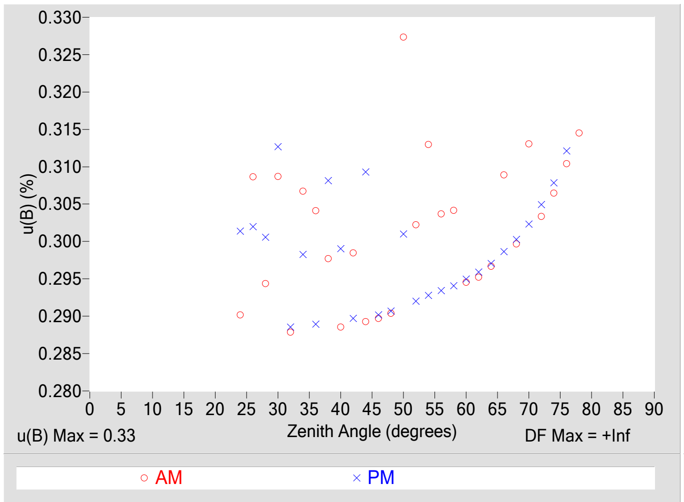


Figure 4. Residuals from Spline Interpolation

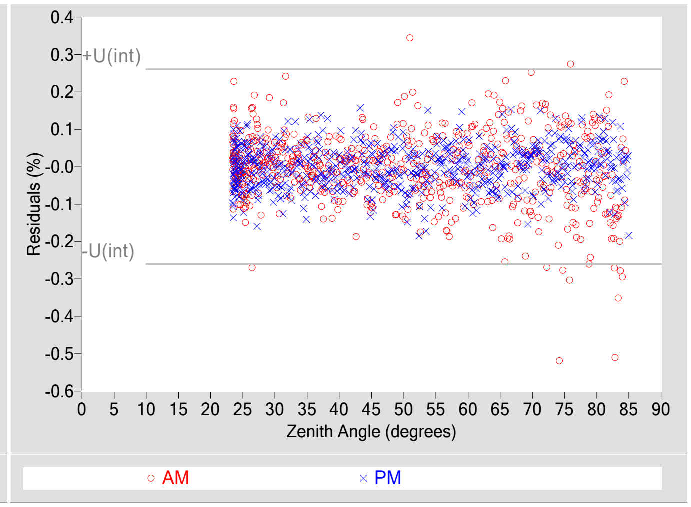


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	61098
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

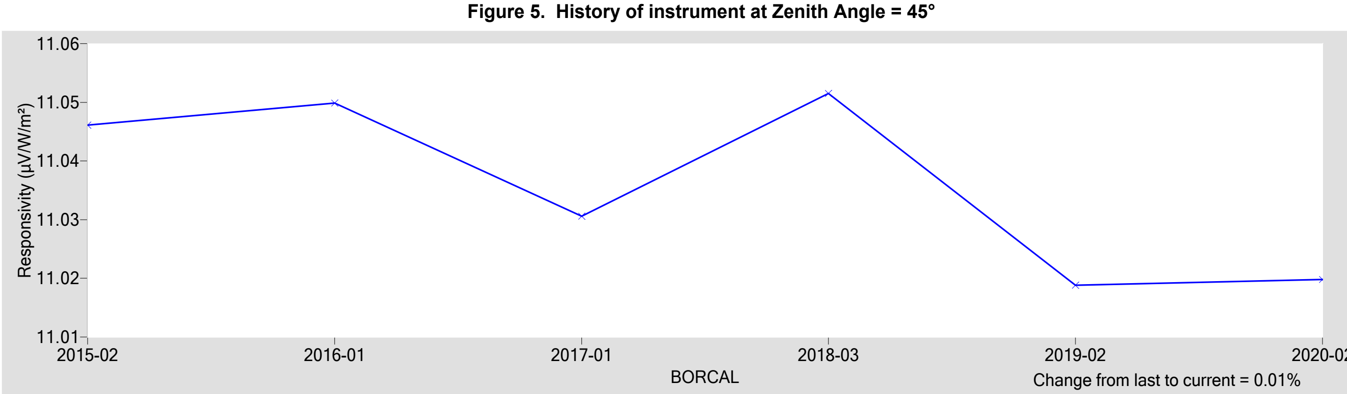
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
11.020	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+0.16 / -0.10
Expanded Uncertainty, U (%)	+0.80 / -0.74
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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-LITE	**Serial Number:**	970003
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

970003 Kipp & Zonen SP-LITE

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

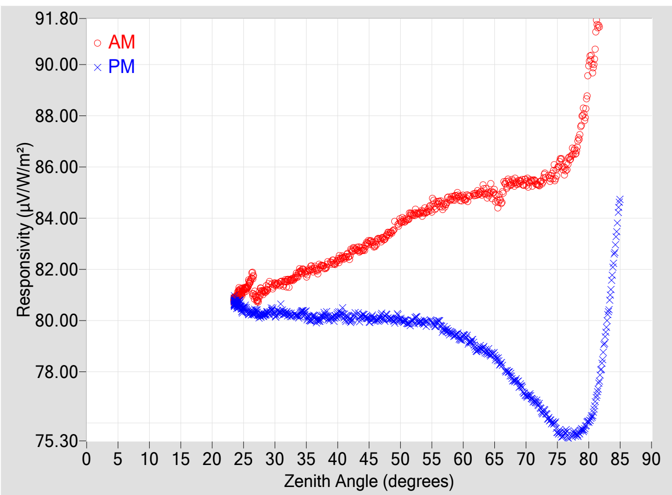


Figure 2. Responsivity vs Local Standard Time

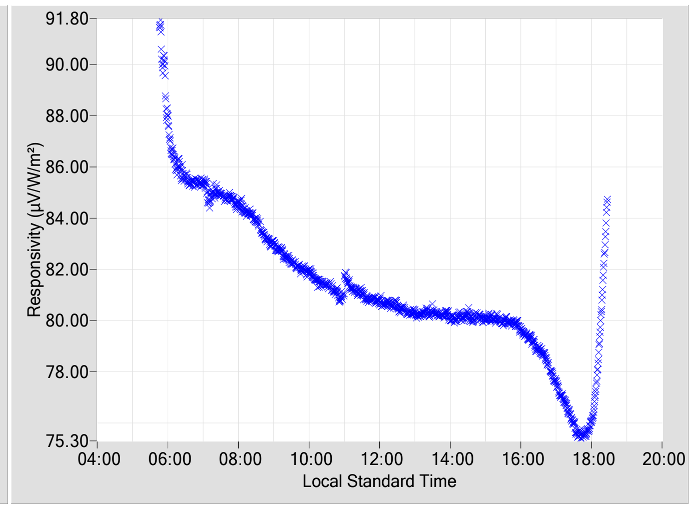


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	82.978	0.31	106.77	80.032	0.32	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	83.380	0.31	104.55	80.126	0.32	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	83.868	0.33	102.41	80.032	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	84.141	0.35	100.38	80.006	0.32	259.29
8	N/A	N/A	N/A	N/A	N/A	N/A	54	84.256	0.34	98.45	79.937	0.32	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	84.587	0.36	96.58	79.955	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	84.751	0.38	94.75	79.519	0.33	264.91
14	N/A	N/A	N/A	N/A	N/A	N/A	60	84.767	0.34	93.05	79.385	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	84.945	0.35	91.35	78.888	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	84.929	0.36	89.68	78.754	0.36	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	84.763	0.40	88.03	78.297	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	85.412	0.39	86.42	77.658	0.40	273.36
24	80.920	0.31	167.16	80.628	0.31	193.01	70	85.432	0.42	84.82	77.075	0.42	274.99
26	81.505	0.32	151.05	80.287	0.31	209.06	72	85.317	0.45	83.18	76.700	0.45	276.60
28	81.148	0.33	140.91	80.212	0.31	218.07	74	85.581	0.49	81.61	76.052	0.49	278.20
30	81.399	0.31	134.42	80.230	0.29	224.61	76	85.910	0.54	79.99	75.564	0.55	279.83
32	81.494	0.30	129.21	80.269	0.32	230.02	78	86.697	0.61	78.39	75.533	N/A	281.44
34	81.921	0.31	124.83	80.265	0.32	234.61	80	89.826	N/A	76.74	76.094	N/A	283.09
36	82.035	0.31	121.06	80.125	0.31	238.40	82	N/A	N/A	N/A	78.271	N/A	284.73
38	82.080	0.31	117.65	80.228	0.31	241.82	84	N/A	N/A	N/A	82.386	N/A	286.39
40	82.377	0.31	114.46	80.229	0.33	244.99	86	N/A	N/A	N/A	N/A	N/A	N/A
42	82.567	0.31	111.82	79.993	0.33	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	82.764	0.30	109.15	80.184	0.36	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

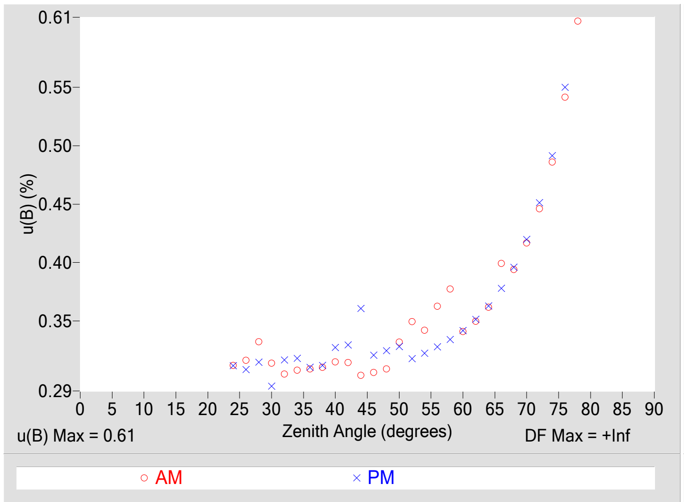


Figure 4. Residuals from Spline Interpolation

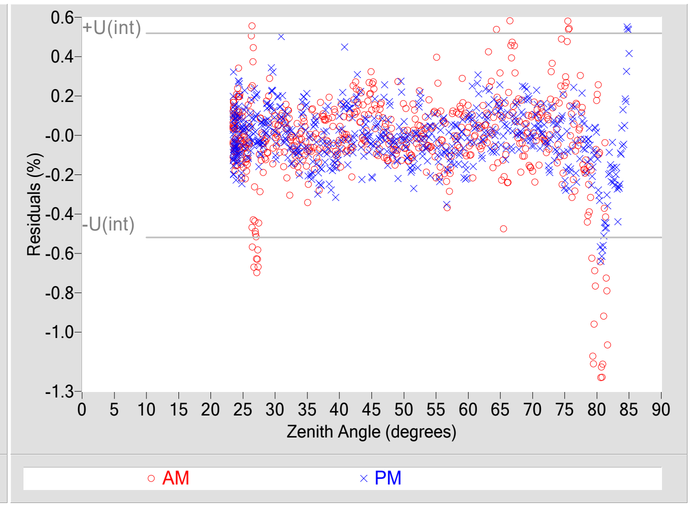


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	48120
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

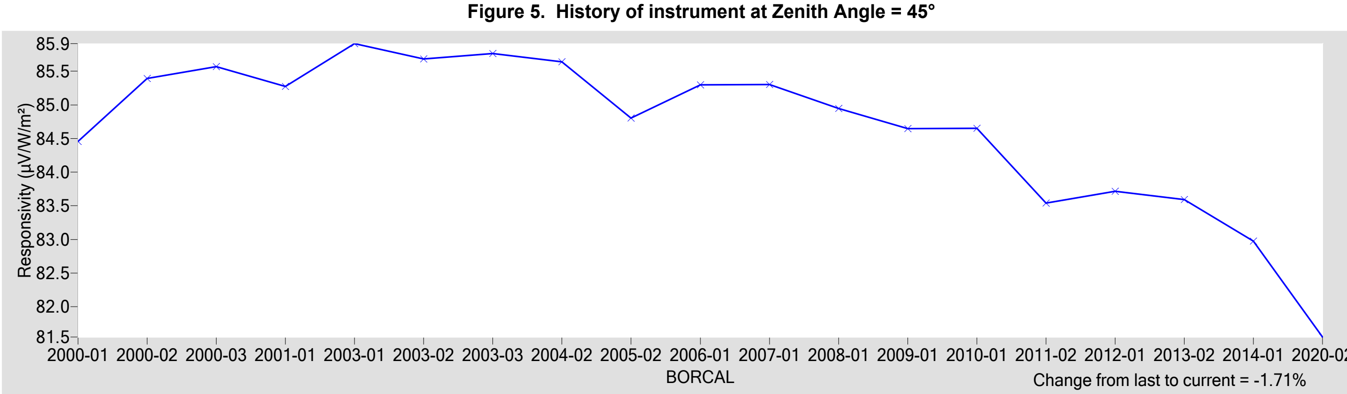
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
81.550	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.74
Offset Uncertainty, U(off) (%)	+3.9 / -2.7
Expanded Uncertainty, U (%)	+4.7 / -3.4
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 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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

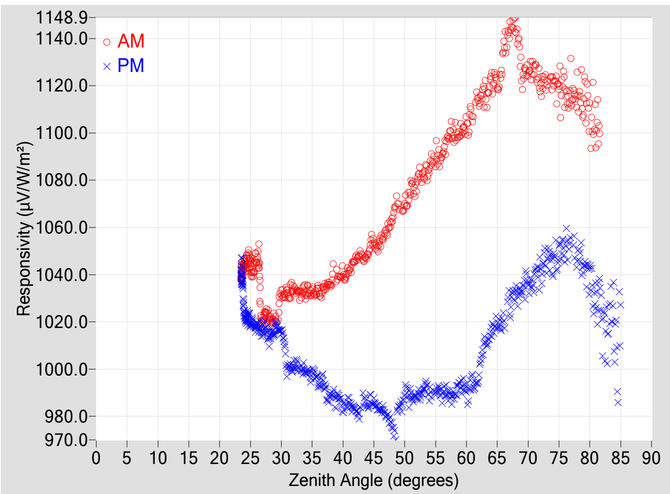


Figure 2. Responsivity vs Local Standard Time

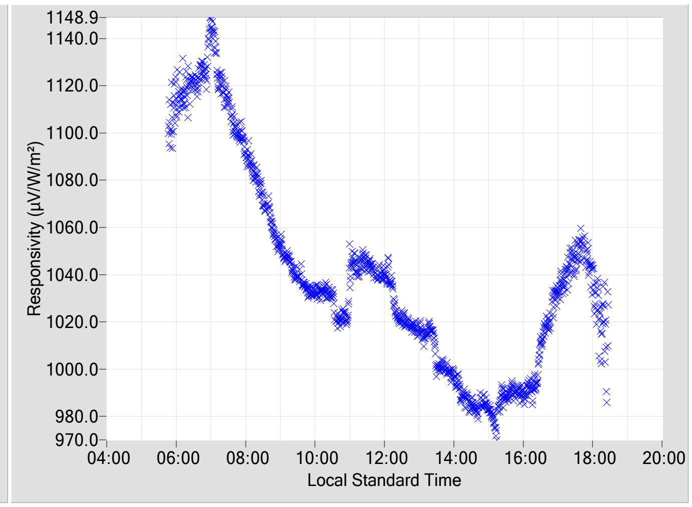


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	1054.0	0.32	106.80	982.91	0.31	252.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	1063.2	0.31	104.58	974.85	0.31	255.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	1069.4	0.31	102.44	989.52	0.31	257.20
6	N/A	N/A	N/A	N/A	N/A	N/A	52	1079.3	0.32	100.41	988.81	0.32	259.27
8	N/A	N/A	N/A	N/A	N/A	N/A	54	1084.7	0.32	98.48	989.30	0.34	261.25
10	N/A	N/A	N/A	N/A	N/A	N/A	56	1090.0	0.33	96.61	989.21	0.33	263.13
12	N/A	N/A	N/A	N/A	N/A	N/A	58	1099.5	0.33	94.82	989.00	0.33	264.94
14	N/A	N/A	N/A	N/A	N/A	N/A	60	1102.4	0.34	93.03	989.70	0.34	266.70
16	N/A	N/A	N/A	N/A	N/A	N/A	62	1113.9	0.35	91.33	998.18	0.35	268.42
18	N/A	N/A	N/A	N/A	N/A	N/A	64	1121.6	0.36	89.70	1016.2	0.36	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	1135.0	0.40	88.02	1020.6	0.38	271.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	1144.1	0.39	86.40	1031.7	0.40	273.38
24	1043.4	0.31	167.06	1025.8	0.31	193.05	70	1125.9	0.42	84.80	1036.3	0.42	274.97
26	1046.3	0.30	150.99	1017.9	0.31	209.17	72	1120.7	0.45	83.21	1040.4	0.45	276.62
28	1021.2	0.32	140.86	1013.0	0.32	218.11	74	1121.6	0.49	81.59	1044.9	0.49	278.18
30	1031.7	0.35	134.40	1015.6	0.34	224.68	76	1118.7	0.54	80.01	1051.8	0.55	279.81
32	1033.9	0.34	129.23	1000.7	0.31	229.98	78	1115.8	0.61	78.37	1047.2	N/A	281.47
34	1032.5	0.31	124.79	998.82	0.30	234.57	80	1104.4	N/A	76.79	1039.4	N/A	283.07
36	1032.7	0.33	120.97	994.14	0.30	238.45	82	N/A	N/A	N/A	1021.4	N/A	284.71
38	1036.1	0.32	117.62	988.99	0.31	241.84	84	N/A	N/A	N/A	1018.9	N/A	286.37
40	1039.6	0.30	114.55	983.36	0.33	244.98	86	N/A	N/A	N/A	N/A	N/A	N/A
42	1046.3	0.33	111.79	982.95	0.32	247.78	88	N/A	N/A	N/A	N/A	N/A	N/A
44	1048.5	0.30	109.19	984.16	0.33	250.42	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

