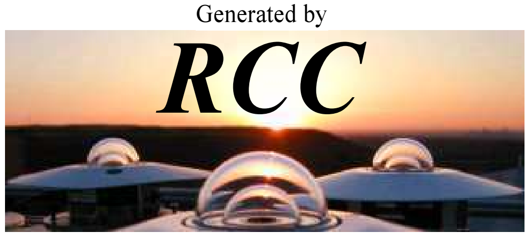
Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2019-04

Generated by



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
07/19/2019 to 07/29/2019

Report Date
July 30, 2019

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

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

This report includes these sections:

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

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

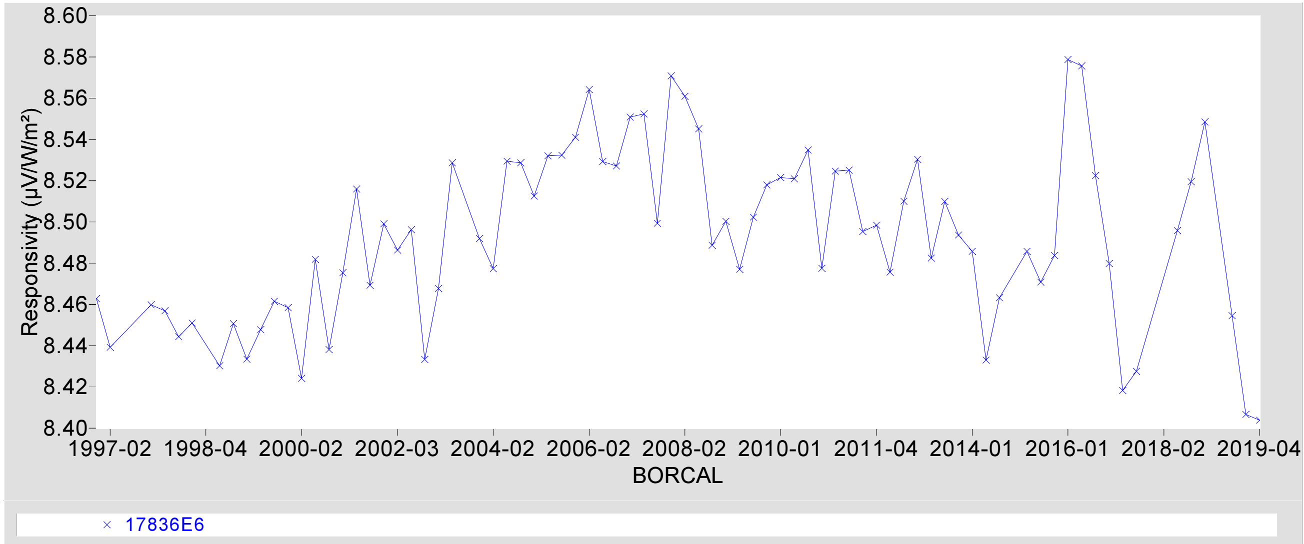
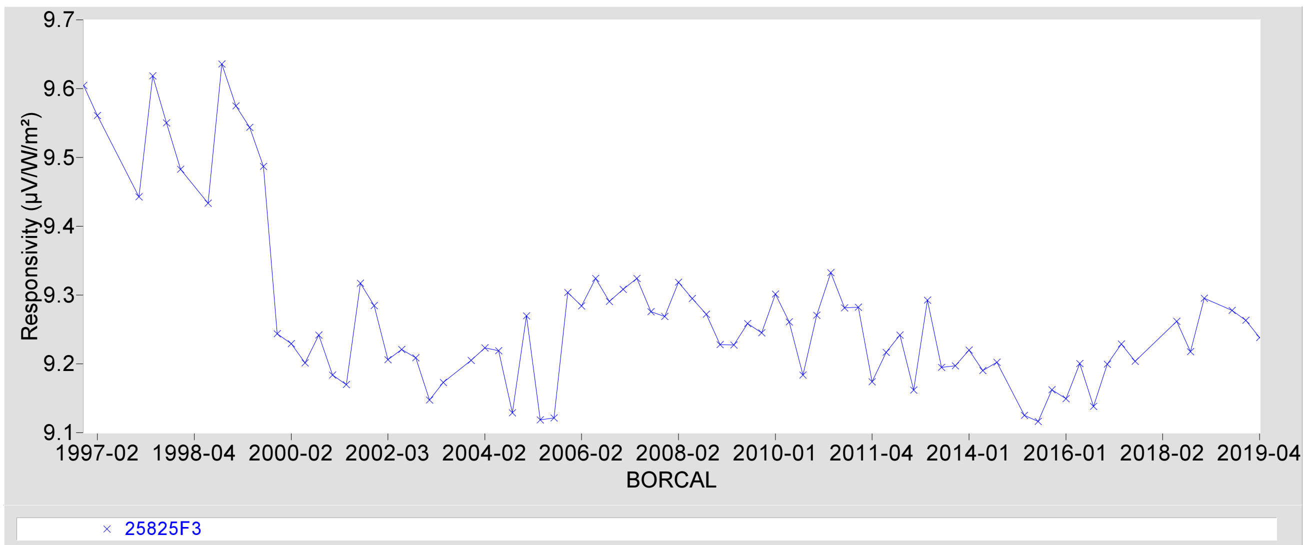


Figure 2. Eppley PSP Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	R@45 ¹ (μV/W/m²)	CF@45 ¹ (W/m²/mV)	U ² (%)	Rnet ³ (μV/W/m²)	Page
19621F3 Eppley PSP	7.6384	130.92	+2.4 / -2.8	0.60000	A1-2
25782F3 Eppley PSP	8.7027	114.91	+4.1 / -6.7	0.76000	A1-5
28400F3 Eppley PSP	7.3857	135.40	+3.1 / -4.1	0.60000	A1-8
31394F3 Eppley PSP	7.9987	125.02	+3.4 / -5.0	0.60000	A1-11
PY1711 Licor LI200	12.498	80.013	+3.2 / -2.8	0	A1-14
PY1744 Licor LI200	14.660	68.211	+2.3 / -2.2	0	A1-17
PY28246 Licor LI200	12.250	81.634	+1.2 / -2.0	0	A1-20
PY28262 Licor LI200	11.435	87.448	+2.1 / -2.4	0	A1-23
PY66482 Licor LI200	7.6323	131.02	+2.7 / -3.7	0	A1-26

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 A1-29.

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:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	19621F3
Calibration Date:	7/29/2019	**Due Date:**	7/29/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	7/19, 7/29		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† 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, Aron Habte, 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

19621F3 Eppley PSP

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

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

where,

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

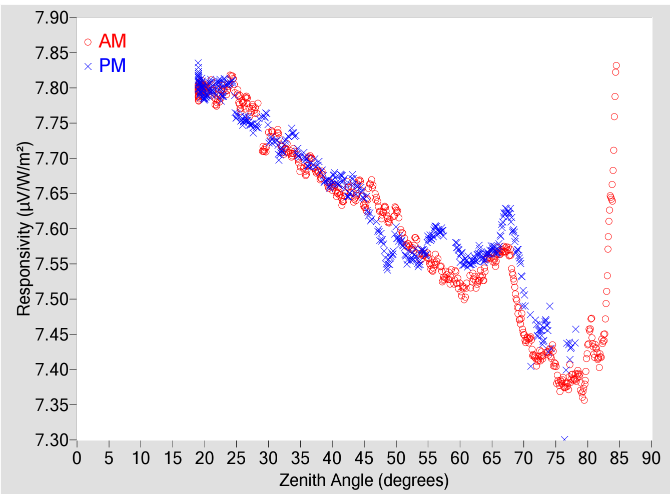


Figure 2. Responsivity vs Local Standard Time

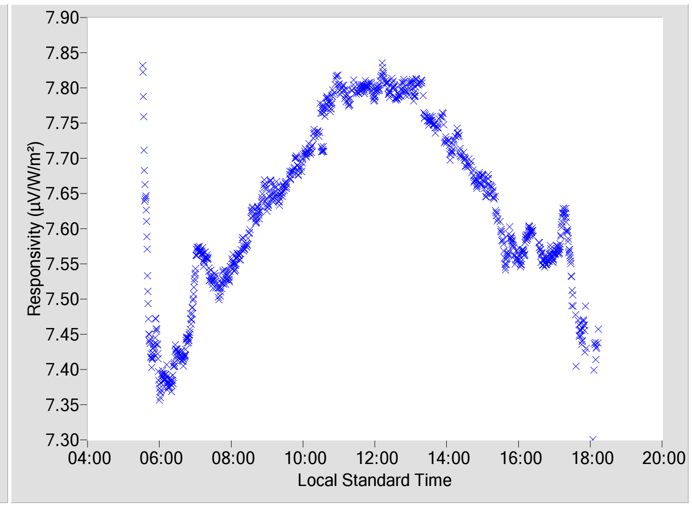


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6637	0.41	102.83	7.6156	0.45	260.66
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6239	0.42	100.82	7.5782	0.47	262.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6255	0.43	98.81	7.5909	0.48	264.54
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5767	0.44	96.98	7.5588	0.49	266.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5603	0.45	95.05	7.5656	0.51	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5497	0.47	93.30	7.5997	0.52	269.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5338	0.49	91.58	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5132	0.51	89.86	7.5635	0.57	272.97
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5305	0.53	88.17	7.5541	0.61	274.59
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5512	0.56	86.56	7.5601	0.65	276.18
20	7.7999	0.35	158.97	7.7890	0.36	200.65	66	7.5661	0.59	84.96	7.5743	0.69	277.75
22	7.7845	0.36	145.83	7.8040	0.36	214.41	68	7.5518	0.63	83.37	7.6114	N/A	279.31
24	7.8106	0.35	137.13	7.8083	0.36	222.97	70	7.4481	0.68	81.79	7.4996	N/A	280.82
26	7.7768	0.36	130.74	7.7530	0.37	229.42	72	7.4133	0.74	80.23	7.4569	N/A	282.45
28	7.7669	0.36	125.64	7.7459	0.37	234.73	74	7.4230	N/A	78.63	7.4500	N/A	283.96
30	7.7340	0.36	127.03	7.7393	0.38	238.76	76	7.3827	N/A	77.07	N/A	N/A	N/A
32	7.7151	0.36	122.79	7.7098	0.39	242.57	78	7.3870	N/A	75.46	7.4475	N/A	287.18
34	7.7093	0.37	119.31	7.7342	0.39	245.86	80	7.4272	N/A	73.84	N/A	N/A	N/A
36	7.6855	0.37	115.79	7.6948	0.40	248.90	82	7.4224	N/A	72.15	N/A	N/A	N/A
38	7.6751	0.38	112.72	7.6882	0.41	251.51	84	7.6978	N/A	70.47	N/A	N/A	N/A
40	7.6596	0.38	110.02	7.6704	0.41	254.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6451	0.39	107.56	7.6642	0.42	256.32	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6563	0.40	105.13	7.6575	0.43	258.50	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

