Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2021-03

Generated by

RCC

Radiometer Calibration and Characterization

Calibration Facility

Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Calibration date

08/24/2021 to 08/25/2021

Report Date

October 27, 2021

ARM

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

Significant outliers in sNIP control 37945E6 possibly due to bugs. Cal still similar to previous BORCALS so it is left in report for consistancy.

In December 2021, the calibration provider of the BORCAL reference diffuse pyranometers (S/N 2551 and 2552) provided revised responsivities. Using the revised responsivities, BORCAL data was reprocessed, and it was found that it only affected the responsivities (R@45) for pyranometers under test issued in this report by only approximately -0.08%. Since this error is much smaller than the total uncertainty of a pyranometer [typically +/- 2.5%] the SGP technical manager and NREL metrologists decided that this error can be ignored, therefore new reports or calibration stickers will not be issued.

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

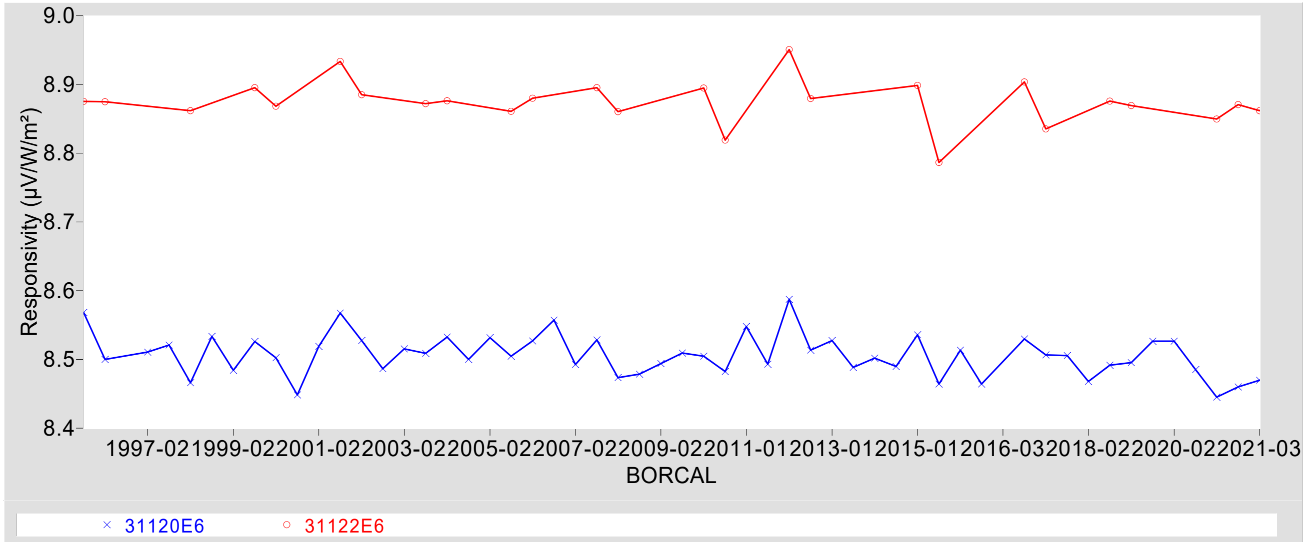


Figure 2. Eppley PSP Control Instrument History

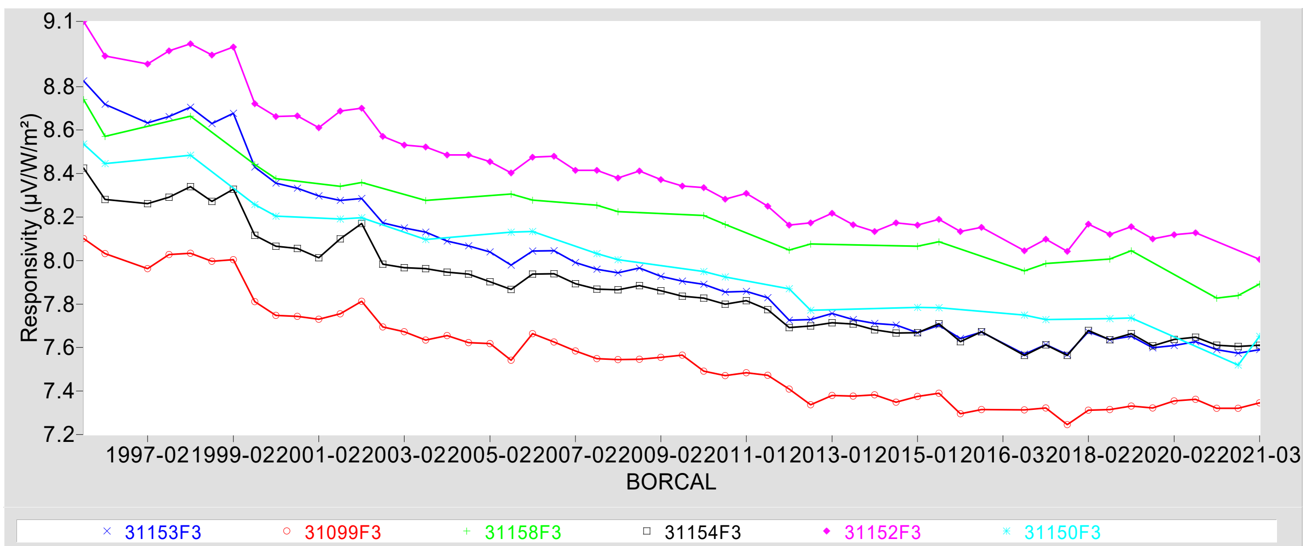
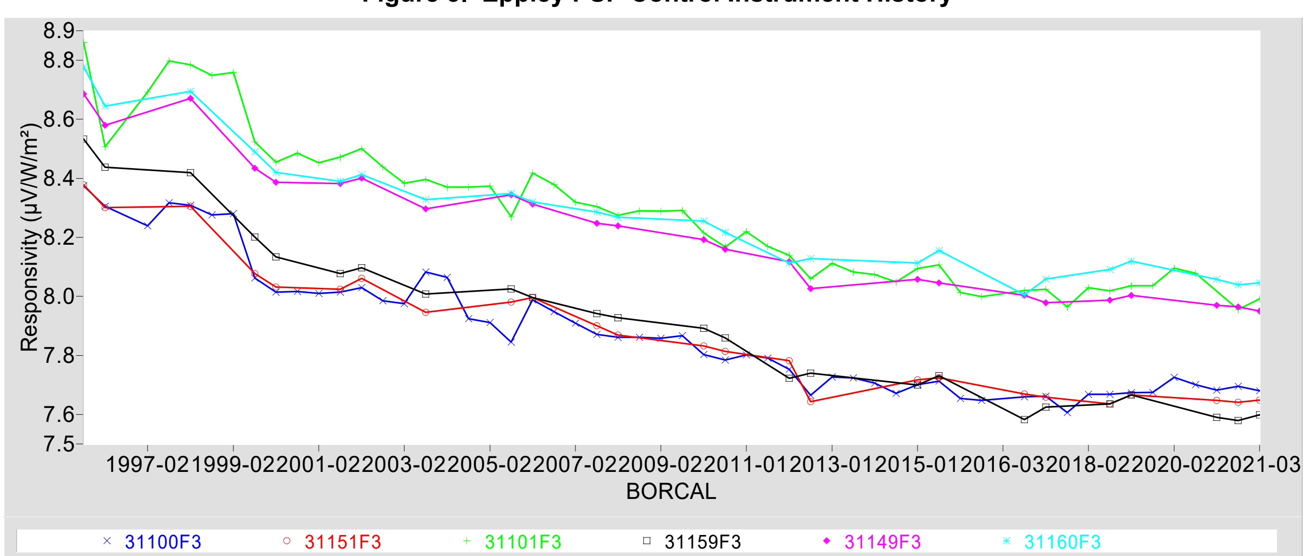