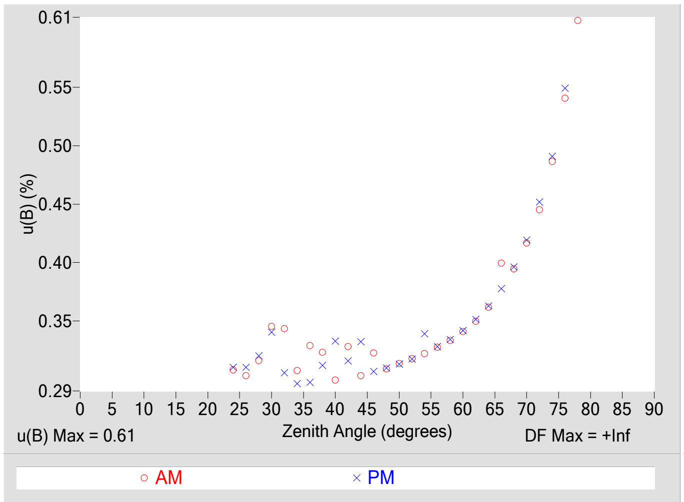


Figure 4. Residuals from Spline Interpolation

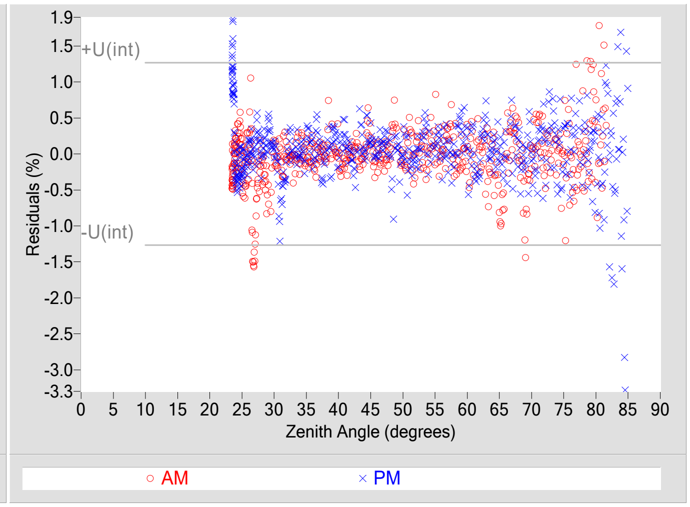


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.63
Combined Standard Uncertainty, u(c) (%)	±0.88
Effective degrees of freedom, DF(c)	4245
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.7
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

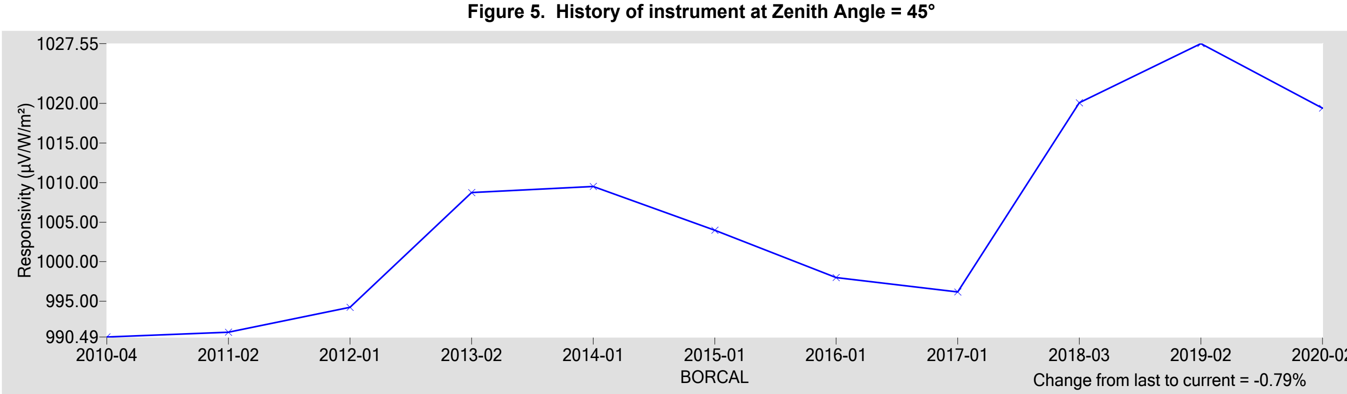
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
1019.4	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.68
Offset Uncertainty, U(off) (%)	+8.1 / -4.4
Expanded Uncertainty, U (%)	+8.8 / -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:**	EKO
Model:	MS-802	**Serial Number:**	F14077R
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

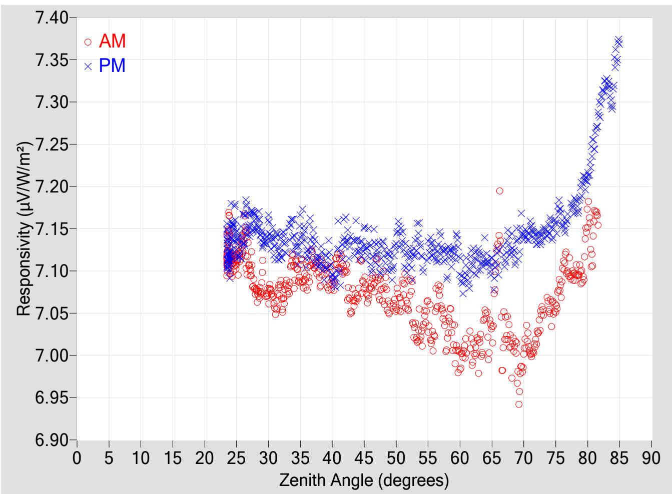


Figure 2. Responsivity vs Local Standard Time

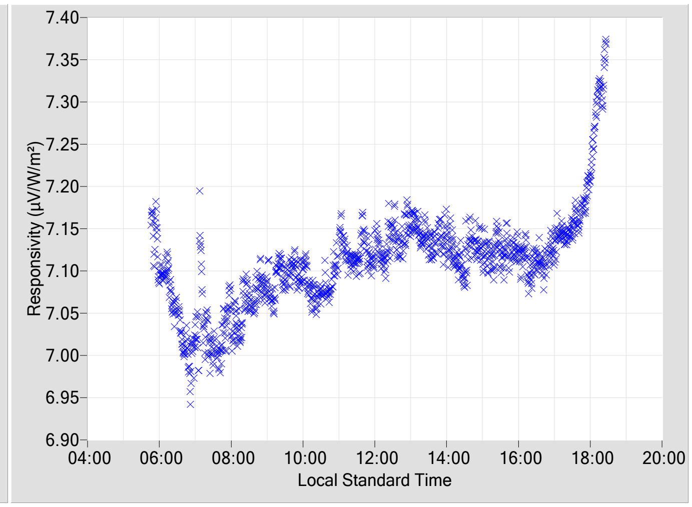


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.0805	0.31	106.82	7.1145	0.33	252.87
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.0772	0.33	104.54	7.1251	0.32	255.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.0638	0.35	102.40	7.1397	0.34	257.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.0701	0.37	100.42	7.1174	0.35	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.0250	0.35	98.44	7.1164	0.35	261.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.0351	0.37	96.62	7.1225	0.34	263.09
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.0205	0.37	94.79	7.1123	0.35	264.95
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9962	0.36	93.04	7.1064	0.36	266.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.0035	0.36	91.34	7.1128	0.37	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.0483	0.40	89.67	7.1169	0.38	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.1443	0.39	88.03	7.1148	0.40	271.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.0063	0.42	86.41	7.1298	0.42	273.35
24	7.1247	0.30	166.84	7.1215	0.31	193.06	70	6.9991	0.47	84.81	7.1430	0.45	274.98
26	7.1389	0.33	151.12	7.1392	0.31	209.06	72	7.0207	0.47	83.18	7.1380	0.48	276.59
28	7.0749	0.32	140.63	7.1562	0.32	218.05	74	7.0573	0.52	81.60	7.1538	0.53	278.19
30	7.0746	0.31	134.37	7.1481	0.32	224.60	76	7.0925	0.58	79.98	7.1604	0.59	279.78
32	7.0707	0.32	129.29	7.1284	0.33	230.04	78	7.0972	0.66	78.38	7.1777	N/A	281.39
34	7.1044	0.33	124.82	7.1395	0.31	234.42	80	7.1611	N/A	76.78	7.2112	N/A	283.04
36	7.0929	0.31	120.99	7.1211	0.30	238.39	82	N/A	N/A	N/A	7.2959	N/A	284.68
38	7.0963	0.32	117.56	7.1137	0.32	241.89	84	N/A	N/A	N/A	7.3192	N/A	286.42
40	7.0872	0.31	114.56	7.0927	0.34	244.98	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.1016	0.33	111.74	7.1439	0.31	247.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.0698	0.33	109.27	7.1321	0.34	250.37	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

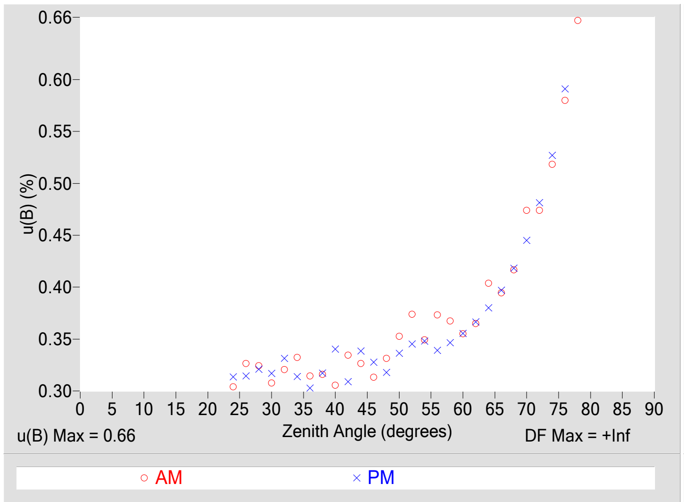


Figure 4. Residuals from Spline Interpolation

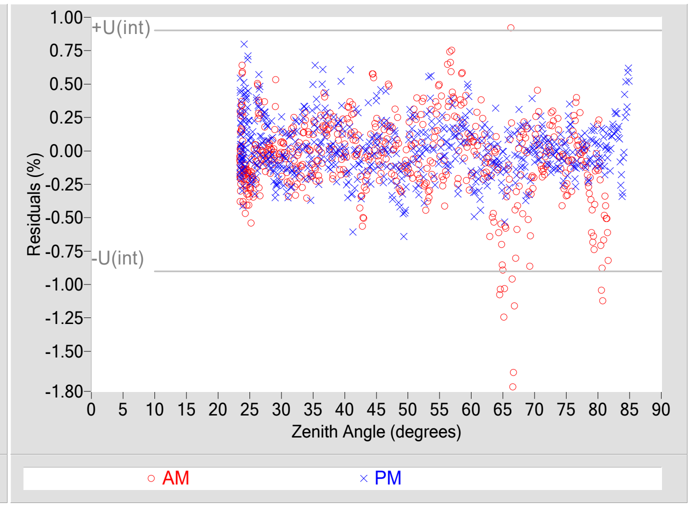


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.66
Type-A Interpolating Function, u(int) (%)	±0.45
Combined Standard Uncertainty, u(c) (%)	±0.80
Effective degrees of freedom, DF(c)	11200
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

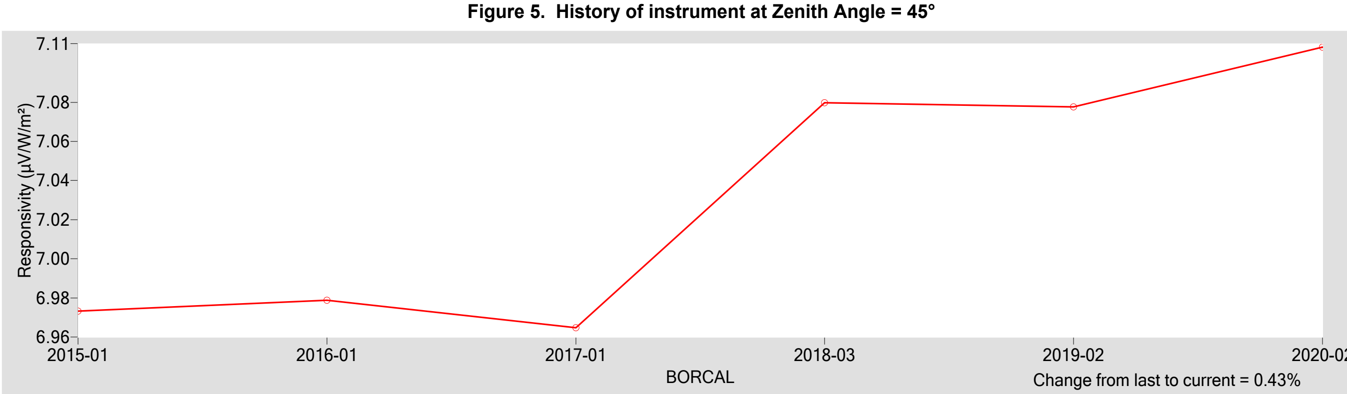
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.1082	0.18000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+0.56 / -1.6
Expanded Uncertainty, U (%)	+1.3 / -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:	Revised Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200R	**Serial Number:**	PY100360
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