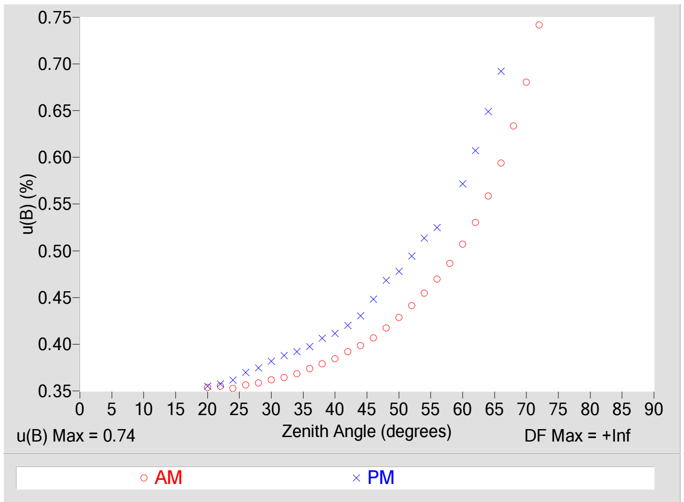


Figure 4. Residuals from Spline Interpolation

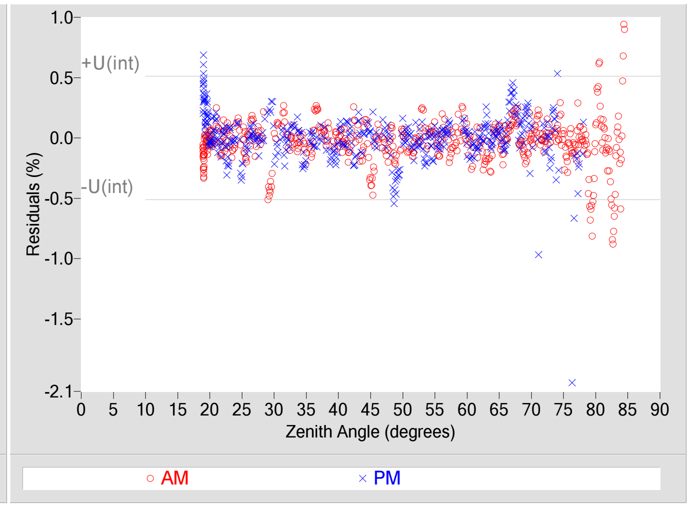


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.78
Effective degrees of freedom, DF(c)	76698
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

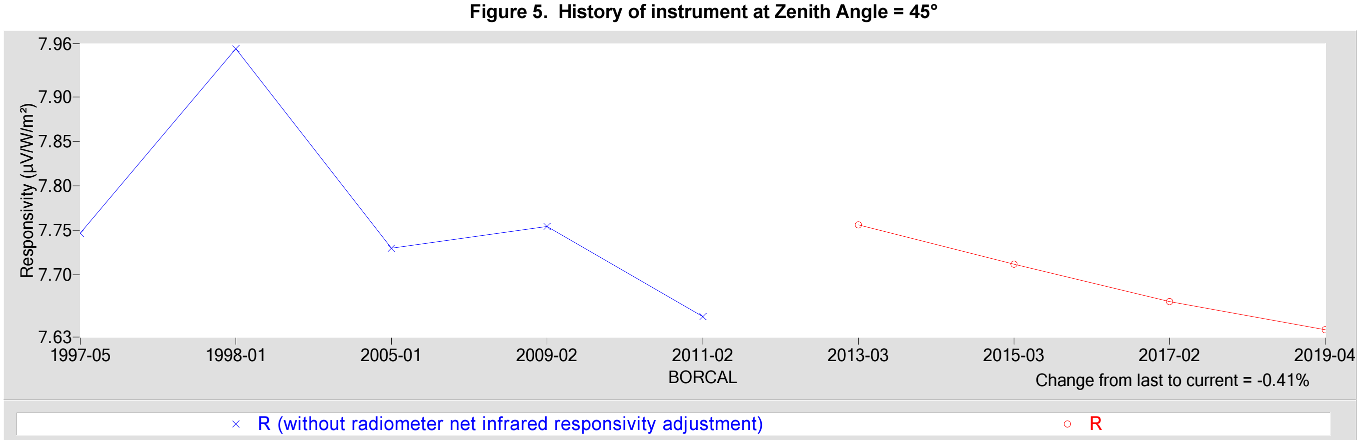
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6384	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.1
Offset Uncertainty, U(off) (%)	+1.3 / -1.6
Expanded Uncertainty, U (%)	+2.4 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	25782F3
Calibration Date:	7/29/2019	**Due Date:**	7/29/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	7/19, 7/29		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† 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, Aron Habte, 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

25782F3 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

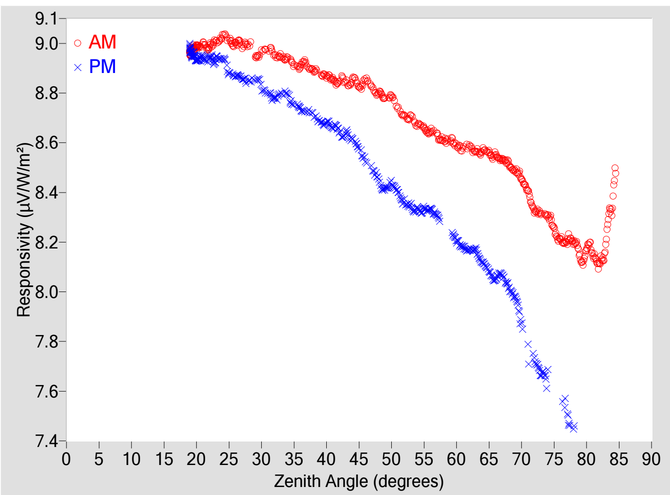


Figure 2. Responsivity vs Local Standard Time

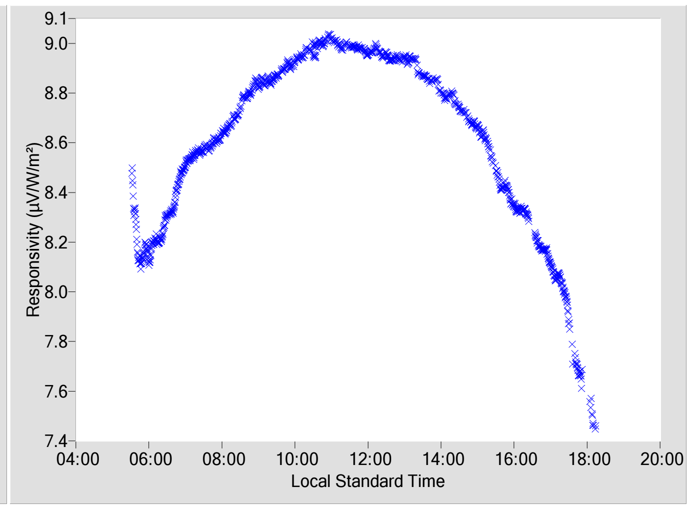


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	8.8533	0.37	102.83	8.5281	0.40	260.66
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7996	0.38	100.82	8.4548	0.41	262.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7857	0.39	98.81	8.4344	0.42	264.54
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7101	0.40	96.98	8.3578	0.44	266.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6726	0.41	95.05	8.3340	0.45	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6432	0.42	93.30	8.3327	0.46	269.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6133	0.44	91.58	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5861	0.45	89.86	8.2082	0.50	272.97
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5861	0.47	88.17	8.1699	0.53	274.59
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5685	0.50	86.56	8.1166	0.56	276.18
20	8.9868	0.33	158.97	8.9345	0.33	200.65	66	8.5499	0.53	84.96	8.0518	0.60	277.75
22	8.9861	0.33	145.83	8.9412	0.33	214.41	68	8.5150	0.56	83.37	8.0165	N/A	279.31
24	9.0267	0.33	137.13	8.9370	0.33	222.97	70	8.4501	0.60	81.79	7.8707	N/A	280.82
26	8.9990	0.33	130.74	8.8690	0.34	229.42	72	8.3266	0.65	80.23	7.7251	N/A	282.45
28	8.9916	0.33	125.64	8.8494	0.34	234.73	74	8.3028	N/A	78.63	7.6491	N/A	283.88
30	8.9712	0.34	127.03	8.8268	0.35	238.76	76	8.2127	N/A	77.07	N/A	N/A	N/A
32	8.9505	0.34	122.79	8.7807	0.35	242.57	78	8.1998	N/A	75.46	7.4540	N/A	287.18
34	8.9412	0.34	119.31	8.7966	0.36	245.86	80	8.1694	N/A	73.84	N/A	N/A	N/A
36	8.9083	0.35	115.79	8.7361	0.36	248.90	82	8.1173	N/A	72.15	N/A	N/A	N/A
38	8.8901	0.35	112.72	8.7145	0.37	251.51	84	8.3659	N/A	70.47	N/A	N/A	N/A
40	8.8682	0.36	110.02	8.6813	0.37	254.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8447	0.36	107.56	8.6501	0.38	256.32	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8496	0.37	105.13	8.6151	0.39	258.50	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

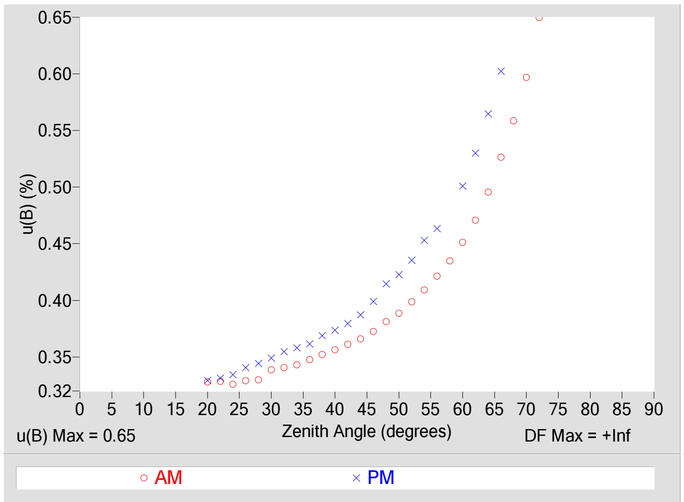


Figure 4. Residuals from Spline Interpolation

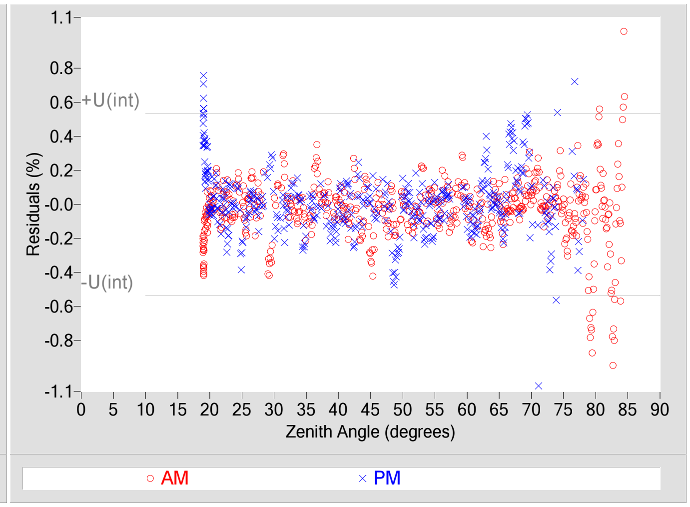


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.70
Effective degrees of freedom, DF(c)	41252
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

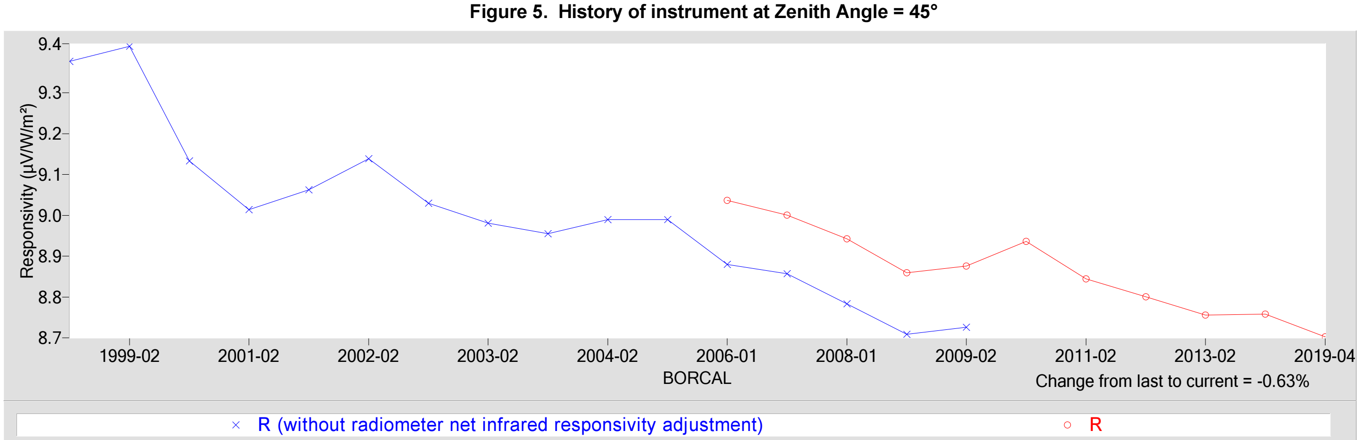
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7027	0.76000