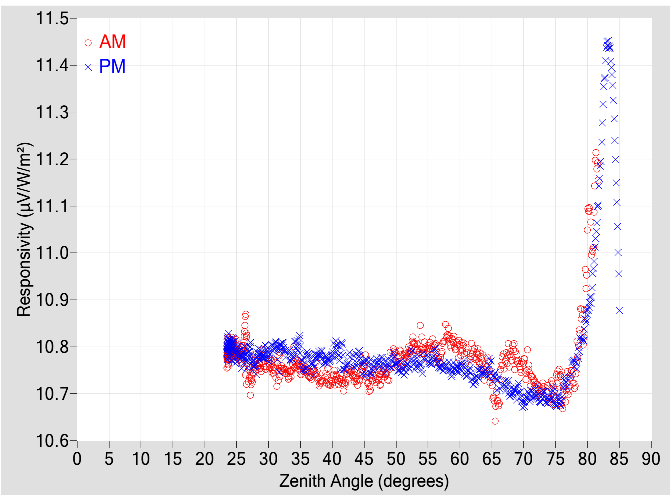


Figure 2. Responsivity vs Local Standard Time

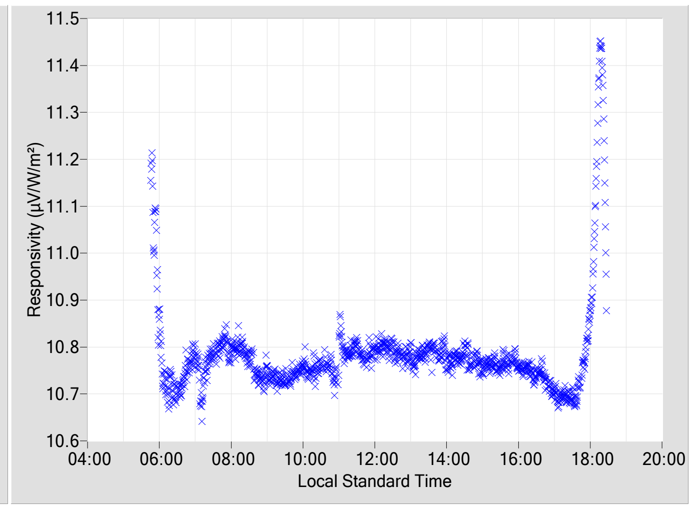


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.719	0.31	106.77	10.750	0.31	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.746	0.33	104.55	10.763	0.33	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.774	0.35	102.42	10.764	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.790	0.33	100.38	10.767	0.33	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.807	0.34	98.46	10.761	0.34	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.799	0.33	96.58	10.786	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.830	0.37	94.80	10.758	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.796	0.34	93.05	10.757	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.789	0.35	91.35	10.730	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.754	0.41	89.68	10.745	0.37	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.693	0.43	88.03	10.723	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.780	0.40	86.42	10.700	0.40	273.36
24	10.788	0.32	166.97	10.800	0.32	193.02	70	10.765	0.42	84.74	10.680	0.42	274.99
26	10.804	0.33	150.85	10.779	0.31	209.04	72	10.709	0.45	83.19	10.702	0.46	276.60
28	10.767	0.29	141.03	10.768	0.31	218.08	74	10.698	0.49	81.61	10.690	0.50	278.20
30	10.765	0.29	134.16	10.783	0.30	224.62	76	10.696	0.65	79.99	10.702	0.56	279.83
32	10.755	0.32	129.22	10.800	0.32	229.97	78	10.730	0.62	78.39	10.765	N/A	281.45
34	10.770	0.31	124.84	10.790	0.30	234.53	80	11.034	N/A	76.75	10.872	N/A	283.05
36	10.747	0.30	121.07	10.773	0.30	238.41	82	N/A	N/A	N/A	11.199	N/A	284.74
38	10.726	0.31	117.65	10.785	0.31	241.83	84	N/A	N/A	N/A	11.331	N/A	286.39
40	10.734	0.33	114.51	10.787	0.33	245.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.723	0.30	111.82	10.756	0.32	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.726	0.34	109.17	10.779	0.35	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

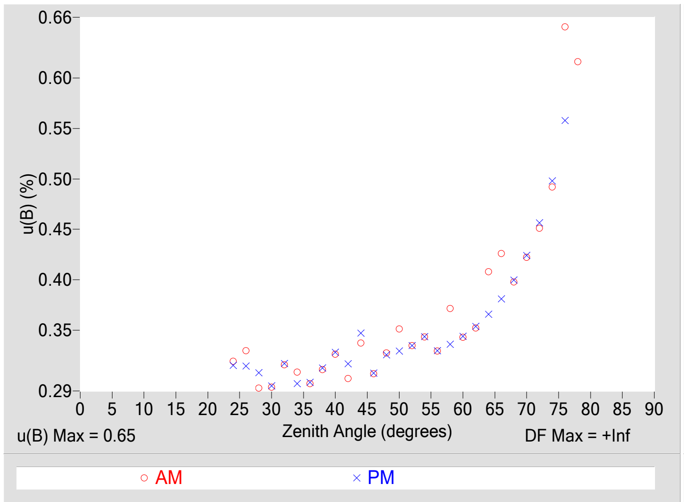


Figure 4. Residuals from Spline Interpolation

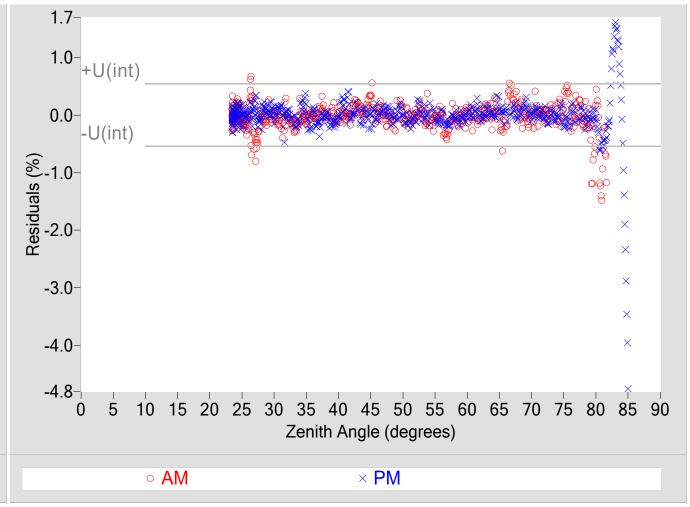


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	52787
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

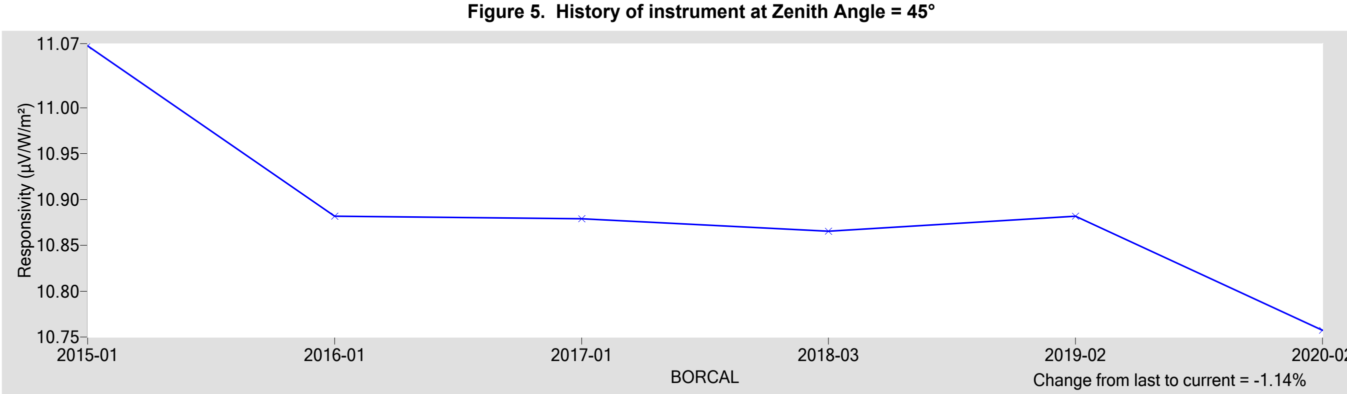
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.757	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+0.67 / -0.35
Expanded Uncertainty, U (%)	+1.4 / -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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument: Revised Silicon Pyranometer
Manufacturer: Licor
Model: LI200R
Serial Number: PY108623
Calibration Date: 5/5/2020
Due Date: 5/5/2021
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 5/4-5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

PY108623 Licor LI200R

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

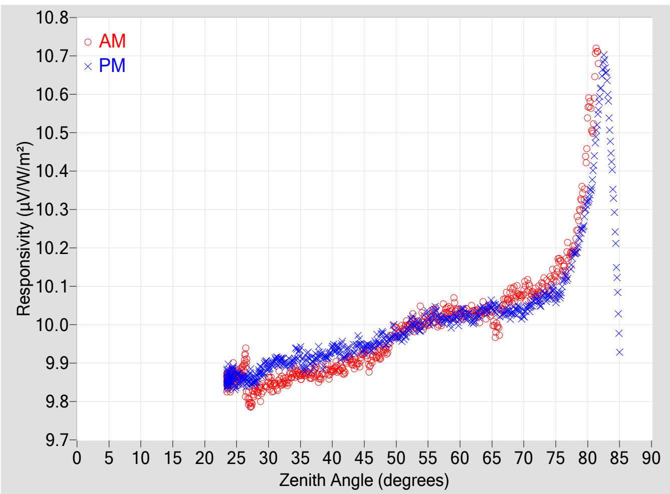


Figure 2. Responsivity vs Local Standard Time

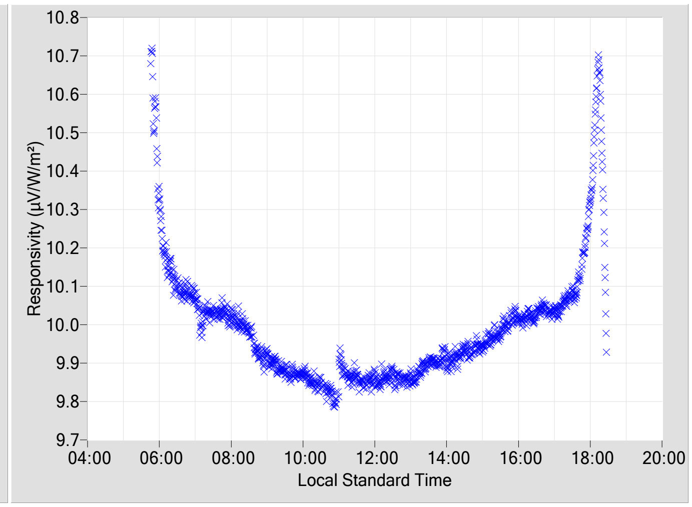


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.8976	0.31	106.77	9.9386	0.31	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.9353	0.33	104.55	9.9677	0.33	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.9778	0.35	102.42	9.9718	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.9936	0.34	100.38	9.9947	0.34	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.014	0.34	98.46	9.9971	0.34	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.030	0.33	96.58	10.037	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.038	0.37	94.80	10.015	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.025	0.34	93.05	10.022	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.033	0.35	91.35	10.010	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.031	0.41	89.68	10.035	0.37	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.9973	0.43	88.03	10.037	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.076	0.40	86.42	10.028	0.40	273.36
24	9.8547	0.32	166.97	9.8632	0.32	193.02	70	10.096	0.42	84.74	10.027	0.42	274.99
26	9.8883	0.33	150.85	9.8567	0.31	209.04	72	10.078	0.45	83.19	10.068	0.46	276.60
28	9.8285	0.29	141.03	9.8567	0.31	218.08	74	10.101	0.49	81.61	10.077	0.50	278.20
30	9.8500	0.29	134.16	9.8878	0.30	224.62	76	10.143	0.65	79.99	10.101	0.56	279.83
32	9.8505	0.32	129.22	9.9061	0.32	229.97	78	10.211	0.62	78.39	10.188	N/A	281.45
34	9.8777	0.31	124.84	9.9114	0.30	234.53	80	10.524	N/A	76.75	10.321	N/A	283.05
36	9.8734	0.30	121.07	9.9100	0.30	238.41	82	N/A	N/A	N/A	10.620	N/A	284.74
38	9.8604	0.31	117.65	9.9228	0.31	241.83	84	N/A	N/A	N/A	10.341	N/A	286.39
40	9.8813	0.33	114.51	9.9388	0.33	245.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8835	0.30	111.82	9.9167	0.32	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8958	0.34	109.17	9.9536	0.35	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

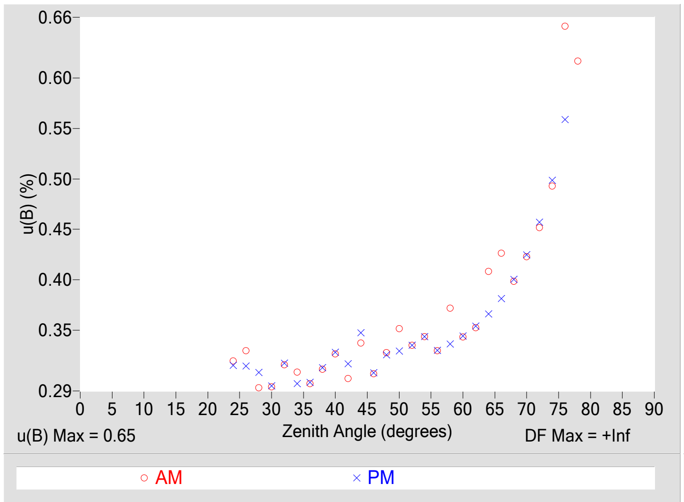


Figure 4. Residuals from Spline Interpolation

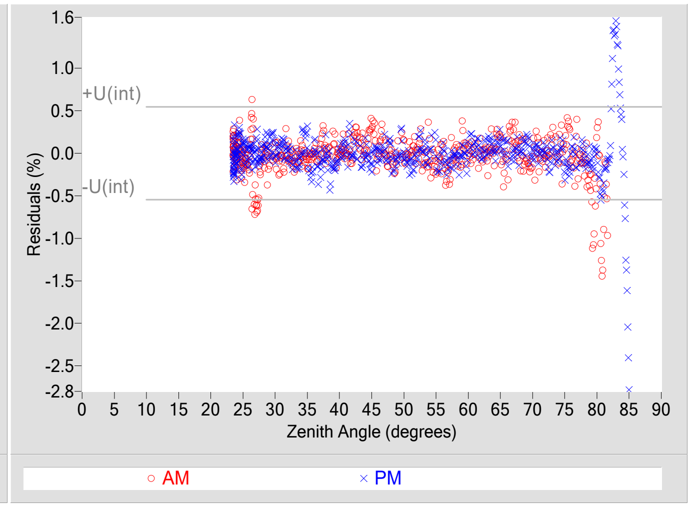


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.71
Effective degrees of freedom, DF(c)	51844
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