† Rnet determination date: 02/28/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+3.1 / -5.7
Expanded Uncertainty, U (%)	+4.1 / -6.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	28400F3
Calibration Date:	7/29/2019	**Due Date:**	7/29/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	7/19, 7/29		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† 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, Aron Habte, 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

28400F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

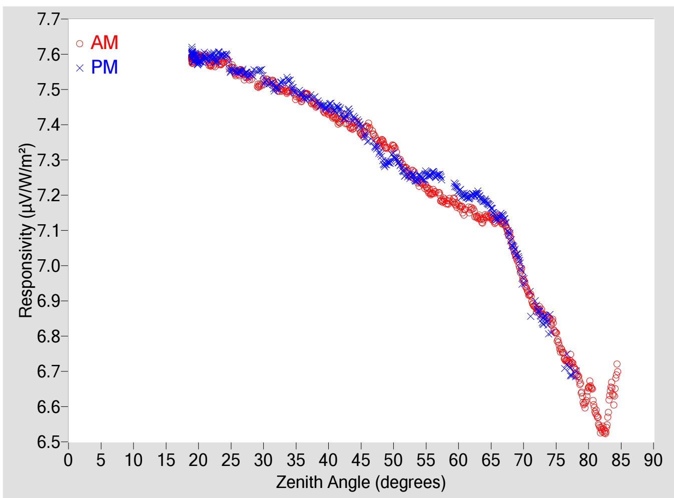


Figure 2. Responsivity vs Local Standard Time

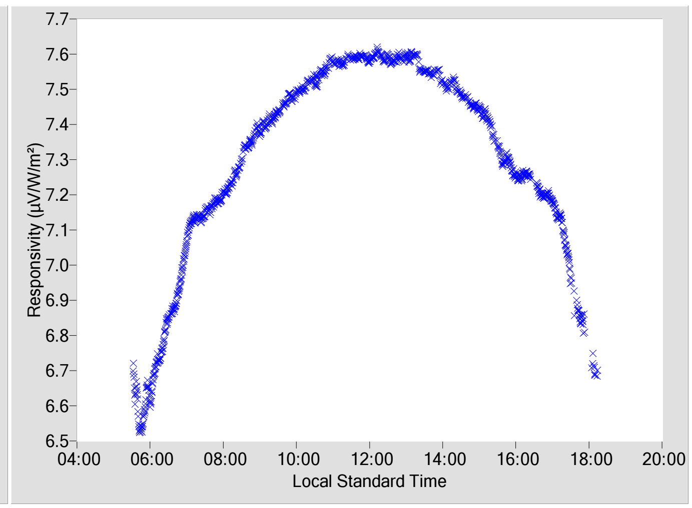


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.3958	0.41	102.83	7.3587	0.45	260.66
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3506	0.42	100.82	7.3170	0.47	262.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3367	0.43	98.81	7.3108	0.48	264.54
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2758	0.45	96.98	7.2596	0.50	266.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2335	0.46	95.05	7.2535	0.52	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2060	0.48	93.30	7.2633	0.53	269.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1844	0.49	91.58	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1677	0.51	89.86	7.2143	0.58	272.97
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1614	0.54	88.17	7.1988	0.62	274.59
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.1371	0.57	86.56	7.1834	0.66	276.18
20	7.5905	0.36	158.97	7.5785	0.36	200.65	66	7.1362	0.61	84.96	7.1336	0.71	277.75
22	7.5748	0.36	145.83	7.5935	0.36	214.41	68	7.0753	0.65	83.37	7.0730	N/A	279.31
24	7.5837	0.36	137.13	7.5985	0.36	222.97	70	6.9571	0.70	81.79	6.9564	N/A	280.82
26	7.5475	0.36	130.74	7.5507	0.37	229.42	72	6.8761	0.76	80.23	6.8816	N/A	282.45
28	7.5322	0.36	125.64	7.5448	0.38	234.73	74	6.8449	N/A	78.63	6.8269	N/A	283.96
30	7.5270	0.36	127.03	7.5335	0.38	238.76	76	6.7541	N/A	77.07	N/A	N/A	N/A
32	7.5026	0.37	122.79	7.5052	0.39	242.57	78	6.7011	N/A	75.46	6.6925	N/A	287.18
34	7.4966	0.37	119.31	7.5238	0.39	245.86	80	6.6512	N/A	73.84	N/A	N/A	N/A
36	7.4752	0.38	115.79	7.4828	0.40	248.90	82	6.5357	N/A	72.15	N/A	N/A	N/A
38	7.4562	0.38	112.72	7.4728	0.41	251.51	84	6.6463	N/A	70.47	N/A	N/A	N/A
40	7.4341	0.39	110.02	7.4552	0.41	254.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4097	0.39	107.56	7.4368	0.42	256.32	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3999	0.40	105.13	7.4177	0.43	258.50	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

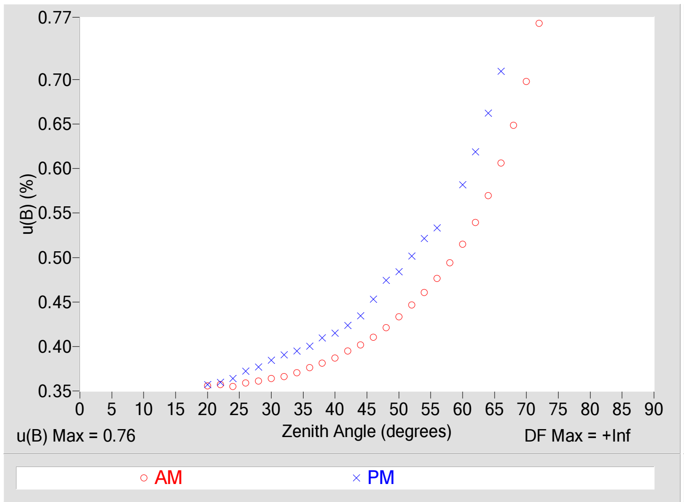


Figure 4. Residuals from Spline Interpolation

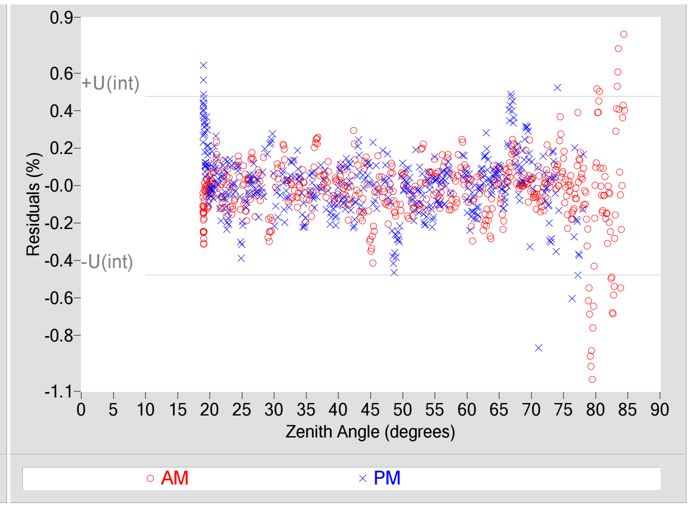


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.76
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.80
Effective degrees of freedom, DF(c)	109500
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.6
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

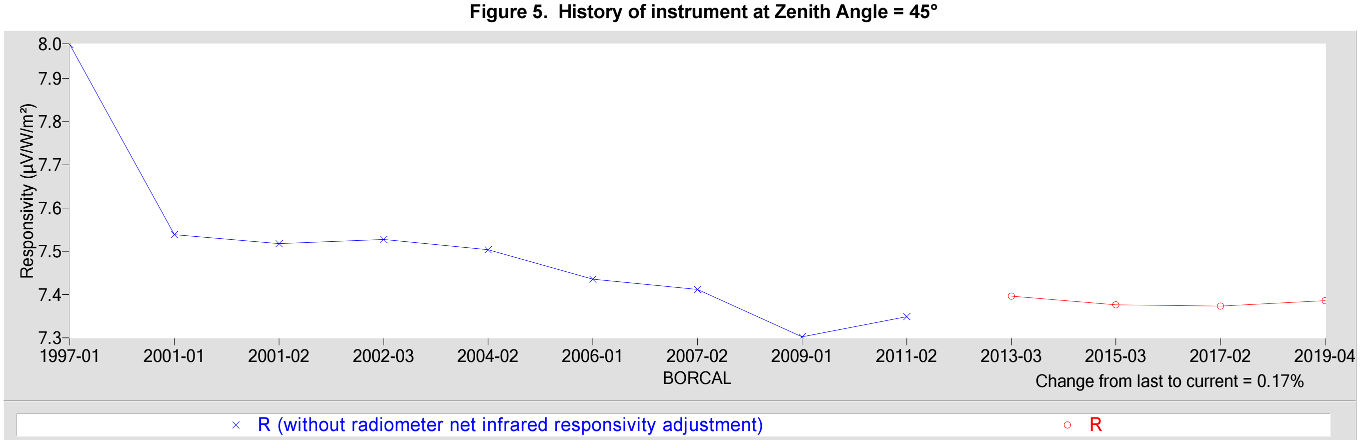
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.3857	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.1
Offset Uncertainty, U(off) (%)	+2.0 / -3.0
Expanded Uncertainty, U (%)	+3.1 / -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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31394F3
Calibration Date:	7/29/2019	**Due Date:**	7/29/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	7/19, 7/29		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/24/2018	09/24/2019
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2541	04/19/2019	04/19/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25, S/N 2542	04/19/2019	04/19/2020
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	02/14/2019	02/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	02/14/2019	02/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 32309F3	08/02/2017	08/02/2022

† 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, Aron Habte, 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

31394F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

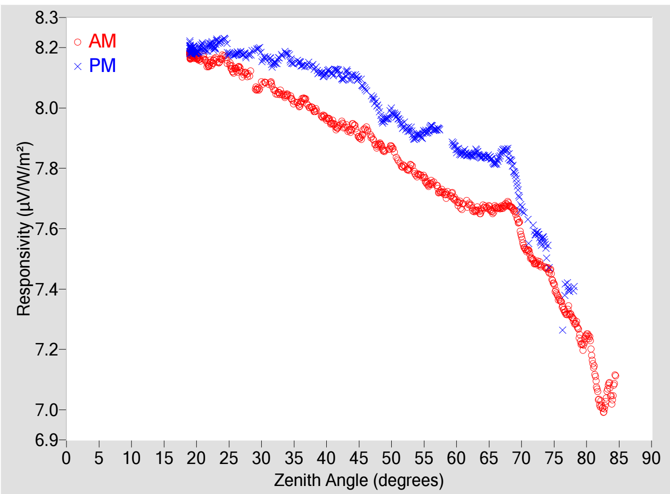


Figure 2. Responsivity vs Local Standard Time

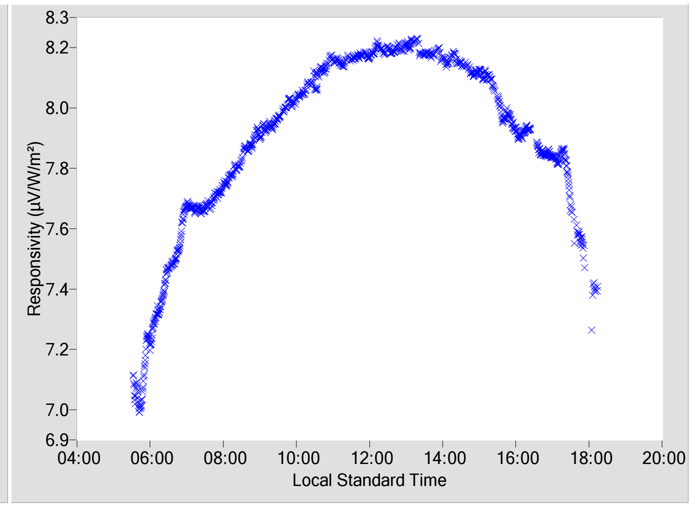


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9303	0.40	102.83	8.0608	0.44	260.66
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8767	0.41	100.82	8.0007	0.46	262.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8691	0.43	98.81	7.9871	0.47	264.54
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8070	0.44	96.98	7.9369	0.49	266.37
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7782	0.45	95.05	7.9108	0.51	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7486	0.47	93.30	7.9370	0.52	269.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7209	0.48	91.58	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6888	0.50	89.86	7.8642	0.56	272.97
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6804	0.53	88.17	7.8452	0.60	274.59
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.6684	0.56	86.56	7.8387	0.64	276.18
20	8.1688	0.35	158.97	8.1864	0.35	200.65	66	7.6702	0.59	84.96	7.8175	0.68	277.75
22	8.1455	0.35	145.83	8.2077	0.35	214.41	68	7.6801	0.63	83.37	7.8436	N/A	279.31
24	8.1678	0.35	137.13	8.2270	0.36	222.97	70	7.5681	0.68	81.79	7.6674	N/A	280.82
26	8.1271	0.35	130.74	8.1790	0.37	229.42	72	7.4881	0.74	80.23	7.5898	N/A	282.45
28	8.1090	0.36	125.64	8.1770	0.37	234.73	74	7.4645	N/A	78.63	7.5134	N/A	283.96
30	8.0834	0.36	127.03	8.1745	0.38	238.76	76	7.3589	N/A	77.07	N/A	N/A	N/A
32	8.0562	0.36	122.79	8.1489	0.38	242.57	78	7.2969	N/A	75.46	7.4010	N/A	287.18
34	8.0443	0.37	119.31	8.1798	0.39	245.86	80	7.2439	N/A	73.84	N/A	N/A	N/A
36	8.0152	0.37	115.79	8.1462	0.39	248.90	82	7.0281	N/A	72.15	N/A	N/A	N/A
38	7.9938	0.38	112.72	8.1368	0.40	251.51	84	7.0513	N/A	70.47	N/A	N/A	N/A
40	7.9662	0.38	110.02	8.1173	0.41	254.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9394	0.39	107.56	8.1185	0.41	256.32	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9358	0.40	105.13	8.1043	0.42	258.50	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

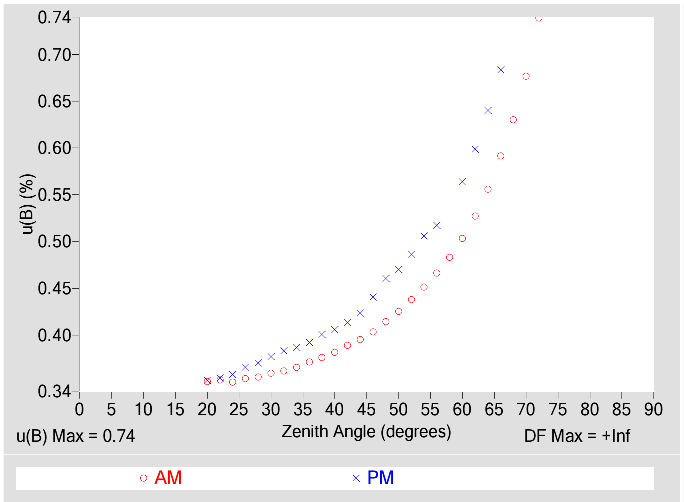


Figure 4. Residuals from Spline Interpolation

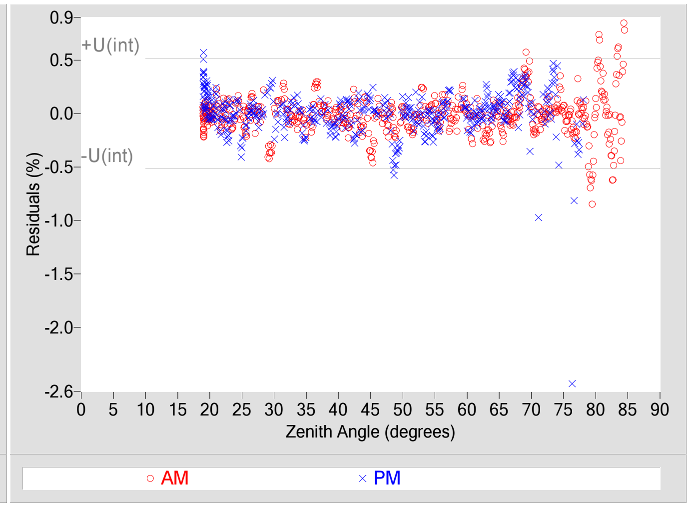


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.74
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.78
Effective degrees of freedom, DF(c)	73638
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

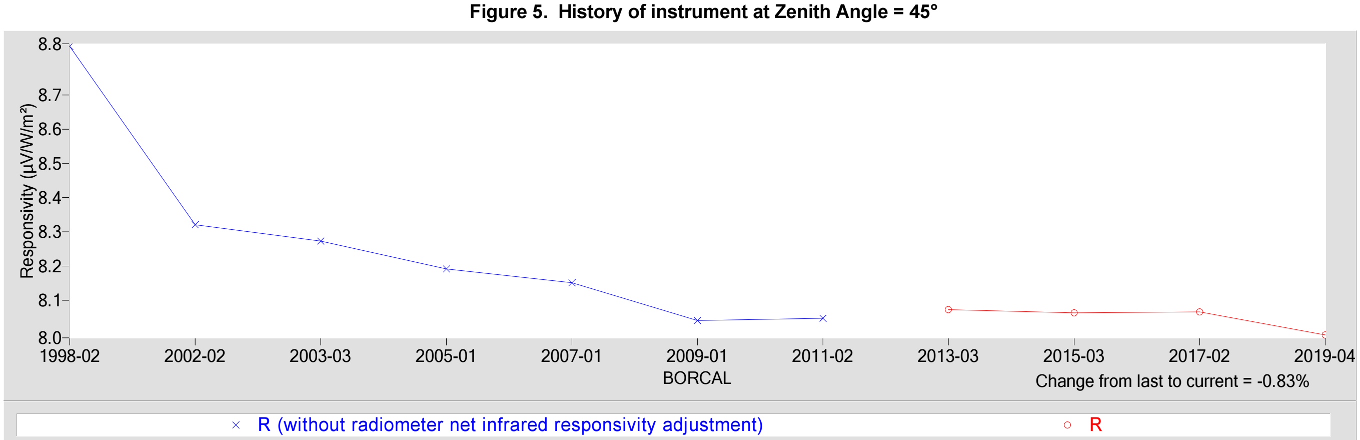
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9987	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.1
Offset Uncertainty, U(off) (%)	+2.3 / -3.9
Expanded Uncertainty, U (%)	+3.4 / -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

Calibration CERT #1239.02

Test Instrument: Silicon Pyranometer
Manufacturer: Licor
Model: LI200
Serial Number: PY1711
Calibration Date: 7/29/2019
Due Date: 7/29/2020
Customer: NREL-SRRL-BMS
Environmental Conditions: see page 4
Test Dates: 7/19, 7/29

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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

Table 1. Traceability

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

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Aron Habte, 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

PY1711 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

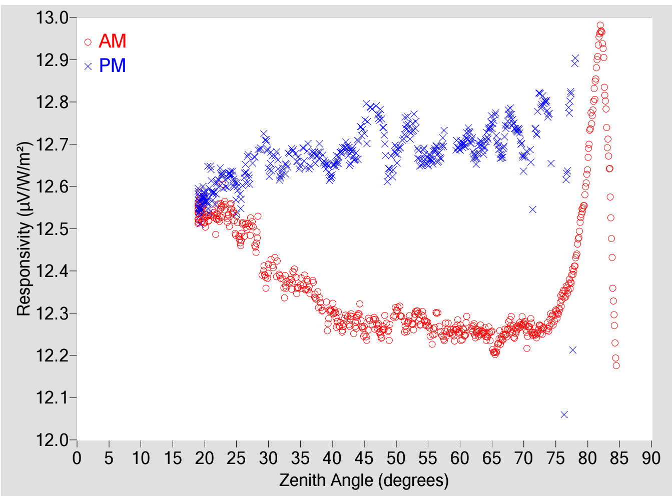


Figure 2. Responsivity vs Local Standard Time

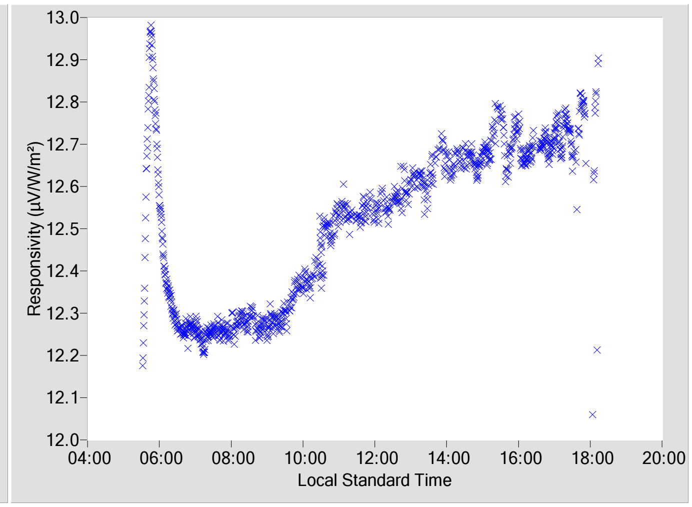


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	12.278	0.36	102.81	12.786	0.37	260.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.265	0.36	100.80	12.722	0.38	262.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.306	0.37	98.74	12.681	0.39	264.49
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.283	0.38	96.98	12.736	0.40	266.33
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.287	0.39	95.05	12.661	0.42	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.266	0.40	93.31	12.682	0.43	269.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.265	0.41	91.59	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.256	0.42	89.86	12.696	0.46	273.03
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.266	0.44	88.26	12.692	0.48	274.57
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.249	0.46	86.63	12.708	0.51	276.16
20	12.539	0.31	159.64	12.575	0.32	200.42	66	12.230	0.49	85.03	12.692	0.54	277.73
22	12.526	0.32	145.93	12.605	0.32	214.23	68	12.271	0.51	83.43	12.765	N/A	279.29
24	12.541	0.31	137.13	12.630	0.32	222.74	70	12.278	0.55	81.86	12.665	N/A	280.80
26	12.494	0.32	130.85	12.606	0.33	229.33	72	12.251	0.60	80.25	12.740	N/A	282.37
28	12.466	0.32	125.31	12.670	0.33	234.01	74	12.275	N/A	78.65	12.741	N/A	283.92
30	12.398	0.33	127.47	12.656	0.33	238.90	76	12.338	N/A	77.05	N/A	N/A	N/A
32	12.384	0.33	123.01	12.630	0.34	242.63	78	12.413	N/A	75.48	12.898	N/A	287.17
34	12.393	0.33	119.35	12.682	0.34	245.88	80	12.656	N/A	73.82	N/A	N/A	N/A
36	12.364	0.33	115.79	12.676	0.34	248.91	82	12.966	N/A	72.17	N/A	N/A	N/A
38	12.328	0.34	112.76	12.682	0.35	251.54	84	12.342	N/A	70.46	N/A	N/A	N/A
40	12.309	0.34	109.97	12.634	0.35	254.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.281	0.35	107.51	12.692	0.36	256.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.288	0.35	105.12	12.691	0.36	258.55	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