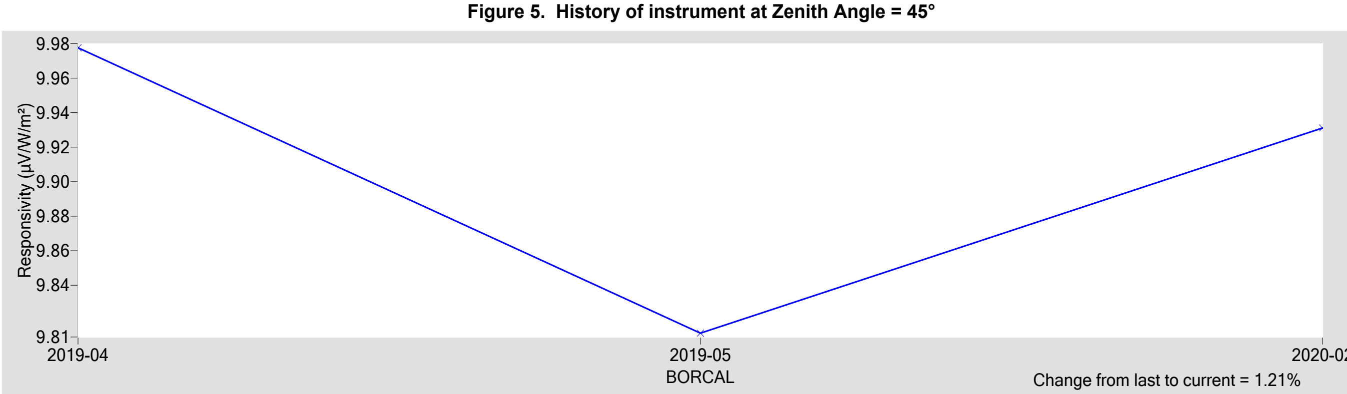
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.9311	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+1.1 / -0.82
Expanded Uncertainty, U (%)	+1.8 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY1750
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

PY1750 Licor LI200

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

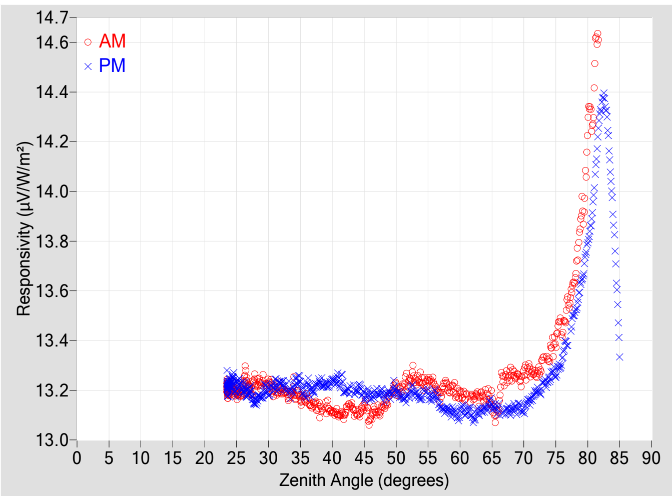


Figure 2. Responsivity vs Local Standard Time

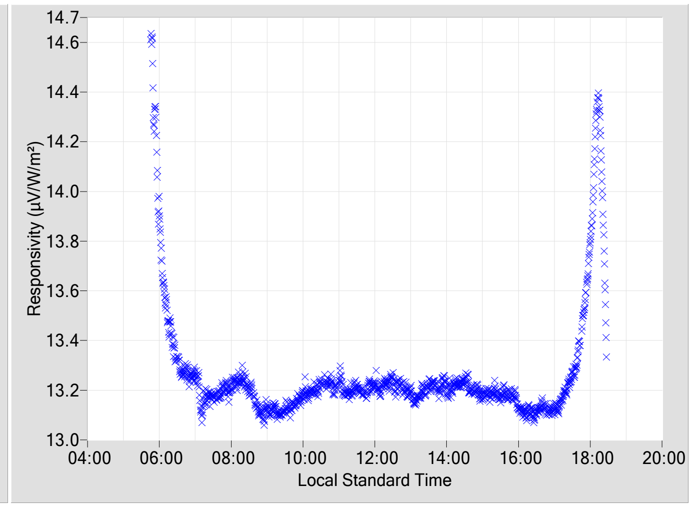


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	13.084	0.31	106.77	13.174	0.31	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.138	0.33	104.55	13.190	0.33	255.04
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.208	0.35	102.42	13.198	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.233	0.33	100.38	13.188	0.33	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.237	0.34	98.46	13.175	0.34	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	13.221	0.33	96.58	13.184	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.216	0.37	94.80	13.125	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.181	0.34	93.05	13.109	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.173	0.35	91.35	13.087	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.171	0.41	89.68	13.123	0.36	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	13.138	0.43	88.03	13.120	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	13.264	0.40	86.42	13.115	0.40	273.36
24	13.200	0.32	166.97	13.227	0.32	193.02	70	13.282	0.42	84.74	13.121	0.42	274.99
26	13.214	0.33	150.85	13.203	0.31	209.04	72	13.266	0.45	83.19	13.198	0.45	276.60
28	13.237	0.29	141.03	13.153	0.31	218.08	74	13.339	0.49	81.61	13.247	0.50	278.20
30	13.228	0.29	134.16	13.187	0.29	224.62	76	13.445	0.65	79.99	13.329	0.55	279.83
32	13.197	0.32	129.22	13.230	0.32	229.97	78	13.657	0.61	78.39	13.516	N/A	281.45
34	13.186	0.31	124.82	13.217	0.30	234.53	80	14.235	N/A	76.75	13.792	N/A	283.05
36	13.164	0.30	121.07	13.212	0.30	238.41	82	N/A	N/A	N/A	14.331	N/A	284.74
38	13.123	0.31	117.65	13.230	0.31	241.83	84	N/A	N/A	N/A	13.889	N/A	286.39
40	13.113	0.33	114.51	13.238	0.33	245.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	13.105	0.30	111.82	13.193	0.32	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	13.100	0.34	109.17	13.206	0.35	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

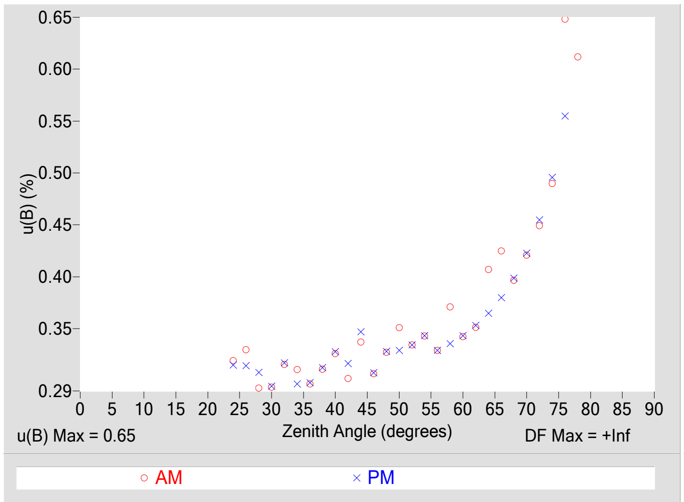


Figure 4. Residuals from Spline Interpolation

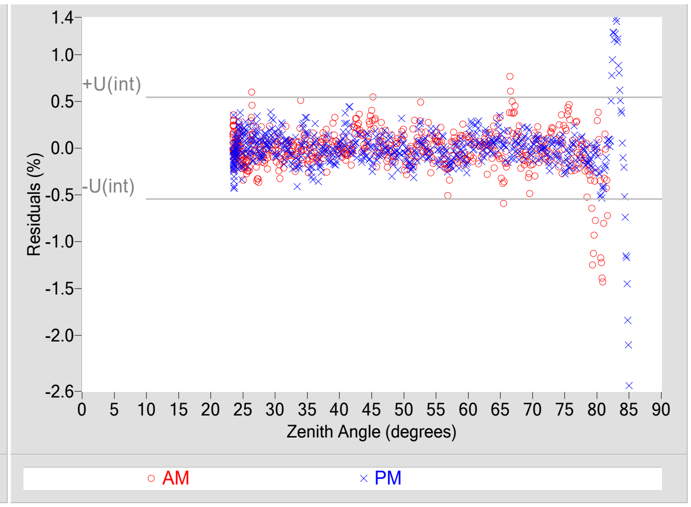


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	51099
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

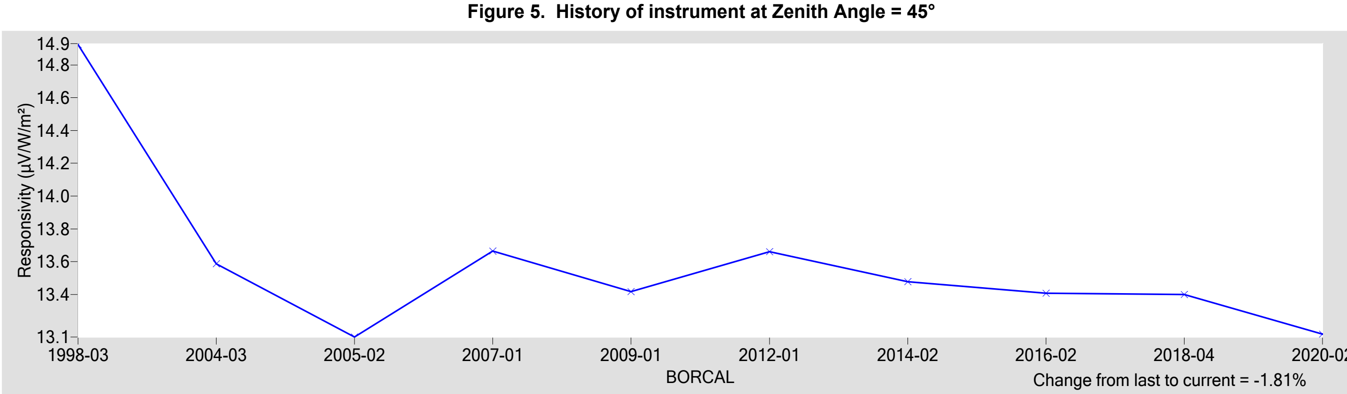
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
13.157	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+0.62 / -0.55
Expanded Uncertainty, U (%)	+1.3 / -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:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY28257
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

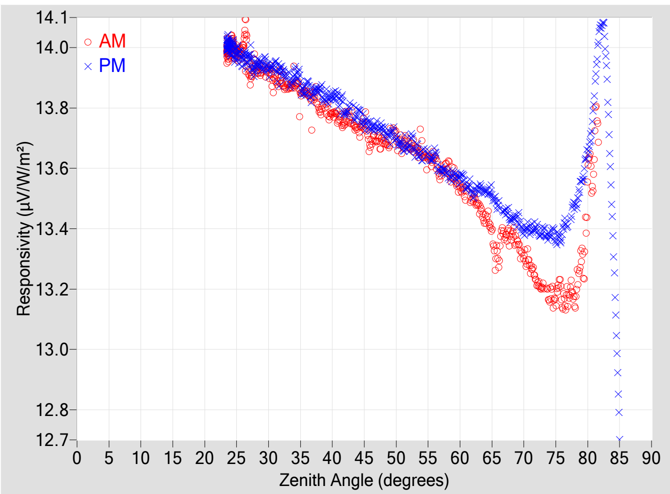


Figure 2. Responsivity vs Local Standard Time

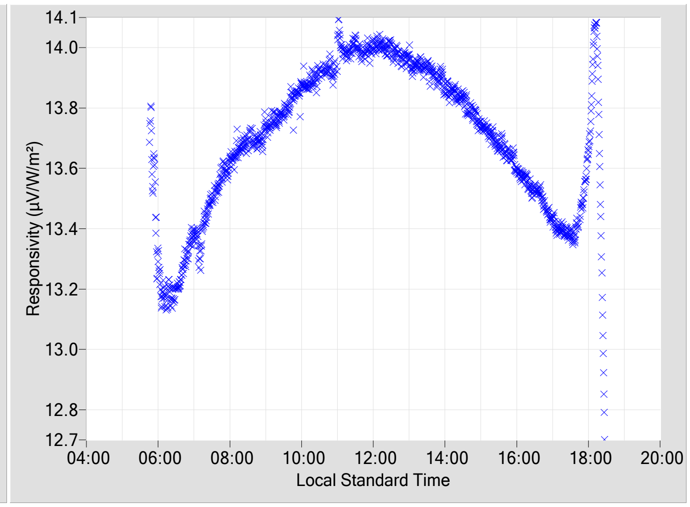


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	13.678	0.31	106.77	13.740	0.31	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	13.695	0.33	104.55	13.728	0.33	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	13.698	0.35	102.42	13.697	0.33	257.23
6	N/A	N/A	N/A	N/A	N/A	N/A	52	13.676	0.33	100.38	13.677	0.33	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	13.671	0.34	98.46	13.642	0.34	261.22
10	N/A	N/A	N/A	N/A	N/A	N/A	56	13.633	0.33	96.58	13.649	0.33	263.10
12	N/A	N/A	N/A	N/A	N/A	N/A	58	13.610	0.37	94.80	13.585	0.34	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	13.532	0.34	93.05	13.570	0.34	266.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	13.502	0.35	91.35	13.517	0.35	268.39
18	N/A	N/A	N/A	N/A	N/A	N/A	64	13.431	0.41	89.68	13.523	0.36	270.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	13.313	0.42	88.03	13.475	0.38	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	13.375	0.40	86.42	13.429	0.40	273.36
24	13.996	0.32	166.97	14.001	0.31	193.02	70	13.309	0.42	84.74	13.393	0.42	274.99
26	14.008	0.33	150.85	13.963	0.31	209.04	72	13.221	0.45	83.19	13.400	0.45	276.60
28	13.945	0.29	141.03	13.936	0.31	218.08	74	13.176	0.49	81.61	13.378	0.50	278.20
30	13.923	0.29	134.16	13.928	0.29	224.62	76	13.166	0.65	79.99	13.387	0.55	279.83
32	13.892	0.32	129.22	13.926	0.32	229.97	78	13.166	0.61	78.39	13.478	N/A	281.45
34	13.887	0.31	124.84	13.911	0.30	234.53	80	13.543	N/A	76.75	13.654	N/A	283.05
36	13.849	0.30	121.07	13.872	0.30	238.41	82	N/A	N/A	N/A	14.069	N/A	284.74
38	13.793	0.31	117.65	13.861	0.31	241.83	84	N/A	N/A	N/A	13.338	N/A	286.39
40	13.781	0.33	114.51	13.842	0.33	245.00	86	N/A	N/A	N/A	N/A	N/A	N/A
42	13.756	0.30	111.82	13.781	0.32	247.81	88	N/A	N/A	N/A	N/A	N/A	N/A
44	13.724	0.34	109.17	13.786	0.35	250.45	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

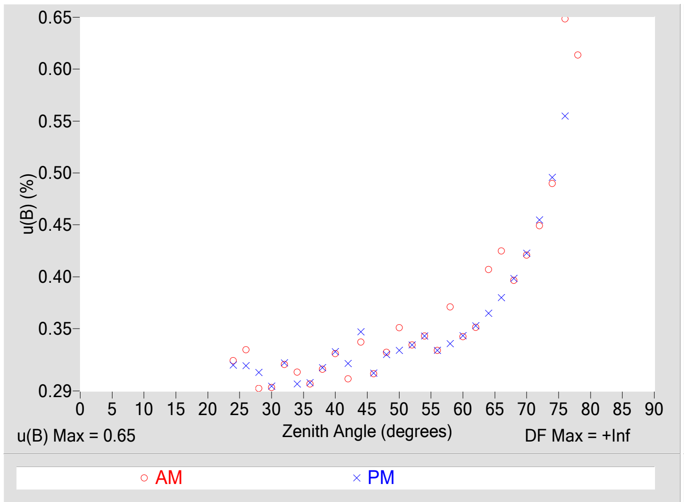


Figure 4. Residuals from Spline Interpolation

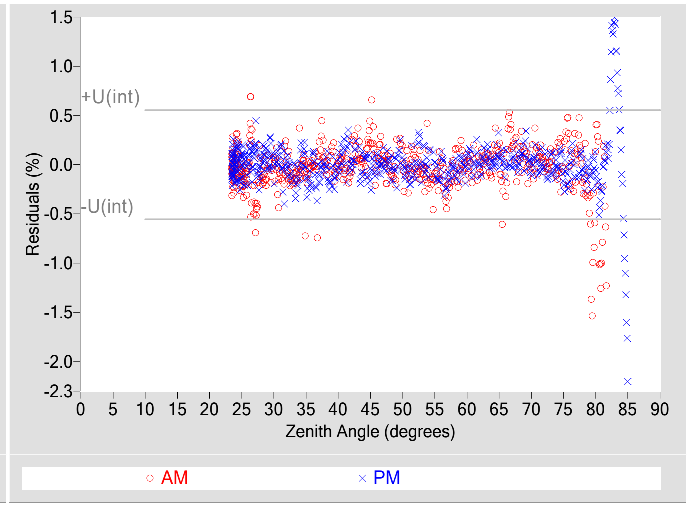


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	48327
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