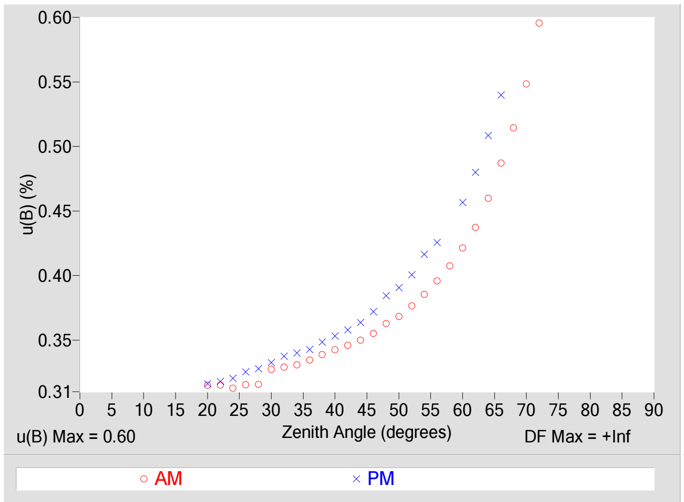


Figure 4. Residuals from Spline Interpolation

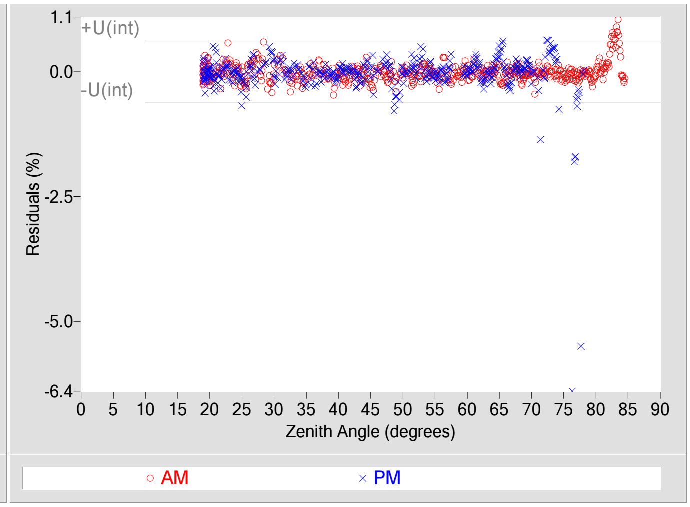


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	18952
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

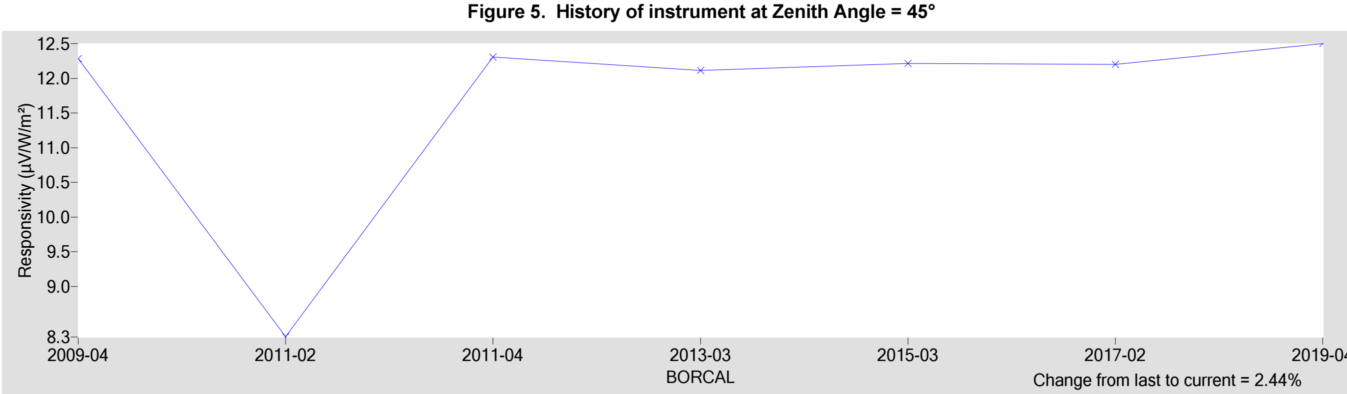
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
12.498	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.90
Offset Uncertainty, U(off) (%)	+2.3 / -1.9
Expanded Uncertainty, U (%)	+3.2 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

National Renewable Energy Laboratory

Solar Radiation Research Laboratory

Metrology Laboratory

Calibration Certificate

Calibration CERT #1239.02

Test Instrument:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY1744
Calibration Date:	7/29/2019	**Due Date:**	7/29/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	7/19, 7/29		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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

Table 1. Traceability

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

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Aron Habte, 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

PY1744 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

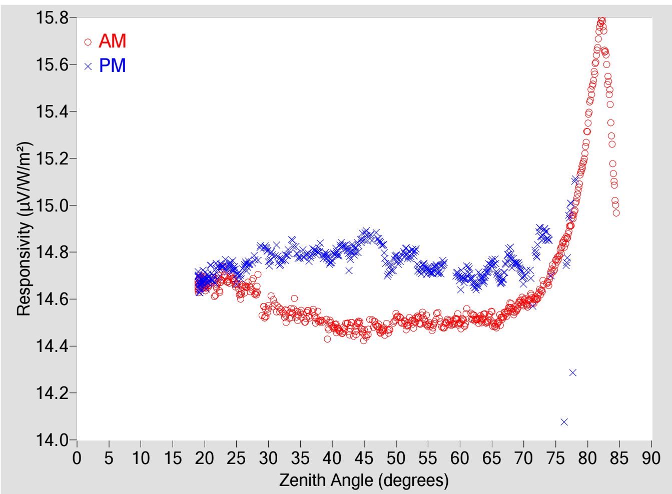


Figure 2. Responsivity vs Local Standard Time

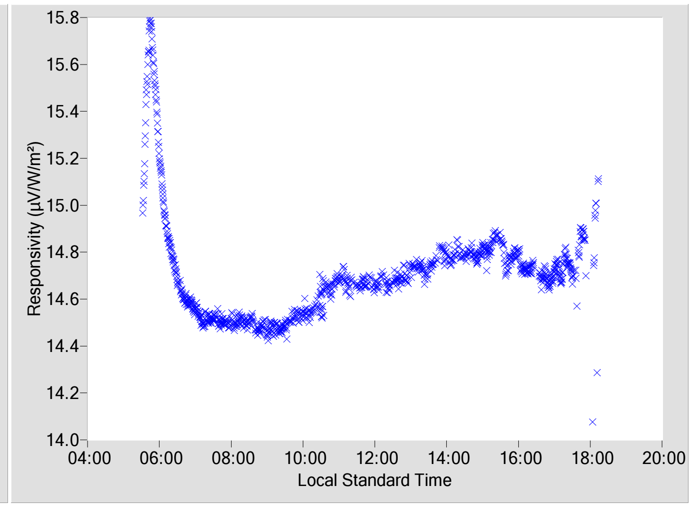


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	14.512	0.35	102.81	14.865	0.37	260.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	14.466	0.36	100.80	14.802	0.38	262.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	14.525	0.37	98.74	14.777	0.39	264.49
6	N/A	N/A	N/A	N/A	N/A	N/A	52	14.499	0.38	96.98	14.781	0.40	266.33
8	N/A	N/A	N/A	N/A	N/A	N/A	54	14.517	0.39	95.05	14.729	0.42	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	14.496	0.40	93.31	14.732	0.43	269.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	14.505	0.41	91.59	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	14.493	0.42	89.86	14.697	0.46	273.03
16	N/A	N/A	N/A	N/A	N/A	N/A	62	14.527	0.44	88.26	14.677	0.48	274.57
18	N/A	N/A	N/A	N/A	N/A	N/A	64	14.518	0.46	86.63	14.705	0.51	276.16
20	14.668	0.31	159.64	14.683	0.32	200.42	66	14.502	0.49	85.03	14.694	0.54	277.73
22	14.662	0.31	145.93	14.727	0.32	214.23	68	14.567	0.51	83.43	14.775	N/A	279.29
24	14.690	0.31	137.13	14.744	0.32	222.74	70	14.593	0.55	81.86	14.689	N/A	280.80
26	14.639	0.32	130.85	14.725	0.33	229.33	72	14.604	0.59	80.25	14.800	N/A	282.37
28	14.630	0.32	125.31	14.777	0.33	234.01	74	14.686	N/A	78.65	14.816	N/A	283.92
30	14.558	0.33	127.47	14.774	0.33	238.90	76	14.827	N/A	77.05	N/A	N/A	N/A
32	14.549	0.33	123.01	14.758	0.34	242.63	78	14.979	N/A	75.48	15.107	N/A	287.17
34	14.561	0.33	119.35	14.833	0.34	245.88	80	15.338	N/A	73.82	N/A	N/A	N/A
36	14.532	0.33	115.79	14.791	0.34	248.91	82	15.772	N/A	72.17	N/A	N/A	N/A
38	14.514	0.34	112.76	14.814	0.35	251.54	84	15.153	N/A	70.46	N/A	N/A	N/A
40	14.485	0.34	109.97	14.773	0.35	254.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	14.482	0.35	107.51	14.819	0.36	256.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	14.486	0.35	105.12	14.822	0.36	258.55	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

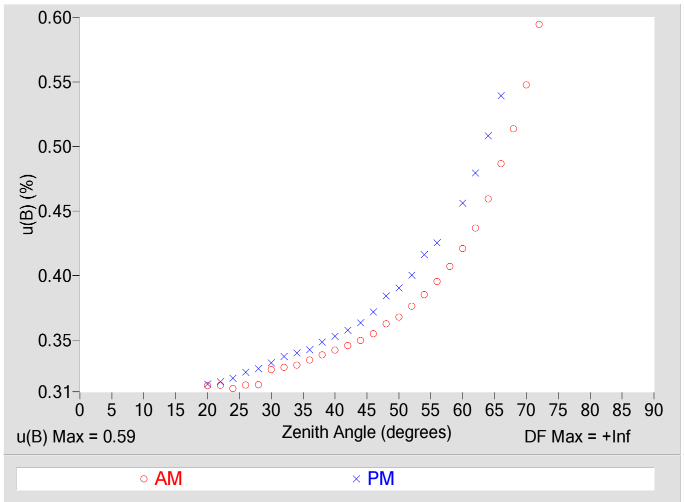


Figure 4. Residuals from Spline Interpolation

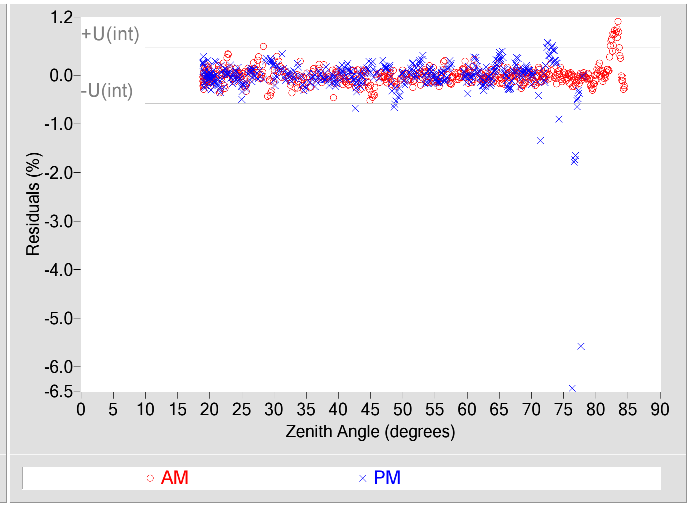


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	23240
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

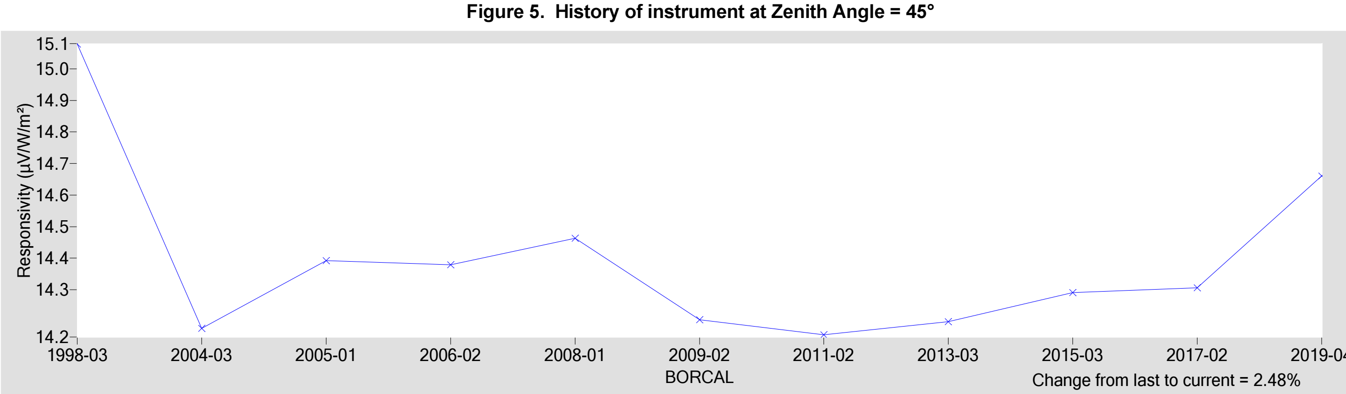
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
14.660	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+1.4 / -1.3
Expanded Uncertainty, U (%)	+2.3 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for 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:**	PY28246
Calibration Date:	7/29/2019	**Due Date:**	7/29/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	7/19, 7/29		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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

Table 1. Traceability

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

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Aron Habte, 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

PY28246 Licor LI200

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

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

where,

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

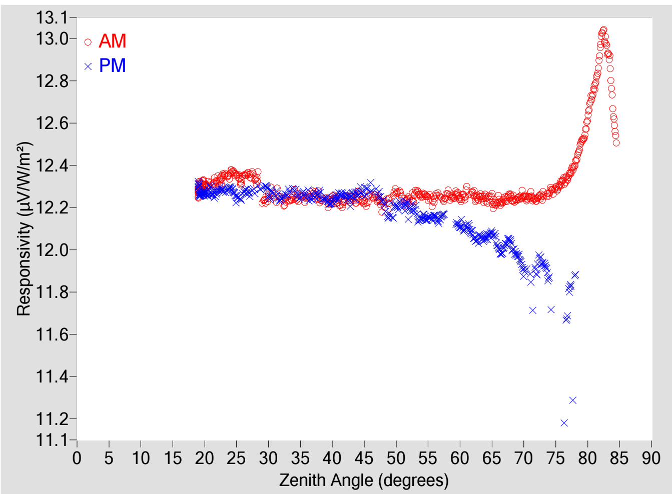


Figure 2. Responsivity vs Local Standard Time

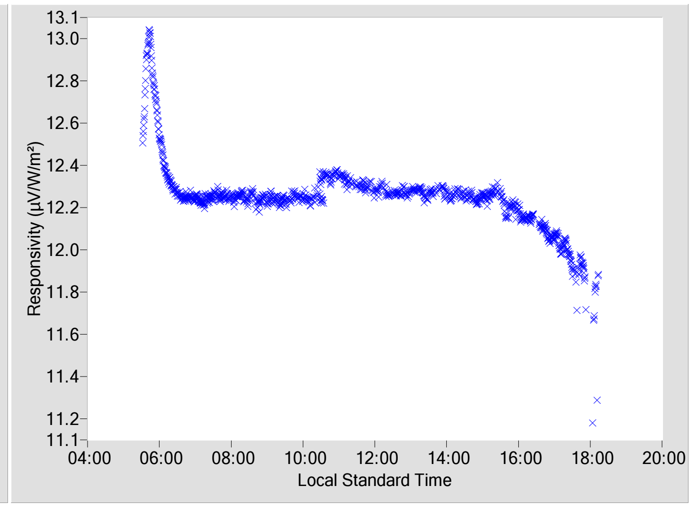


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	12.257	0.36	102.81	12.290	0.37	260.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	12.214	0.36	100.80	12.219	0.38	262.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	12.274	0.37	98.74	12.207	0.39	264.49
6	N/A	N/A	N/A	N/A	N/A	N/A	52	12.241	0.38	96.98	12.190	0.40	266.33
8	N/A	N/A	N/A	N/A	N/A	N/A	54	12.257	0.39	95.05	12.149	0.42	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	12.243	0.40	93.31	12.158	0.43	269.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	12.265	0.41	91.59	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	12.242	0.42	89.86	12.117	0.46	273.03
16	N/A	N/A	N/A	N/A	N/A	N/A	62	12.269	0.44	88.26	12.074	0.48	274.57
18	N/A	N/A	N/A	N/A	N/A	N/A	64	12.243	0.46	86.63	12.058	0.51	276.16
20	12.308	0.31	159.64	12.269	0.32	200.42	66	12.231	0.49	85.03	12.006	0.54	277.73
22	12.317	0.32	145.93	12.277	0.32	214.23	68	12.248	0.51	83.43	12.027	N/A	279.29
24	12.362	0.31	137.13	12.291	0.32	222.74	70	12.251	0.55	81.82	11.901	N/A	280.80
26	12.340	0.32	130.85	12.264	0.33	229.33	72	12.241	0.60	80.25	11.905	N/A	282.37
28	12.330	0.32	125.31	12.277	0.33	234.01	74	12.273	N/A	78.65	11.827	N/A	283.92
30	12.245	0.33	127.47	12.262	0.33	238.90	76	12.325	N/A	77.05	N/A	N/A	N/A
32	12.246	0.33	123.01	12.242	0.34	242.63	78	12.401	N/A	75.48	11.880	N/A	287.17
34	12.258	0.33	119.35	12.288	0.34	245.88	80	12.624	N/A	73.82	N/A	N/A	N/A
36	12.251	0.33	115.79	12.260	0.34	248.91	82	12.964	N/A	72.17	N/A	N/A	N/A
38	12.242	0.34	112.76	12.268	0.35	251.54	84	12.652	N/A	70.46	N/A	N/A	N/A
40	12.241	0.34	109.97	12.230	0.35	254.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	12.240	0.35	107.51	12.254	0.36	256.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	12.255	0.35	105.12	12.269	0.36	258.55	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

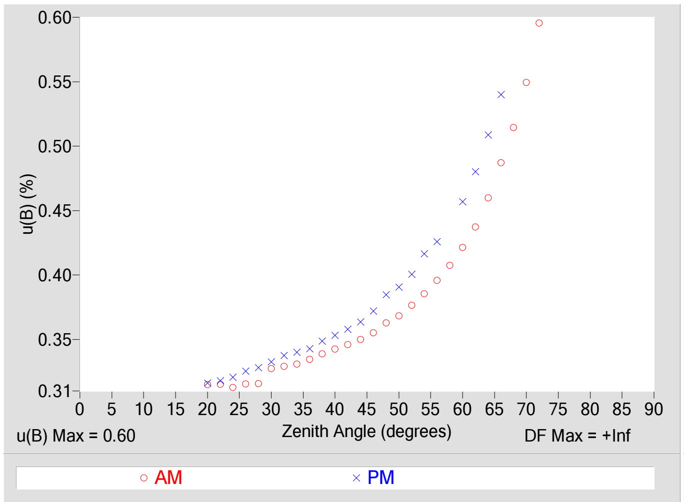


Figure 4. Residuals from Spline Interpolation

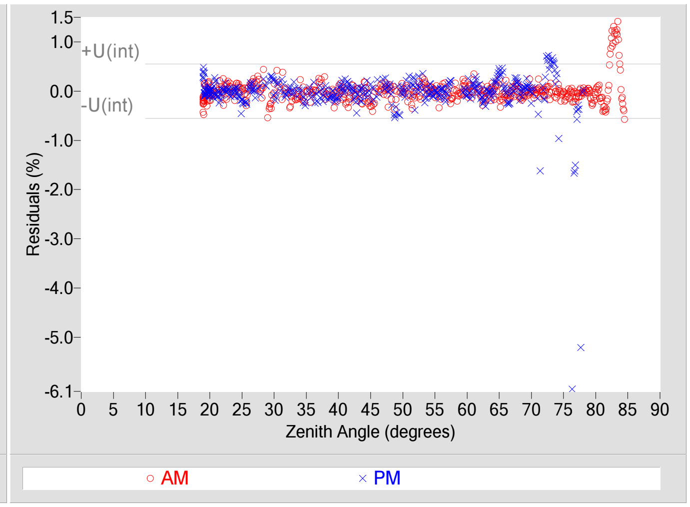


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	27367
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

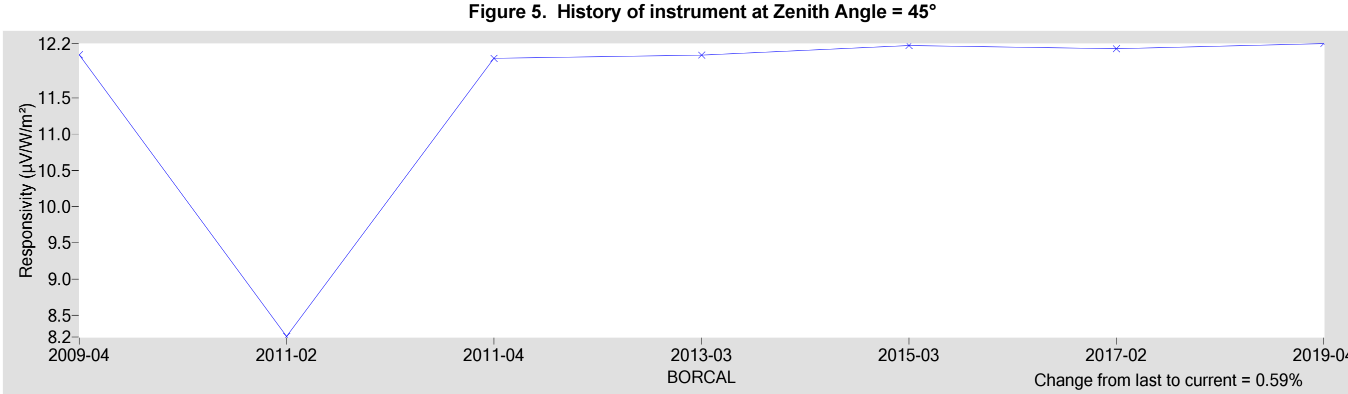
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
12.250	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.90
Offset Uncertainty, U(off) (%)	+0.33 / -1.1
Expanded Uncertainty, U (%)	+1.2 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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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: Silicon Pyranometer **Manufacturer:** Licor

Model: LI200 **Serial Number:** PY28262

Calibration Date: 7/29/2019 **Due Date:** 7/29/2020

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

Test Dates: 7/19, 7/29

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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Table 1. Traceability

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

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Aron Habte, 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