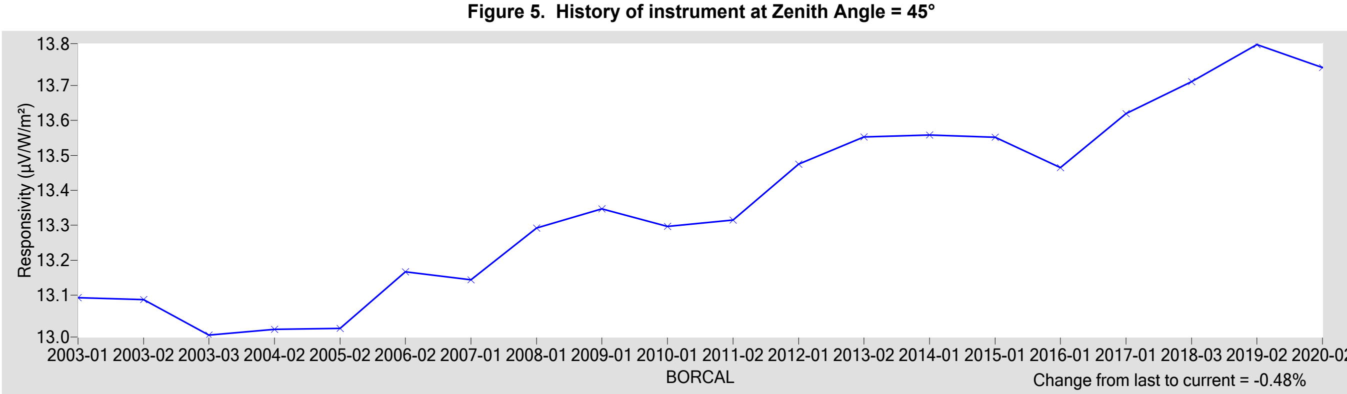
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
13.751	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+1.3 / -1.6
Expanded Uncertainty, U (%)	+2.0 / -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:	Semiconductor Pyrheliometer	**Manufacturer:**	Licor
Model:	LI201SB	**Serial Number:**	PYHR101
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

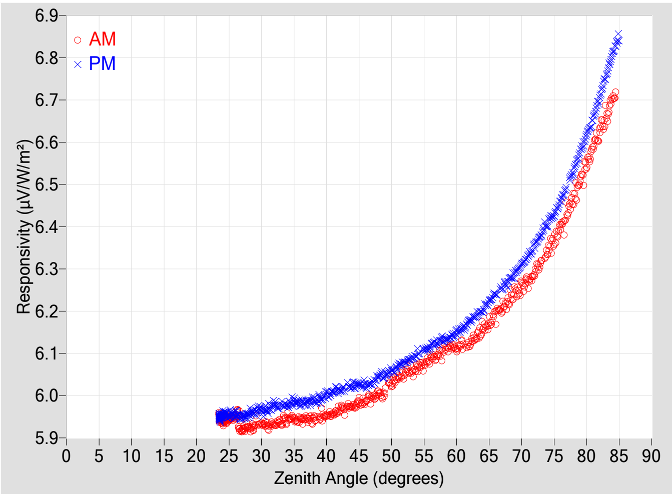


Figure 2. Responsivity vs Local Standard Time

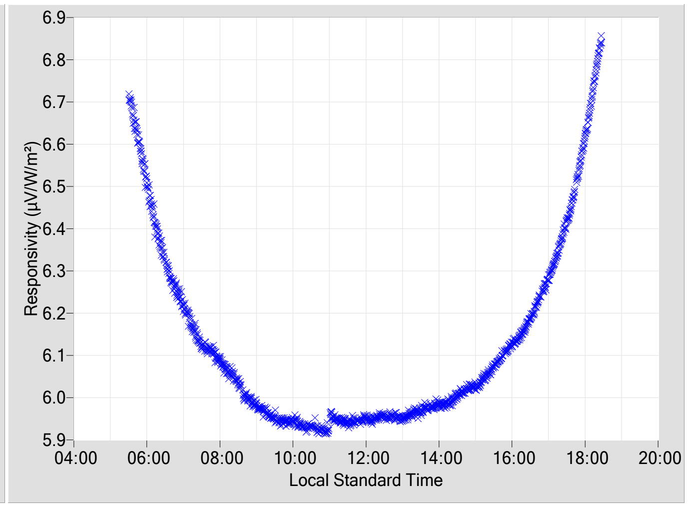


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	5.9852	0.29	106.77	6.0261	0.29	252.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.0071	0.29	104.55	6.0459	0.31	255.08
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.0272	0.33	102.42	6.0605	0.31	257.24
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.0519	0.31	100.38	6.0779	0.29	259.30
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.0661	0.31	98.46	6.0994	0.31	261.23
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.0874	0.31	96.59	6.1171	0.30	263.11
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.1064	0.32	94.80	6.1316	0.30	264.92
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.1101	0.31	93.06	6.1502	0.30	266.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.1214	0.30	91.35	6.1773	0.30	268.40
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.1579	0.32	89.68	6.2000	0.30	270.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.1939	0.31	88.04	6.2402	0.30	271.72
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.2235	0.30	86.42	6.2709	0.30	273.36
24	5.9419	0.31	167.11	5.9538	0.31	192.94	70	6.2605	0.32	84.78	6.3105	0.30	274.99
26	5.9537	0.31	150.89	5.9542	0.30	208.97	72	6.2889	0.31	83.19	6.3581	0.31	276.60
28	5.9260	0.31	140.89	5.9543	0.31	217.98	74	6.3400	0.31	81.61	6.4064	0.32	278.20
30	5.9325	0.29	134.31	5.9650	0.30	224.74	76	6.4027	0.31	80.00	6.4621	0.31	279.80
32	5.9318	0.29	129.22	5.9795	0.31	229.97	78	6.4661	0.32	78.39	6.5337	N/A	281.45
34	5.9433	0.31	124.84	5.9768	0.29	234.53	80	6.5480	N/A	76.75	6.6185	N/A	283.05
36	5.9449	0.31	121.01	5.9826	0.31	238.41	82	6.6247	N/A	75.09	6.7073	N/A	284.74
38	5.9423	0.30	117.66	5.9897	0.30	241.83	84	6.7022	N/A	73.42	6.8091	N/A	286.39
40	5.9522	0.32	114.51	6.0040	0.31	245.01	86	N/A	N/A	N/A	N/A	N/A	N/A
42	5.9661	0.29	111.82	6.0118	0.29	247.82	88	N/A	N/A	N/A	N/A	N/A	N/A
44	5.9753	0.31	109.16	6.0236	0.29	250.46	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

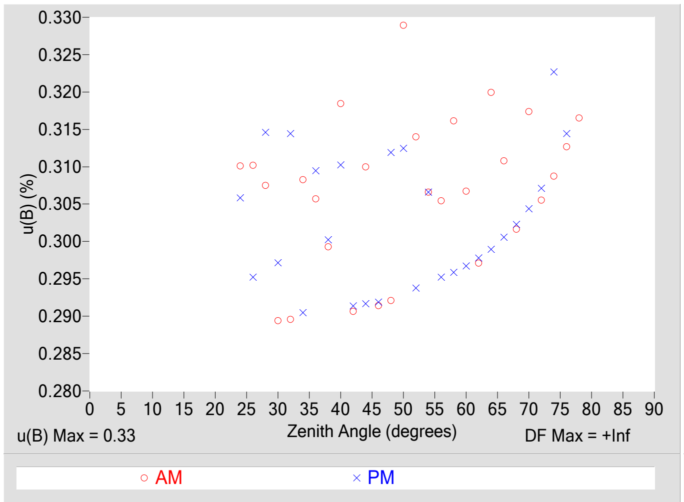


Figure 4. Residuals from Spline Interpolation

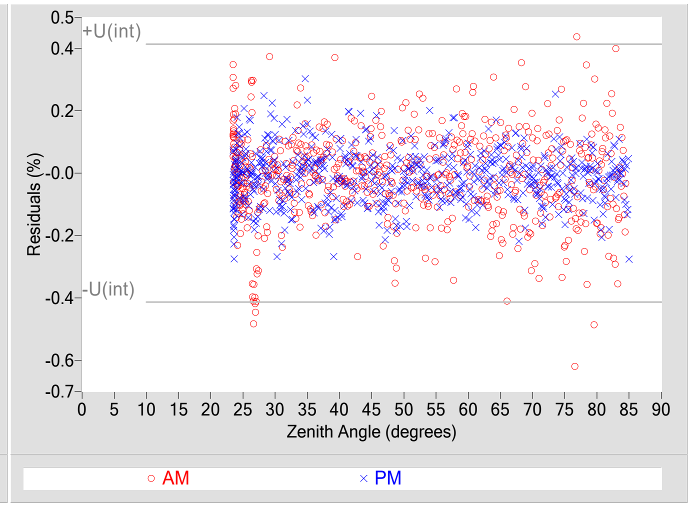


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	14290
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.76
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

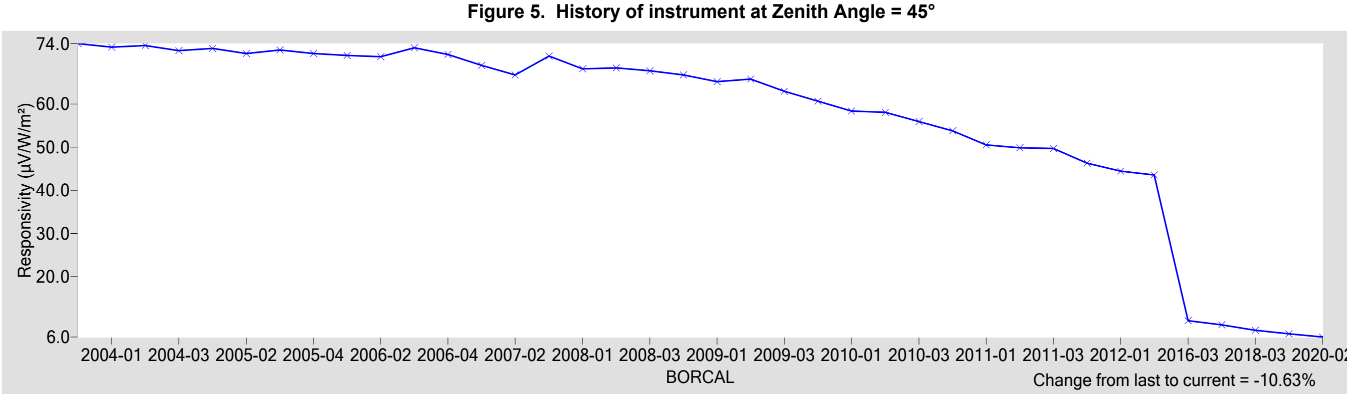
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
6.0067	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.64
Offset Uncertainty, U(off) (%)	+2.4 / -1.2
Expanded Uncertainty, U (%)	+3.0 / -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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

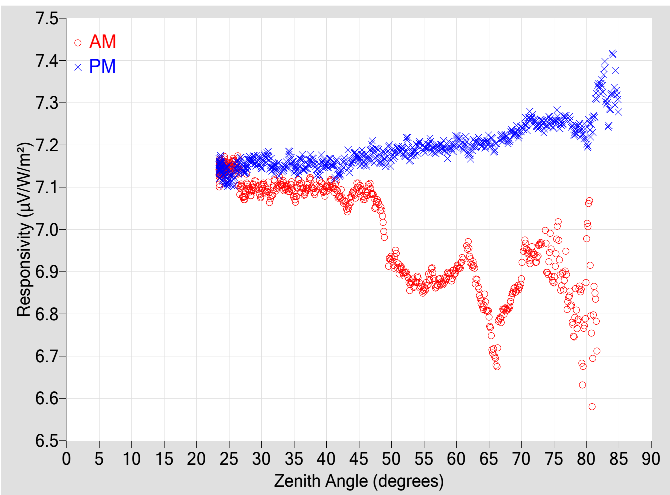


Figure 2. Responsivity vs Local Standard Time

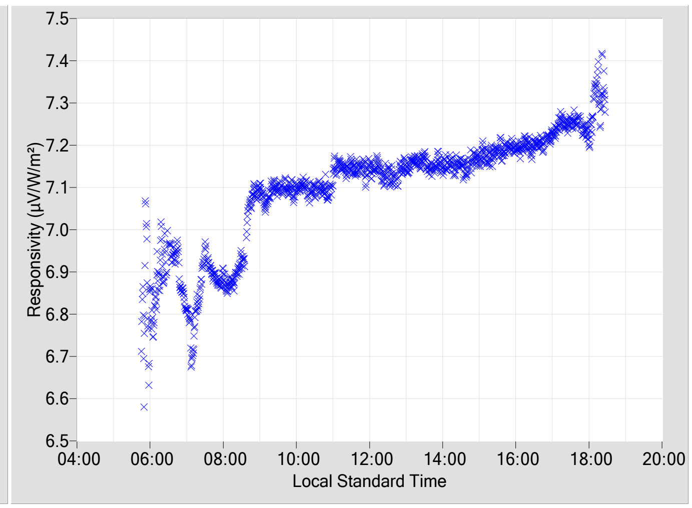


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.0779	0.34	106.81	7.1605	0.32	252.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.0606	0.34	104.56	7.1739	0.35	255.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.9277	0.35	102.39	7.1690	0.36	257.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.8965	0.40	100.41	7.1800	0.34	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.8800	0.37	98.47	7.1945	0.34	261.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.8945	0.39	96.61	7.2003	0.37	263.08
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.8758	0.38	94.83	7.1942	0.36	264.95
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9067	0.39	93.03	7.2119	0.37	266.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9426	0.41	91.33	7.1795	0.38	268.42
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.8207	0.47	89.66	7.2033	0.40	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.6896	0.45	88.02	7.1952	0.42	271.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.8131	0.44	86.41	7.2108	0.44	273.35
24	7.1473	0.32	166.92	7.1368	0.32	193.02	70	6.8847	0.47	84.85	7.2373	0.47	274.97
26	7.1461	0.32	150.78	7.1381	0.31	209.24	72	6.9380	0.54	83.21	7.2564	0.51	276.58
28	7.0977	0.34	140.87	7.1595	0.32	218.03	74	6.9161	0.56	81.59	7.2544	0.57	278.23
30	7.0945	0.34	134.35	7.1538	0.31	224.80	76	6.9021	0.62	79.98	7.2495	0.64	279.82
32	7.1017	0.31	129.35	7.1442	0.33	230.03	78	6.7766	0.71	78.42	7.2351	N/A	281.39
34	7.0960	0.35	124.80	7.1620	0.32	234.50	80	6.9058	N/A	76.77	7.2165	N/A	283.03
36	7.1037	0.33	120.98	7.1609	0.32	238.38	82	N/A	N/A	N/A	7.3377	N/A	284.68
38	7.0907	0.31	117.47	7.1594	0.32	241.88	84	N/A	N/A	N/A	7.3548	N/A	286.42
40	7.0952	0.35	114.55	7.1508	0.32	244.97	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0795	0.32	111.72	7.1313	0.33	247.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.0816	0.32	109.20	7.1630	0.35	250.36	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

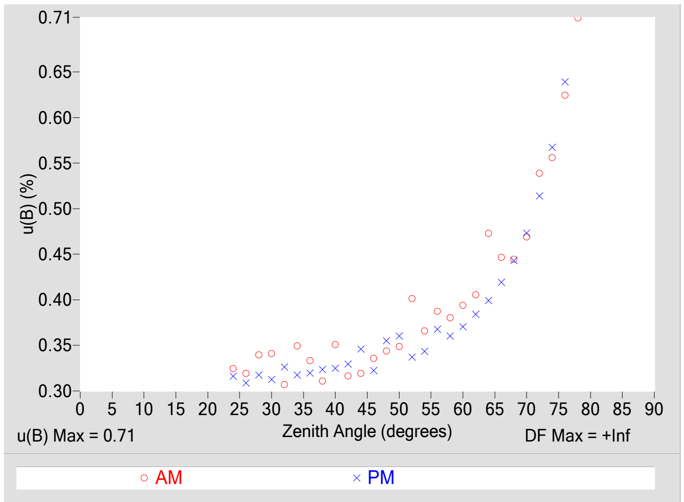


Figure 4. Residuals from Spline Interpolation

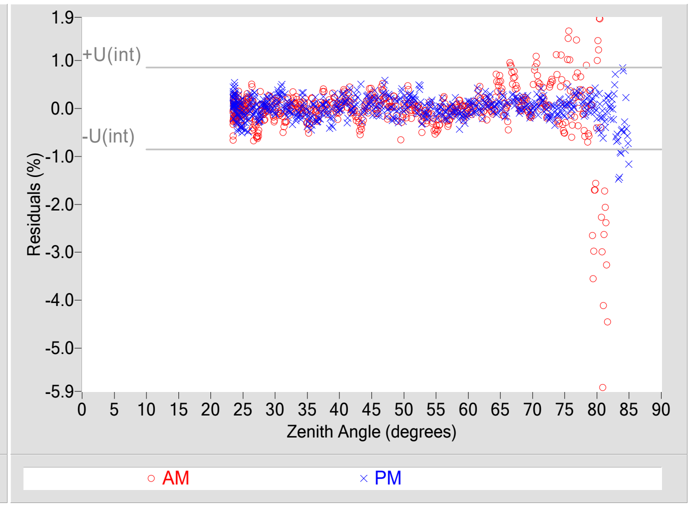


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.71
Type-A Interpolating Function, u(int) (%)	±0.43
Combined Standard Uncertainty, u(c) (%)	±0.83
Effective degrees of freedom, DF(c)	16212
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

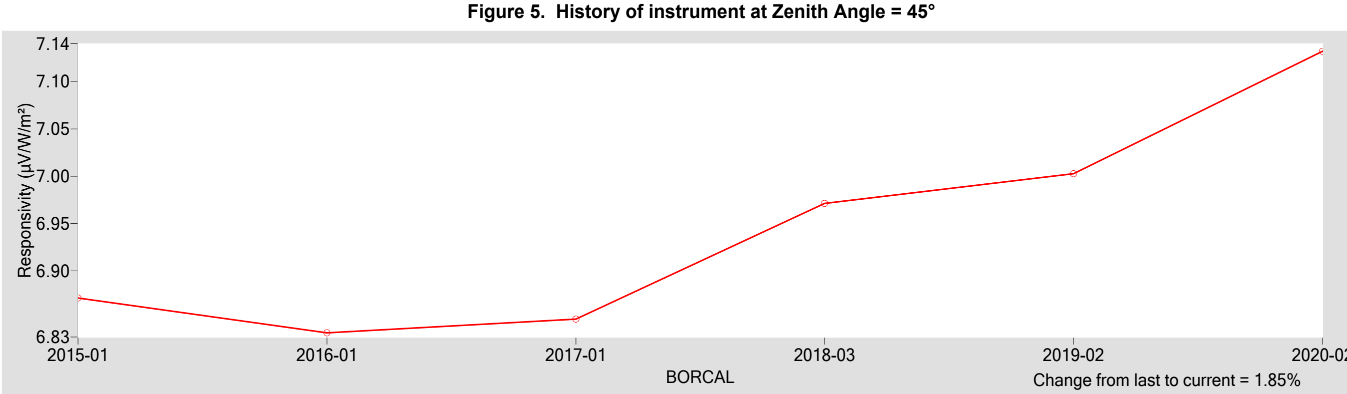
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.1318	0.30000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+1.1 / -3.6
Expanded Uncertainty, U (%)	+1.9 / -4.4
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: Silicon Pyranometer

Manufacturer: EKO

Model: ML-01

Serial Number: S13135063

Calibration Date: 5/5/2020

Due Date: 5/5/2021

Customer: NREL-SRRL-BMS

Environmental Conditions: see page 4

Test Dates: 5/4-5

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

S13135063 EKO ML-01

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

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

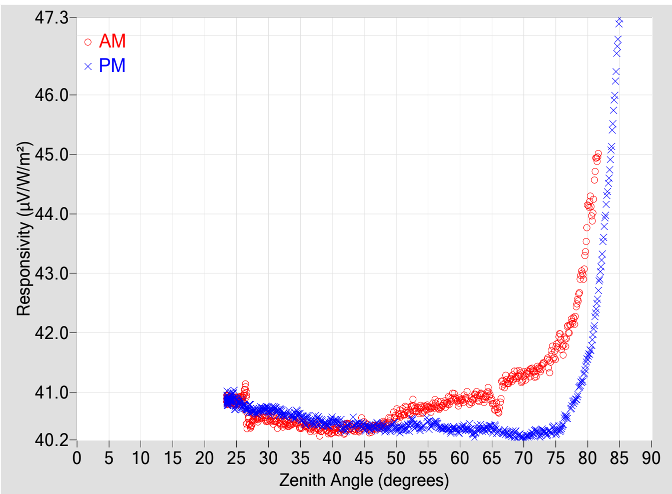


Figure 2. Responsivity vs Local Standard Time

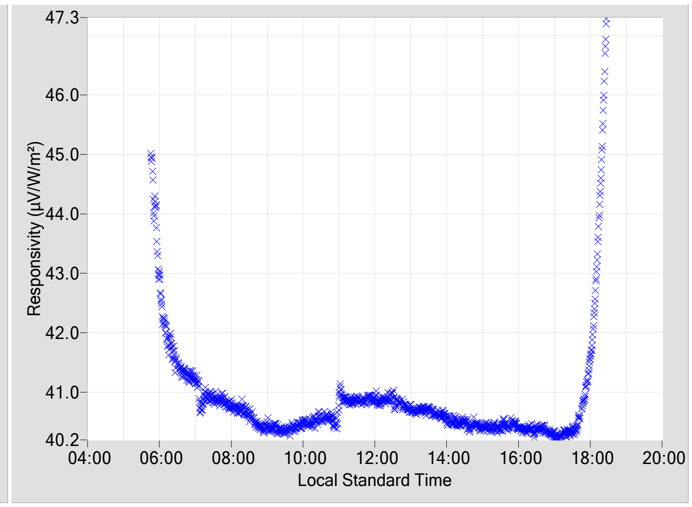


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	40.355	0.32	106.80	40.399	0.31	252.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	40.462	0.31	104.58	40.412	0.33	255.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	40.593	0.33	102.44	40.402	0.31	257.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	40.640	0.34	100.41	40.440	0.32	259.27
8	N/A	N/A	N/A	N/A	N/A	N/A	54	40.717	0.37	98.48	40.410	0.34	261.25
10	N/A	N/A	N/A	N/A	N/A	N/A	56	40.801	0.35	96.61	40.486	0.33	263.13
12	N/A	N/A	N/A	N/A	N/A	N/A	58	40.823	0.36	94.82	40.391	0.33	264.89
14	N/A	N/A	N/A	N/A	N/A	N/A	60	40.851	0.36	93.03	40.372	0.34	266.70
16	N/A	N/A	N/A	N/A	N/A	N/A	62	40.889	0.35	91.33	40.296	0.35	268.42
18	N/A	N/A	N/A	N/A	N/A	N/A	64	40.919	0.38	89.66	40.391	0.36	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	40.738	0.38	88.02	40.338	0.38	271.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	41.227	0.39	86.40	40.282	0.40	273.39
24	40.866	0.30	167.14	40.887	0.31	193.11	70	41.247	0.50	84.81	40.231	0.42	274.97
26	40.918	0.31	150.99	40.767	0.31	209.17	72	41.337	0.45	83.21	40.350	0.45	276.58
28	40.584	0.30	140.90	40.667	0.33	218.11	74	41.510	0.49	81.59	40.334	0.49	278.18
30	40.559	0.31	134.53	40.695	0.33	224.68	76	41.795	0.54	80.02	40.444	0.55	279.82
32	40.506	0.34	129.24	40.660	0.33	230.02	78	42.305	0.61	78.37	40.862	N/A	281.43
34	40.523	0.31	124.79	40.600	0.32	234.58	80	43.940	N/A	76.77	41.588	N/A	283.07
36	40.436	0.31	121.06	40.542	0.30	238.40	82	N/A	N/A	N/A	43.077	N/A	284.72
38	40.352	0.32	117.62	40.517	0.31	241.87	84	N/A	N/A	N/A	45.617	N/A	286.37
40	40.353	0.30	114.55	40.533	0.35	244.97	86	N/A	N/A	N/A	N/A	N/A	N/A
42	40.360	0.32	111.72	40.379	0.30	247.78	88	N/A	N/A	N/A	N/A	N/A	N/A
44	40.388	0.34	109.19	40.468	0.32	250.42	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

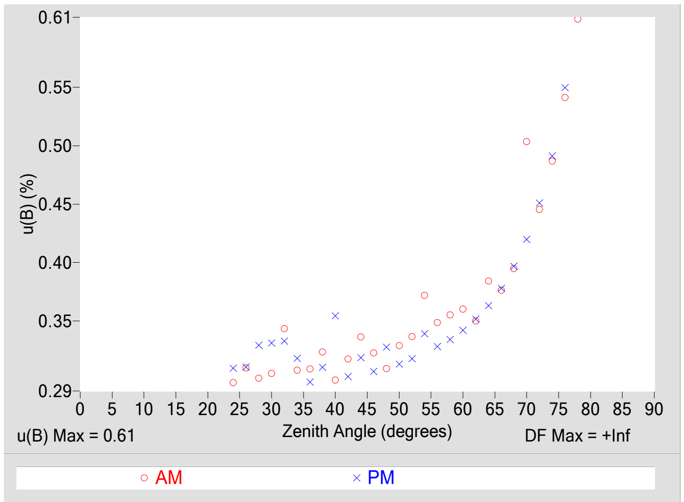


Figure 4. Residuals from Spline Interpolation

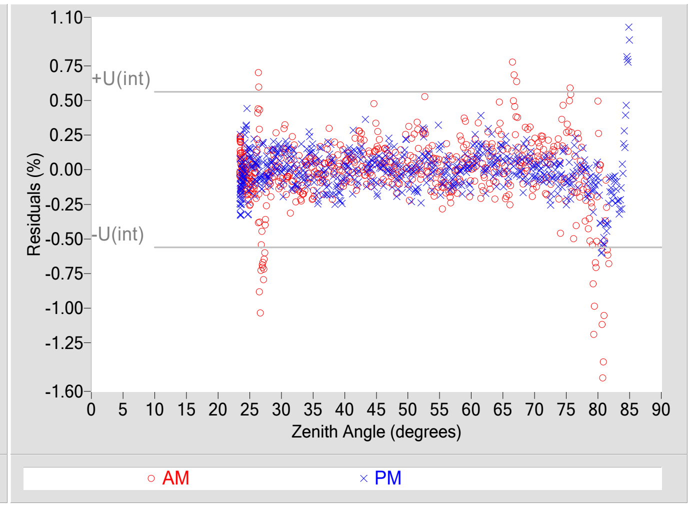


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	37749
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

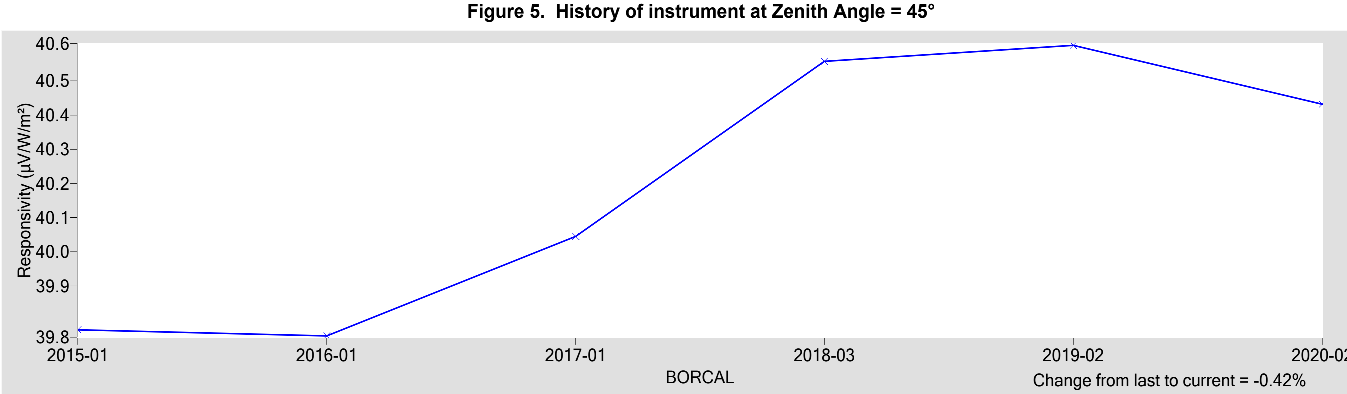
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
40.432	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.73
Offset Uncertainty, U(off) (%)	+1.0 / -0.20
Expanded Uncertainty, U (%)	+1.8 / -0.93
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Pyranometer	**Manufacturer:**	EKO
Model:	MS-410	**Serial Number:**	S13144.085R
Calibration Date:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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