PY28262 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

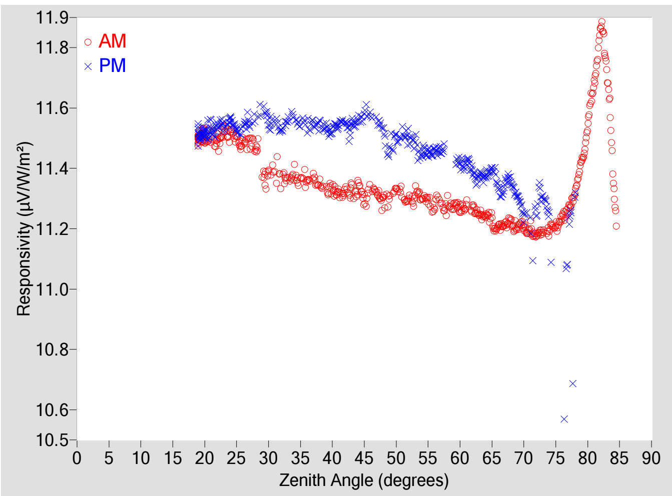


Figure 2. Responsivity vs Local Standard Time

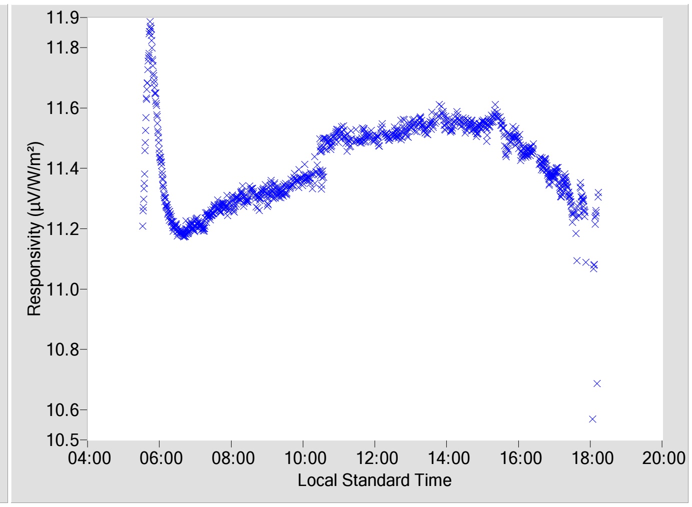


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	11.334	0.36	102.81	11.575	0.37	260.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	11.292	0.36	100.80	11.516	0.38	262.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	11.331	0.37	98.74	11.503	0.39	264.49
6	N/A	N/A	N/A	N/A	N/A	N/A	52	11.299	0.38	96.98	11.499	0.40	266.33
8	N/A	N/A	N/A	N/A	N/A	N/A	54	11.298	0.39	95.05	11.448	0.42	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	11.274	0.40	93.31	11.461	0.43	269.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	11.278	0.41	91.59	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	11.263	0.42	89.86	11.419	0.46	273.03
16	N/A	N/A	N/A	N/A	N/A	N/A	62	11.270	0.44	88.26	11.391	0.48	274.57
18	N/A	N/A	N/A	N/A	N/A	N/A	64	11.243	0.46	86.63	11.376	0.51	276.16
20	11.504	0.31	159.64	11.516	0.32	200.42	66	11.208	0.49	85.03	11.334	0.54	277.73
22	11.487	0.32	145.93	11.540	0.32	214.23	68	11.221	0.51	83.43	11.353	N/A	279.29
24	11.519	0.31	137.13	11.562	0.32	222.74	70	11.208	0.55	81.86	11.245	N/A	280.80
26	11.486	0.32	130.85	11.538	0.33	229.33	72	11.180	0.60	80.25	11.261	N/A	282.37
28	11.463	0.32	125.31	11.568	0.33	234.01	74	11.197	N/A	78.65	11.211	N/A	283.92
30	11.386	0.33	127.47	11.546	0.33	238.90	76	11.241	N/A	77.05	N/A	N/A	N/A
32	11.365	0.33	123.01	11.527	0.34	242.63	78	11.315	N/A	75.48	11.313	N/A	287.17
34	11.382	0.33	119.35	11.569	0.34	245.88	80	11.540	N/A	73.82	N/A	N/A	N/A
36	11.355	0.33	115.79	11.542	0.34	248.91	82	11.858	N/A	72.17	N/A	N/A	N/A
38	11.347	0.34	112.76	11.547	0.35	251.54	84	11.368	N/A	70.46	N/A	N/A	N/A
40	11.328	0.34	109.97	11.525	0.35	254.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	11.326	0.35	107.51	11.548	0.36	256.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	11.333	0.35	105.12	11.562	0.36	258.55	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

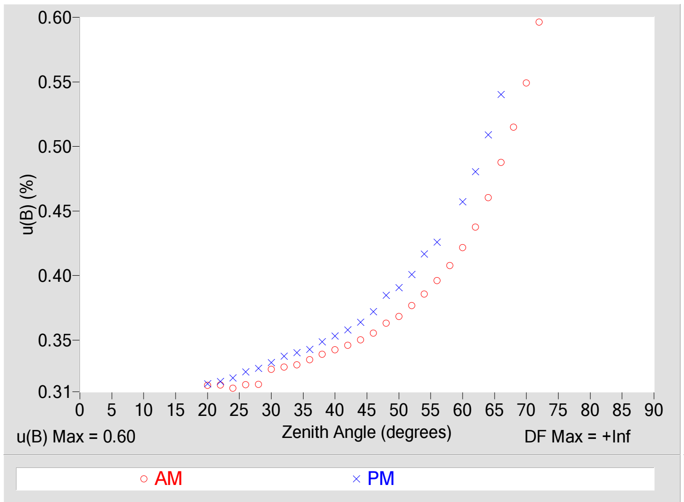


Figure 4. Residuals from Spline Interpolation

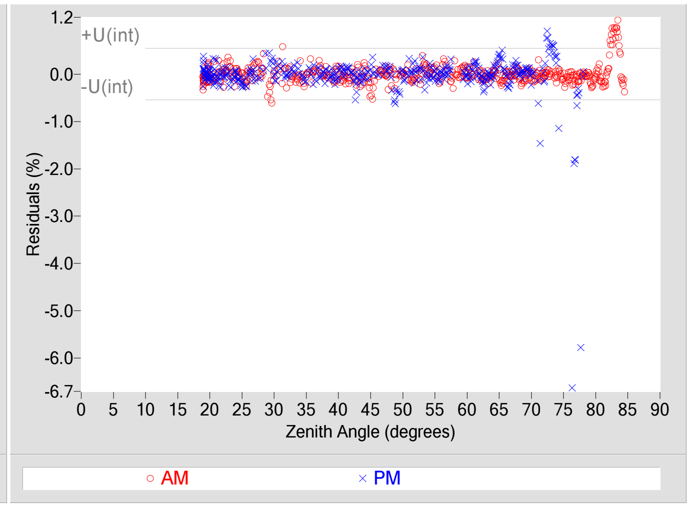


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	28829
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

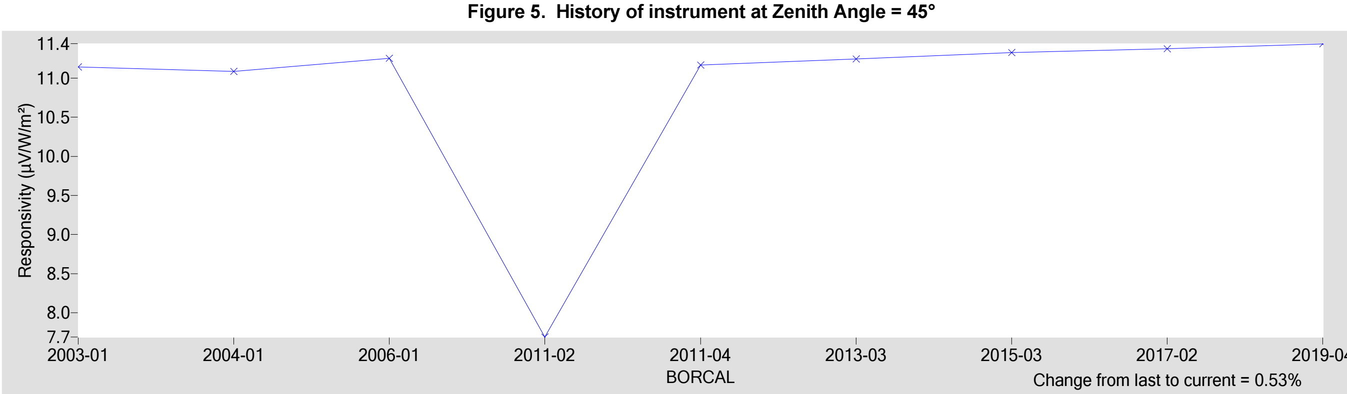
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
11.435	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.90
Offset Uncertainty, U(off) (%)	+1.2 / -1.5
Expanded Uncertainty, U (%)	+2.1 / -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:	Silicon Pyranometer	**Manufacturer:**	Licor
Model:	LI200	**Serial Number:**	PY66482
Calibration Date:	7/29/2019	**Due Date:**	7/29/2020
Customer:	NREL-SRRL-BMS	**Environmental Conditions:**	see page 4
Test Dates:	7/19, 7/29		

This certifies that the above product was calibrated in compliance with ISO/IEC 17025:2005. Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM) using Reda et al., 2008. All nominal values are traceable to the International System (SI) Units of Measurement.

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

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

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

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

Table 1. Traceability

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

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

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

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

Calibrated by: Afshin Andreas, Aron Habte, 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

PY66482 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

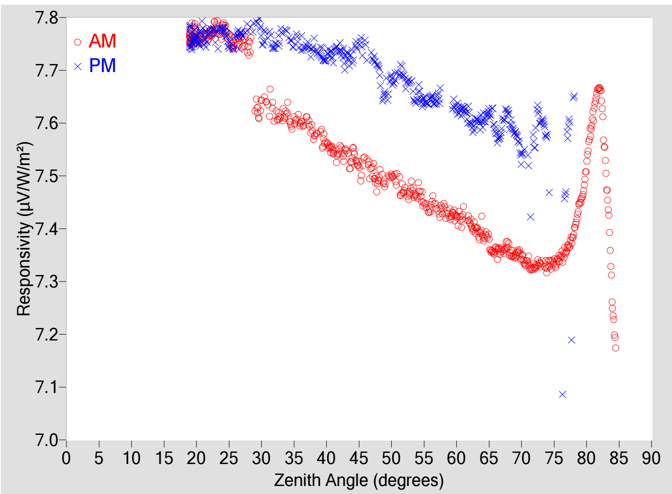


Figure 2. Responsivity vs Local Standard Time

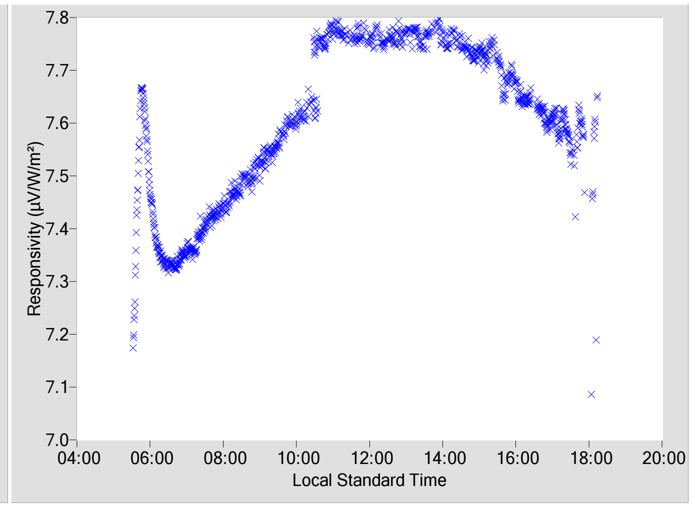


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5335	0.36	102.81	7.7413	0.37	260.74
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4910	0.36	100.80	7.6988	0.39	262.67
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4995	0.37	98.74	7.6821	0.39	264.49
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4716	0.38	96.98	7.6819	0.40	266.33
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4677	0.39	95.05	7.6519	0.42	268.03
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4393	0.40	93.31	7.6465	0.43	269.73
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4394	0.41	91.59	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4193	0.42	89.86	7.6280	0.46	273.03
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4156	0.44	88.26	7.6086	0.48	274.57
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.3875	0.46	86.63	7.6060	0.51	276.16
20	7.7669	0.32	159.64	7.7625	0.32	200.42	66	7.3591	0.49	85.03	7.5824	0.54	277.73
22	7.7657	0.32	145.93	7.7726	0.32	214.23	68	7.3634	0.52	83.43	7.6111	N/A	279.29
24	7.7784	0.31	137.13	7.7776	0.32	222.74	70	7.3493	0.55	81.86	7.5381	N/A	280.80
26	7.7526	0.32	130.85	7.7602	0.33	229.33	72	7.3273	0.60	80.25	7.5680	N/A	282.37
28	7.7417	0.32	125.31	7.7811	0.33	234.01	74	7.3294	N/A	78.65	7.5488	N/A	283.92
30	7.6369	0.33	127.47	7.7630	0.33	238.90	76	7.3479	N/A	77.05	N/A	N/A	N/A
32	7.6220	0.33	123.01	7.7454	0.34	242.63	78	7.3886	N/A	75.48	7.6499	N/A	287.17
34	7.6246	0.33	119.35	7.7705	0.34	245.88	80	7.5209	N/A	73.82	N/A	N/A	N/A
36	7.6001	0.34	115.79	7.7484	0.34	248.91	82	7.6646	N/A	72.17	N/A	N/A	N/A
38	7.5808	0.34	112.76	7.7454	0.35	251.54	84	7.2590	N/A	70.46	N/A	N/A	N/A
40	7.5604	0.34	109.97	7.7237	0.35	254.10	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5492	0.35	107.51	7.7382	0.36	256.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5398	0.35	105.12	7.7254	0.36	258.55	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