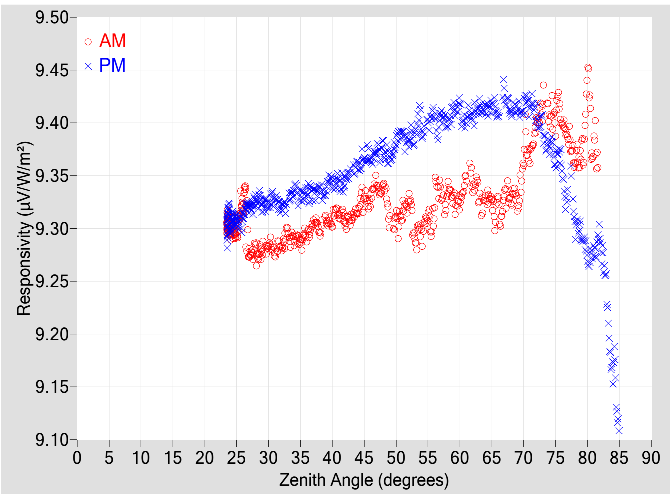


Figure 2. Responsivity vs Local Standard Time

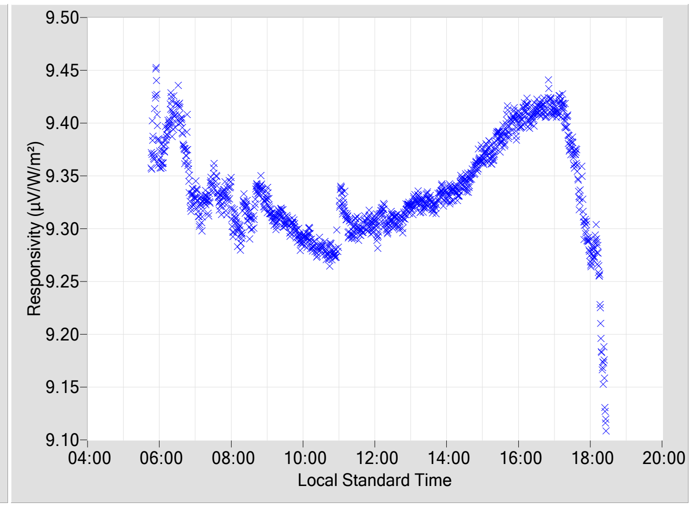


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.3273	0.31	106.80	9.3645	0.31	252.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.3392	0.34	104.53	9.3755	0.32	255.11
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3062	0.32	102.39	9.3819	0.33	257.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3241	0.34	100.41	9.3833	0.34	259.27
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2952	0.35	98.46	9.3973	0.33	261.20
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3238	0.34	96.61	9.4081	0.35	263.08
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3299	0.36	94.82	9.3985	0.34	264.94
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3256	0.39	93.08	9.4147	0.35	266.70
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3418	0.38	91.33	9.4067	0.36	268.42
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.3273	0.42	89.66	9.4145	0.37	270.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.3219	0.47	88.02	9.4070	0.39	271.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.3274	0.41	86.40	9.4097	0.41	273.34
24	9.3003	0.31	166.89	9.3073	0.31	193.02	70	9.3722	0.43	84.80	9.4160	0.44	274.97
26	9.3260	0.30	150.99	9.3103	0.32	209.18	72	9.3990	0.46	83.21	9.4054	0.47	276.58
28	9.2822	0.32	140.68	9.3257	0.31	218.11	74	9.4060	0.51	81.59	9.3778	0.52	278.22
30	9.2830	0.32	134.45	9.3232	0.32	224.80	76	9.3999	0.57	79.97	9.3565	0.58	279.82
32	9.2818	0.30	129.21	9.3193	0.31	230.02	78	9.3659	0.64	78.41	9.3053	N/A	281.43
34	9.2908	0.31	124.79	9.3365	0.31	234.49	80	9.4339	N/A	76.77	9.2731	N/A	283.03
36	9.2939	0.33	120.99	9.3363	0.34	238.46	82	N/A	N/A	N/A	9.2858	N/A	284.67
38	9.2985	0.30	117.62	9.3380	0.32	241.92	84	N/A	N/A	N/A	9.1719	N/A	286.41
40	9.3070	0.32	114.55	9.3433	0.31	244.97	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3050	0.32	111.72	9.3456	0.32	247.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3161	0.32	109.19	9.3610	0.32	250.36	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

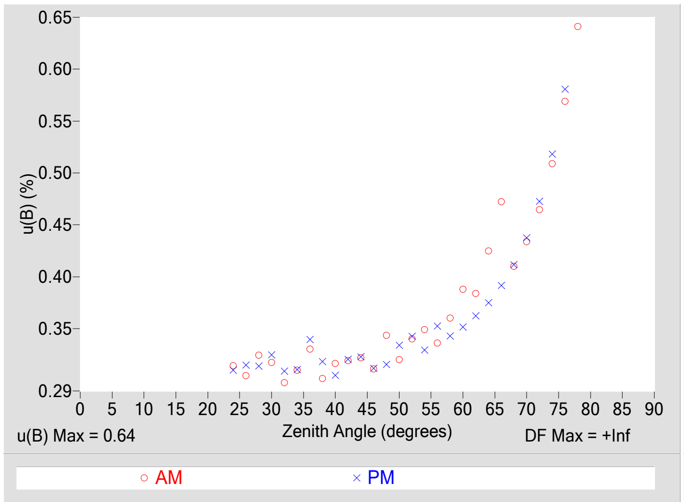


Figure 4. Residuals from Spline Interpolation

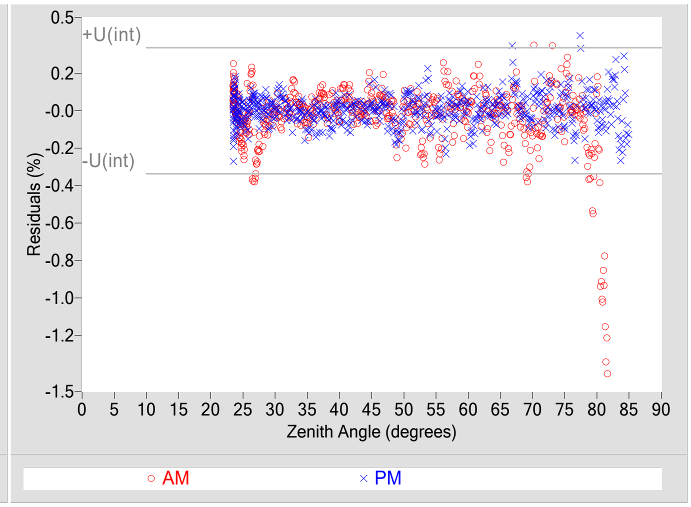


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	273164
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

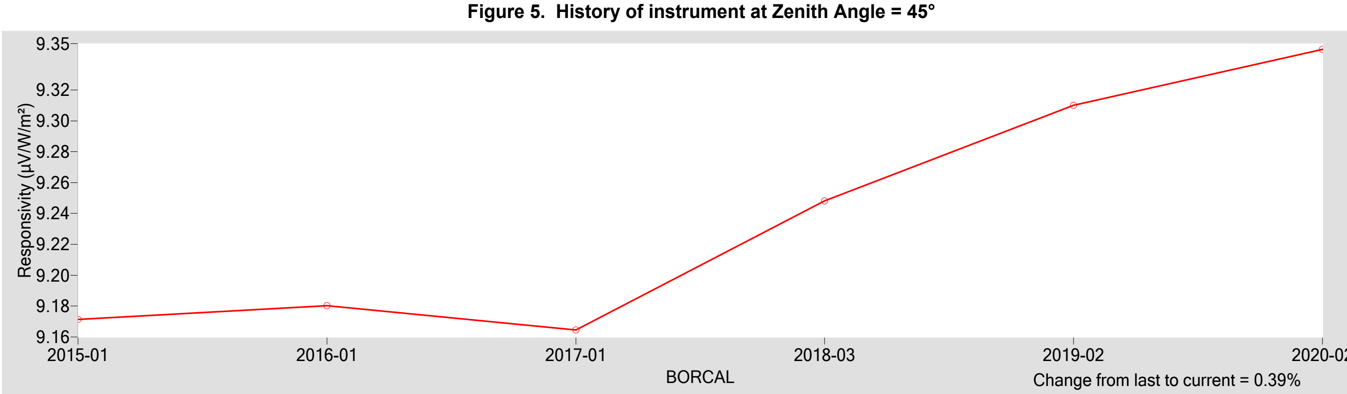
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3463	0.20000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.76
Offset Uncertainty, U(off) (%)	+0.73 / -0.69
Expanded Uncertainty, U (%)	+1.5 / -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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

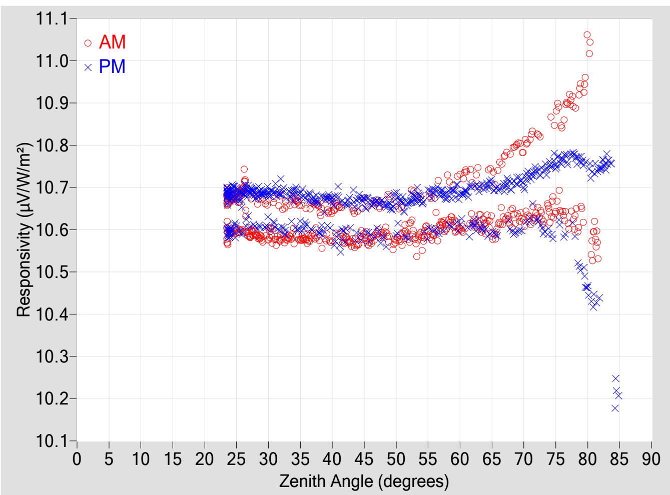


Figure 2. Responsivity vs Local Standard Time

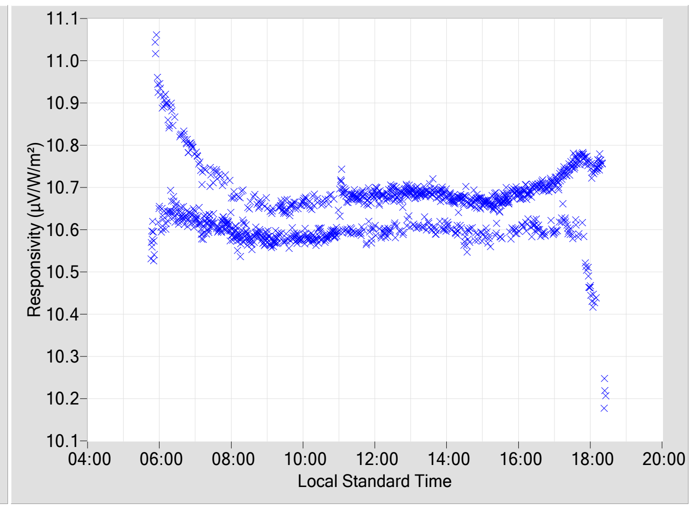


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.574	0.31	106.81	10.635	0.32	252.87
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.602	0.33	104.57	10.635	0.31	255.12
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.592	0.33	102.40	10.639	0.31	257.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.594	0.32	100.41	10.648	0.34	259.28
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.594	0.34	98.44	10.668	0.34	261.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.614	0.36	96.62	10.659	0.33	263.09
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.633	0.34	94.78	10.670	0.34	264.95
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.627	0.34	93.04	10.646	0.34	266.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.638	0.35	91.34	10.632	0.35	268.38
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.614	0.42	89.66	10.686	0.37	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.667	0.38	88.02	10.669	0.38	271.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.659	0.40	86.41	10.669	0.40	273.35
24	10.653	0.30	167.05	10.637	0.31	193.13	70	10.722	0.46	84.81	10.709	0.42	274.98
26	10.684	0.30	151.01	10.666	0.31	209.20	72	10.676	0.45	83.22	10.683	0.46	276.59
28	10.622	0.34	140.63	10.666	0.32	218.04	74	10.687	0.49	81.59	10.691	0.50	278.19
30	10.599	0.34	134.24	10.681	0.30	224.70	76	10.744	0.59	79.98	10.733	0.56	279.78
32	10.606	0.32	129.36	10.681	0.32	230.04	78	10.715	0.62	78.42	10.744	N/A	281.39
34	10.634	0.33	124.81	10.675	0.30	234.50	80	11.039	N/A	76.69	10.557	N/A	283.04
36	10.589	0.32	120.99	10.656	0.30	238.41	82	N/A	N/A	N/A	10.684	N/A	284.72
38	10.635	0.32	117.55	10.619	0.34	241.88	84	N/A	N/A	N/A	10.178	N/A	286.64
40	10.621	0.34	114.56	10.653	0.31	244.98	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.582	0.32	111.73	10.625	0.30	247.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.580	0.30	109.26	10.657	0.31	250.37	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

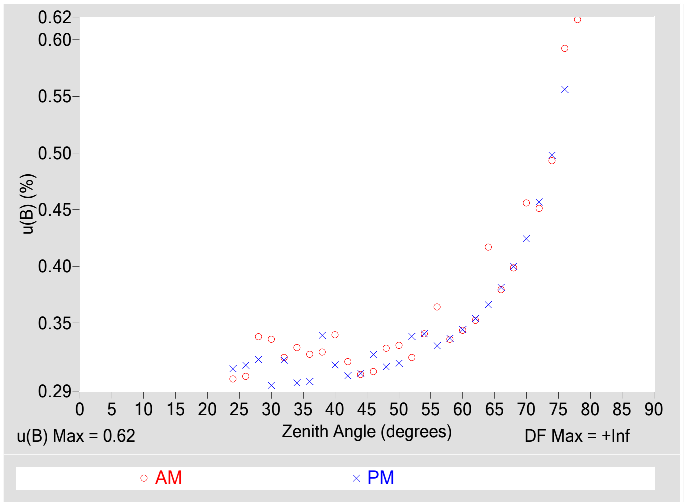


Figure 4. Residuals from Spline Interpolation

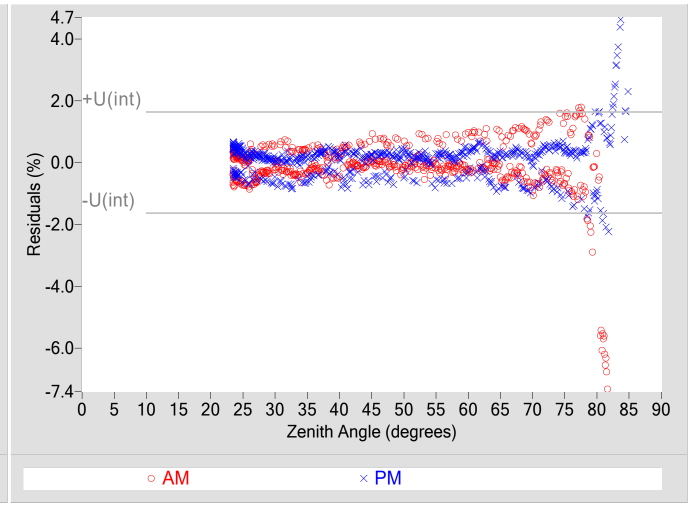


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.82
Combined Standard Uncertainty, u(c) (%)	±1.0
Effective degrees of freedom, DF(c)	2831
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±2.0
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

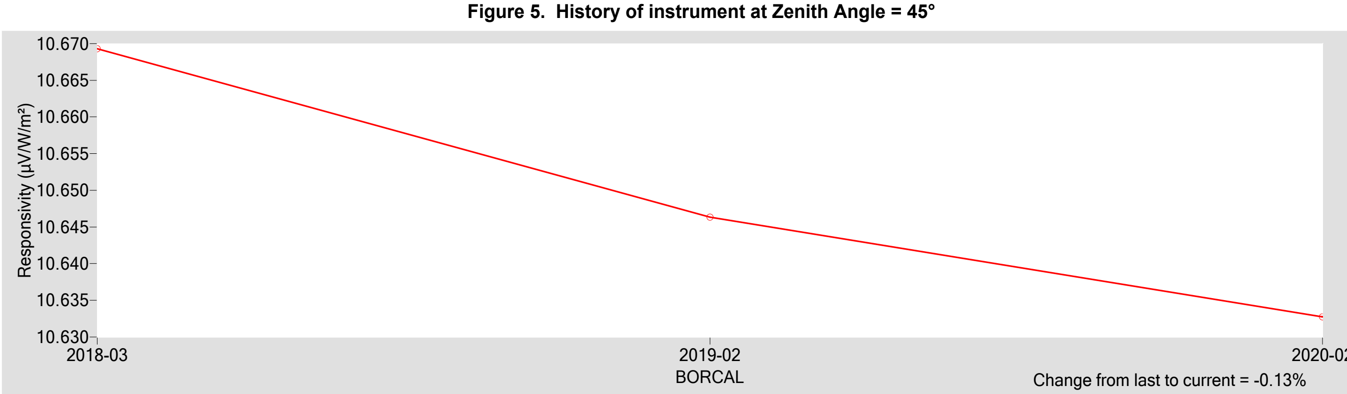
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.633	0.043000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.45 / -0.56
Expanded Uncertainty, U (%)	+1.2 / -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:	5/5/2020	**Due Date:**	5/5/2021
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	5/4-5		