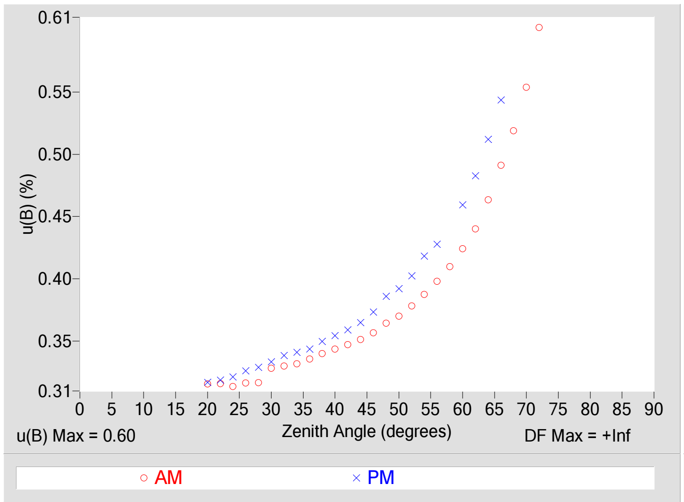


Figure 4. Residuals from Spline Interpolation

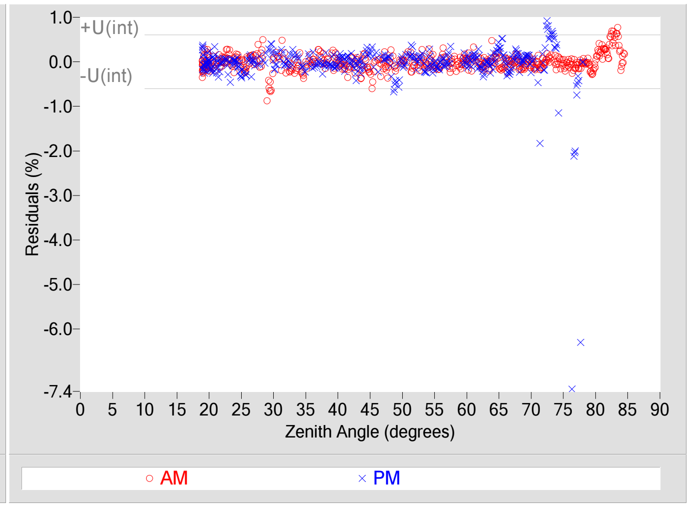


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	21032
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	20° to 72°
PM Valid zenith angle range	20° to 66°

‡ 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

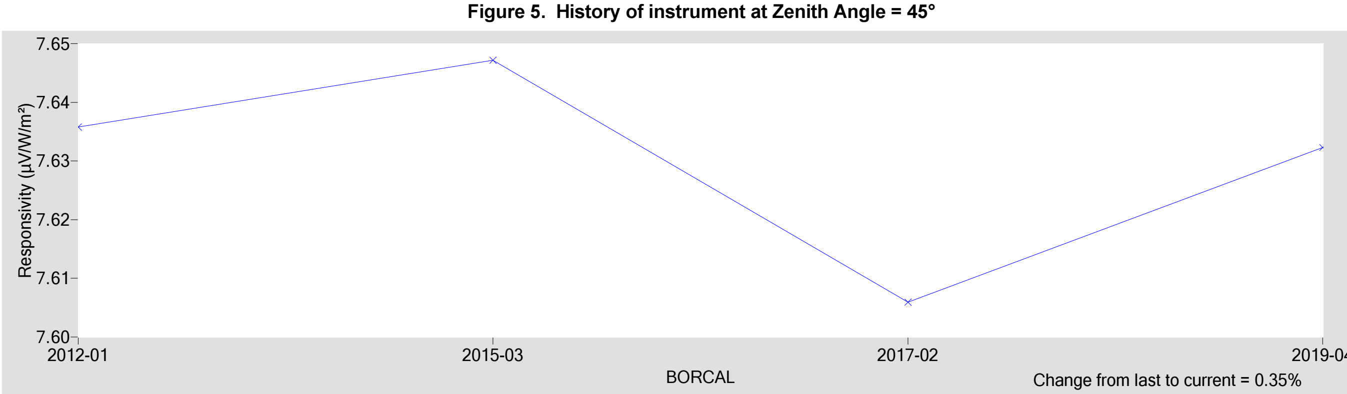
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6323	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.90
Offset Uncertainty, U(off) (%)	+1.8 / -2.8
Expanded Uncertainty, U (%)	+2.7 / -3.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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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).

Environmental and Sky Conditions for BORCAL-SW 2019-04

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

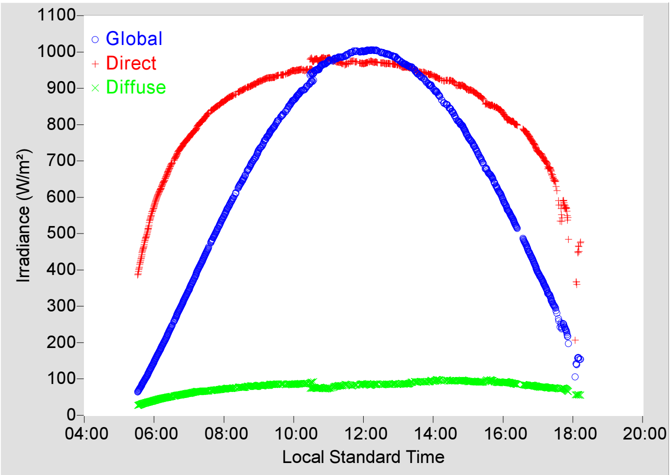
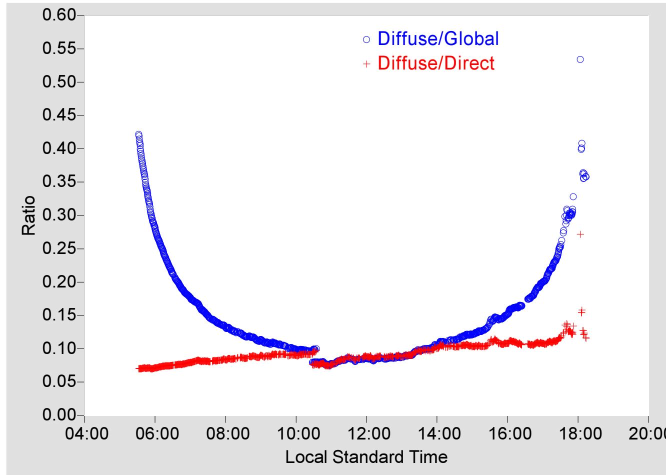


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

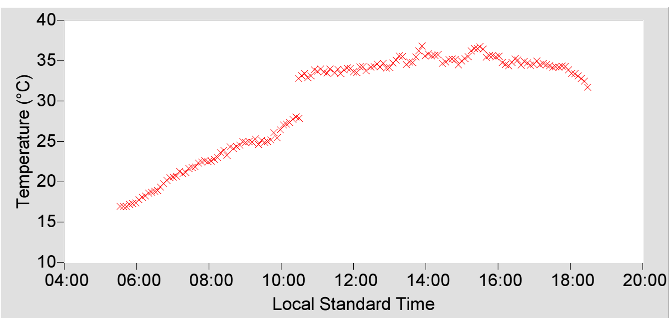


Figure 9. Humidity

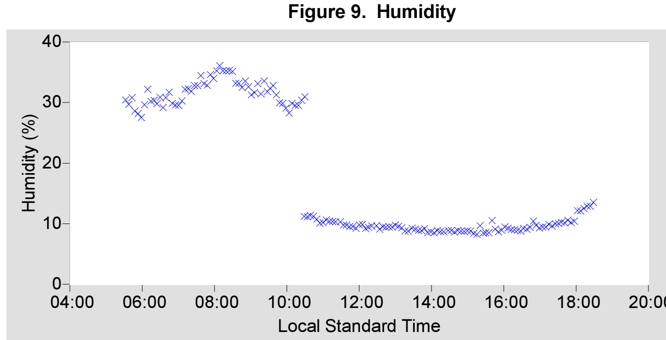


Figure 10. Pressure

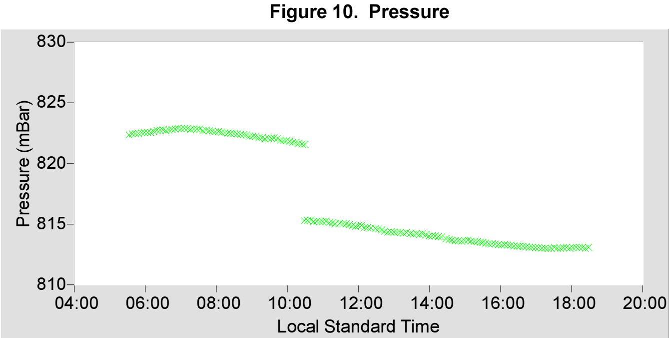


Figure 11. Effective Net Infrared

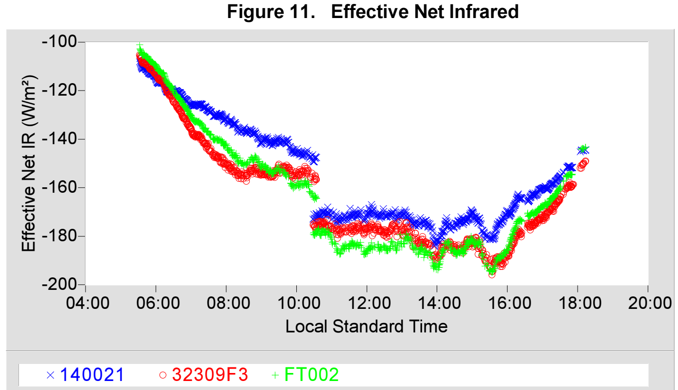


Figure 12. Estimated Broadband Aerosol Optical Depth

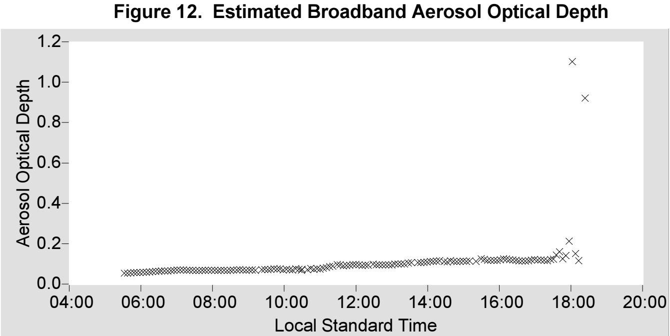


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	29.84	16.88	36.82
Humidity (%)	18.22	8.27	36.11
Pressure (mBar)	817.2	813.0	822.9
Est. Aerosol Optical Depth (BB)	0.105	0.054	1.101

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).

PY1711 Licor LI200
Comments:
Cal'd with mated 147 Ohm Licor shunt