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

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/27/2019	09/27/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/17/2020	04/17/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/17/2020	04/17/2021
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: Afshin Andreas, Ibrahim Reda, Peter Gotseff, and 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:

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

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

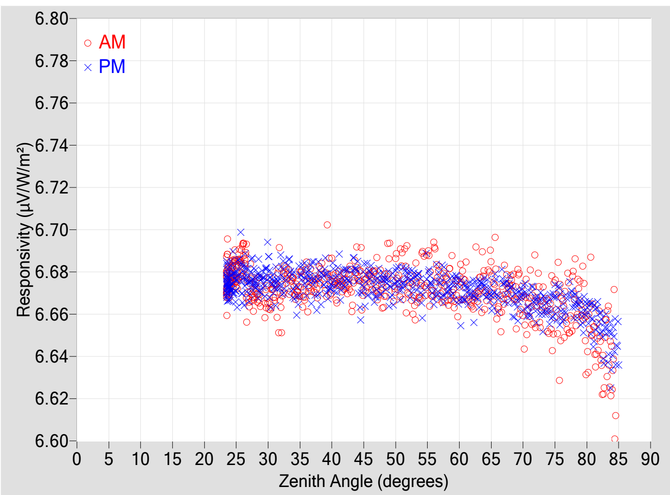


Figure 2. Responsivity vs Local Standard Time

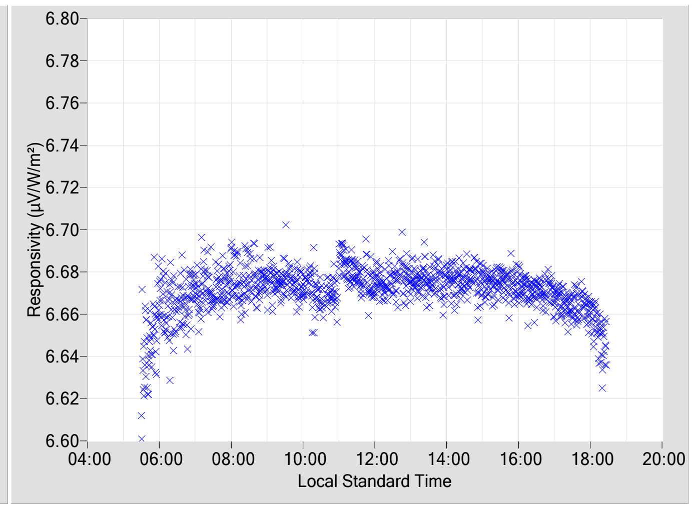


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	6.6780	0.29	106.81	6.6780	0.30	252.80
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.6682	0.29	104.53	6.6753	0.30	255.05
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.6768	0.30	102.45	6.6773	0.29	257.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.6759	0.31	100.41	6.6763	0.29	259.27
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.6771	0.30	98.49	6.6688	0.29	261.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.6833	0.29	96.61	6.6695	0.29	263.13
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.6714	0.32	94.78	6.6728	0.30	264.90
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.6724	0.32	93.04	6.6687	0.30	266.70
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.6649	0.31	91.33	6.6720	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.6714	0.31	89.66	6.6720	0.30	270.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.6660	0.32	88.02	6.6685	0.30	271.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	6.6739	0.30	86.40	6.6732	0.30	273.39
24	6.6766	0.29	166.93	6.6737	0.30	192.72	70	6.6613	0.30	84.81	6.6702	0.30	274.97
26	6.6876	0.30	151.14	6.6756	0.30	209.18	72	6.6659	0.30	83.21	6.6636	0.31	276.58
28	6.6686	0.30	140.90	6.6767	0.30	218.15	74	6.6596	0.31	81.59	6.6634	0.31	278.18
30	6.6678	0.31	134.48	6.6817	0.30	224.69	76	6.6571	0.31	80.02	6.6610	0.31	279.82
32	6.6693	0.31	129.18	6.6779	0.29	230.13	78	6.6726	0.32	78.37	6.6646	N/A	281.43
34	6.6739	0.30	124.80	6.6732	0.29	234.40	80	6.6425	N/A	76.77	6.6616	N/A	283.07
36	6.6726	0.31	120.98	6.6767	0.31	238.46	82	6.6479	N/A	75.12	6.6567	N/A	284.72
38	6.6768	0.31	117.62	6.6743	0.32	241.82	84	6.6391	N/A	73.41	6.6422	N/A	286.37
40	6.6755	0.29	114.48	6.6773	0.29	244.97	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.6754	0.31	111.80	6.6775	0.29	247.78	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.6812	0.30	109.13	6.6783	0.29	250.43	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

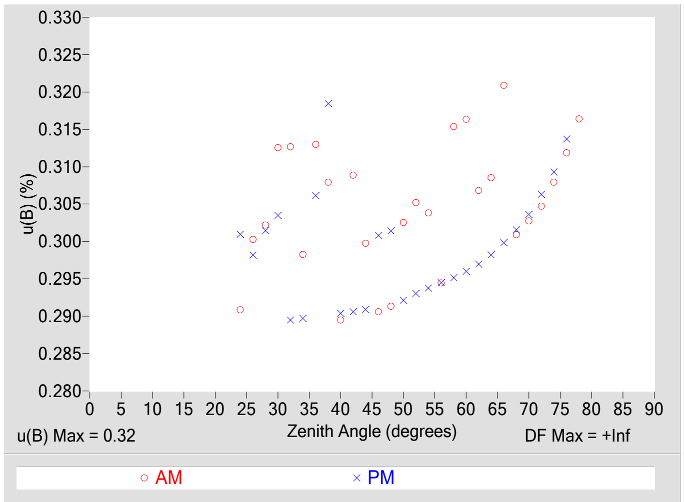


Figure 4. Residuals from Spline Interpolation

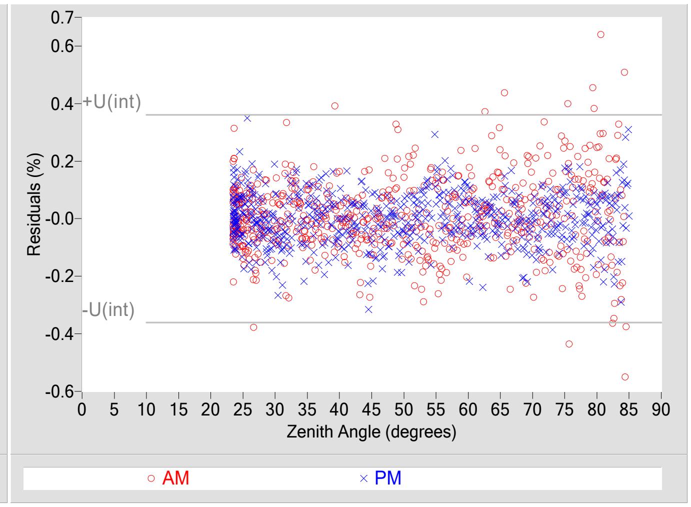


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	19866
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.72
AM Valid zenith angle range	24° to 78°
PM Valid zenith angle range	24° to 76°

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

Table 4. Calibration Label Values

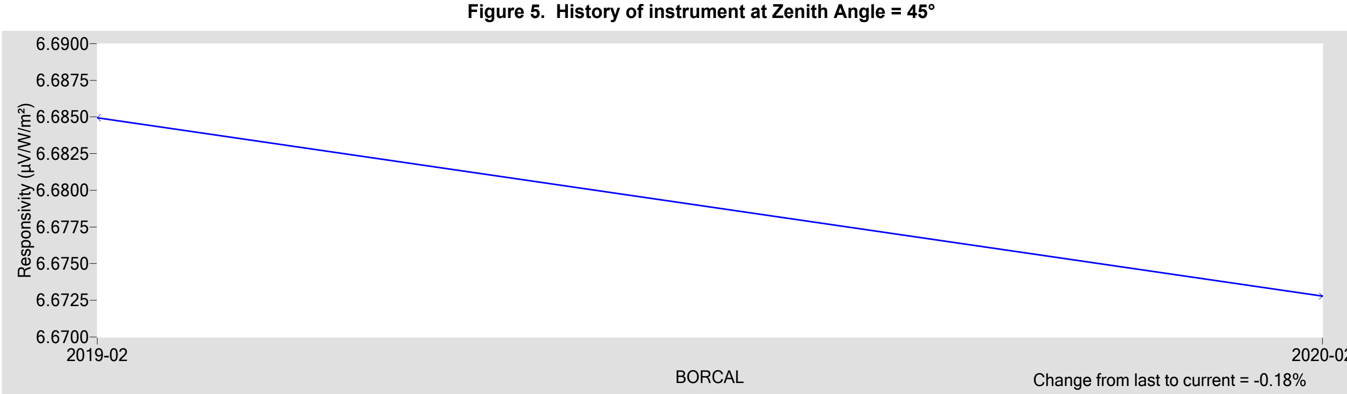
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
6.6728	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.16 / -0.075
Expanded Uncertainty, U (%)	+0.78 / -0.70
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Environmental and Sky Conditions for BORCAL-SW 2020-02

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

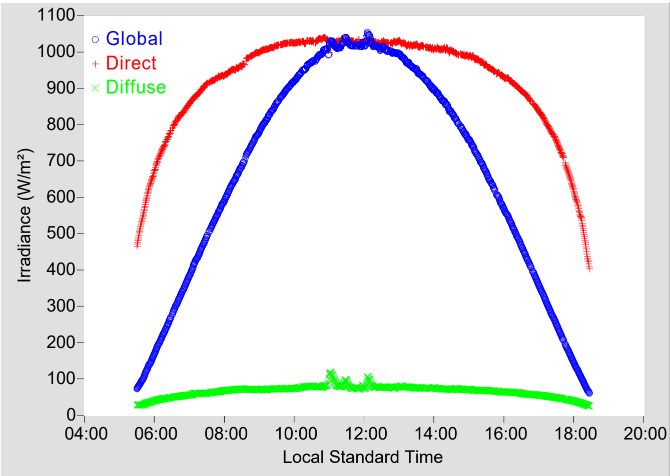
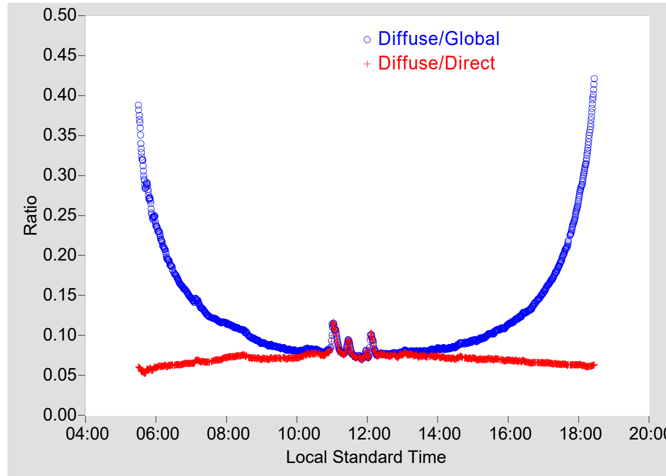


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

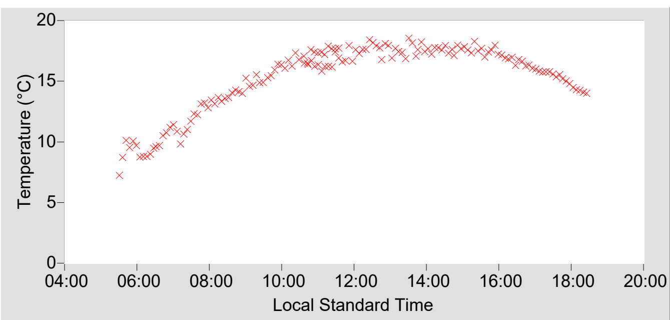


Figure 9. Humidity

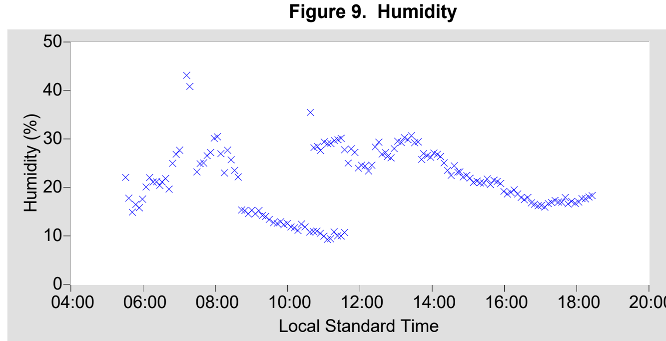


Figure 10. Pressure

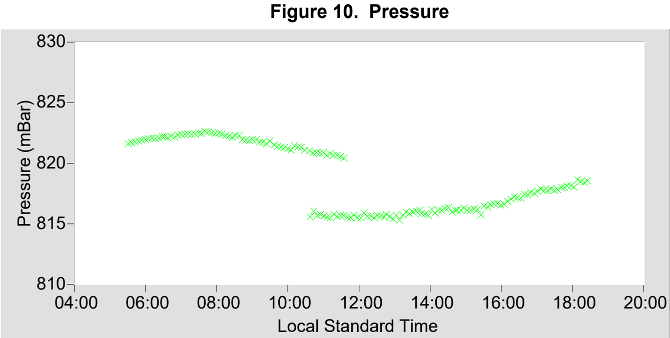


Figure 11. Effective Net Infrared

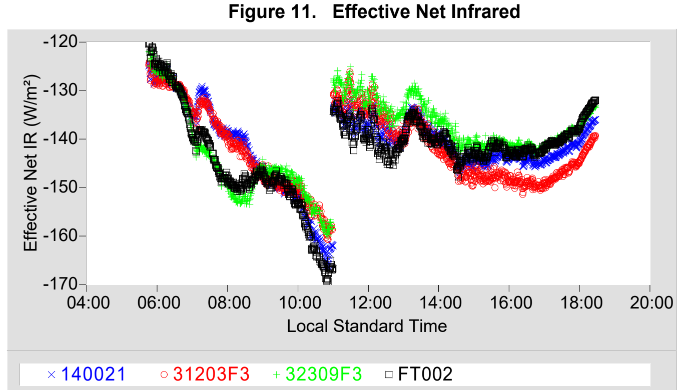


Figure 12. Estimated Broadband Aerosol Optical Depth

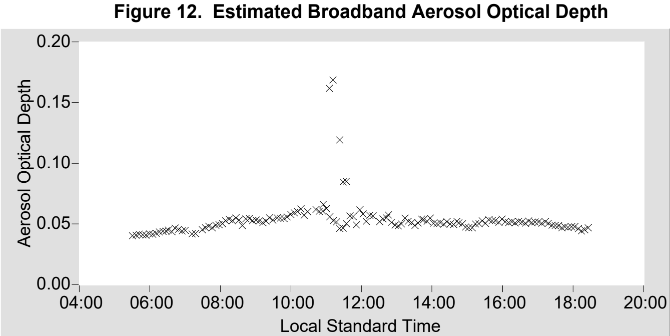


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	15.40	7.23	18.54
Humidity (%)	21.22	9.24	43.11
Pressure (mBar)	818.7	815.3	822.6
Est. Aerosol Optical Depth (BB)	0.053	0.040	0.168

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).

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

Session Config: 1171 Apogee SP-510; Number: 2
Comments:
30K Thermistor measured by spare SP-510 pyrgeometer mounted next to pyranometer.