Figure 3. Eppley PSP Control Instrument History



Results Summary

Table 1. Results Summary

Instrument	Customer	R@45 [1] (µV/W/m²)	U [2] (%)	Rnet [3] (µV/W/m²)	Page
200695	SGP	10.508	+1.2 / -1.4	0.087000	A1-2
200710	SGP	9.8504	+1.3 / -1.5	0.087000	A1-5
200803	SGP	8.4117	+0.80 / -0.68	0	A1-8
27973F3	TWP	8.3597	+1.8 / -2.0	0.60000	A1-11
29554E6	SGP	8.0265	+1.5 / -1.2	0	A1-14
29619F3	SGP	8.4031	+2.8 / -3.7	0.69050	A1-17
29743E6	SGP	8.1510	+1.1 / -1.1	0	A1-20
29856E6	SGP	7.8478	+1.1 / -1.1	0	A1-23
29869E6	TWP	8.4751	+1.3 / -1.0	0	A1-26
29913F3	TWP	7.6097	+2.3 / -2.3	0.53900	A1-29
29915F3	TWP	7.4381	+2.1 / -2.5	0.63274	A1-32
29934E6	TWP	8.3291	+1.6 / -1.2	0	A1-35
29938E6	SGP	8.3191	+1.2 / -1.0	0	A1-38
30617F3	SGP	7.9826	+1.9 / -2.8	0.67027	A1-41
30653F3	SGP	8.1393	+1.9 / -2.6	0.61000	A1-44
30665F3	SGP	7.9960	+2.6 / -3.6	0.68202	A1-47
30673F3	SGP	7.7023	+1.9 / -2.1	0.57412	A1-50
30709F3	SGP	7.8371	+2.2 / -2.9	0.61495	A1-53
30717E6	SGP	8.3620	+1.4 / -1.4	0	A1-56
30718E6	SGP	8.2769	+1.2 / -1.1	0	A1-59
30722E6	SGP	8.5855	+1.2 / -1.2	0	A1-62
30776F3	SGP	8.1196	+1.9 / -3.4	0.64865	A1-65
30820F3	SGP	7.8334	+2.0 / -3.3	0.63499	A1-68
30891F3	SGP	7.3728	+1.8 / -2.4	0.57550	A1-71
30900F3	SGP	8.1037	+2.1 / -2.8	0.63379	A1-74
30951F3	SGP	8.3762	+1.9 / -2.5	0.64270	A1-77
30953F3	SGP	8.2691	+2.7 / -3.7	0.67080	A1-80
31096F3	SGP	8.2257	+2.1 / -2.8	0.71483	A1-83
31099F3	Calibration System	7.3457	+2.0 / -3.1	0.57866	A1-86
31100F3	Calibration System	7.6807	+1.9 / -2.4	0.64729	A1-89
31101F3	Calibration System	7.9922	+2.2 / -3.5	0.64834	A1-92
31120E6	Calibration System	8.4699	+1.2 / -1.0	0	A1-95
31122E6	Calibration System	8.8620	+1.0 / -1.1	0	A1-98
31149F3	Calibration System	7.9499	+1.7 / -2.1	0.54900	A1-101
31150F3	Calibration System	7.6519	+2.1 / -3.2	0.55100	A1-104
31151F3	Calibration System	7.6488	+2.0 / -2.5	0.53300	A1-107
31152F3	Calibration System	8.0063	+2.4 / -3.0	0.63390	A1-110
31153F3	Calibration System	7.5905	+3.4 / -4.9	0.64286	A1-113
31154F3	Calibration System	7.6103	+2.4 / -2.7	0.56158	A1-116
31158F3	Calibration System	7.8915	+2.1 / -2.4	0.52400	A1-119
31159F3	Calibration System	7.5992	+2.7 / -3.5	0.53200	A1-122
31160F3	Calibration System	8.0459	+2.3 / -2.9	0.49000	A1-125
31277F3	TWP	7.3071	+2.0 / -2.7	0.50400	A1-128
31283F3	TWP	8.1673	+1.8 / -3.0	0.60171	A1-131
31284F3	TWP	7.4162	+2.4 / -3.3	0.54600	A1-134
31289F3	TWP	8.1326	+1.8 / -2.6	0.65232	A1-137
31291F3	TWP	8.0697	+2.3 / -3.2	0.61842	A1-140
31294F3	NSA	8.8074	+1.6 / -2.0	0.54700	A1-143
31636F3	SGP	8.4622	+2.0 / -2.6	0.62111	A1-146

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

Results Summary

Table 1. Results Summary

Instrument	Customer	R@45 [1] (µV/W/m²)	U [2] (%)	Rnet [3] (µV/W/m²)	Page
31763E6	NSA	8.1351	+1.5 / -1.4	0	A1-149
31875E6	TWP	8.4797	+1.5 / -1.1	0	A1-152
32026F3	NSA	8.6807	+1.0 / -1.5	0.62415	A1-155
32882	TWP	8.5418	+3.3 / -2.6	0	A1-158
33247	SGP	9.2422	+4.5 / -2.4	0	A1-161
33251	TWP	8.2609	+2.9 / -2.5	0	A1-164
33262	SGP	8.1765	+2.7 / -3.2	0	A1-167
33267	SGP	9.0212	+2.2 / -2.4	0	A1-170
33273	SGP	9.6908	+1.8 / -2.5	0	A1-173
33279	SGP	8.8488	+2.3 / -2.9	0	A1-176
33386	TWP	8.9973	+3.1 / -2.8	0	A1-179
34281	TWP	10.043	+1.3 / -1.5	0	A1-182
35830F3	AMF#2	7.8801	+2.0 / -2.7	0.54714	A1-185
35864	SGP	8.4908	+2.2 / -2.4	0	A1-188
36291F3	AMF#2	9.0822	+1.8 / -2.4	0.60000	A1-191
37286E6	AMF	8.1646	+1.4 / -0.97	0	A1-194
37297F3	AMF	8.2387	+2.1 / -1.4	0.60000	A1-197
37300F3	NSA	8.8673	+1.2 / -1.5	0.60000	A1-200
37945E6	SGP	8.3957	+0.93 / -1.3	0	A1-203
37946E6	SGP	8.5527	+0.88 / -0.91	0	A1-206
38909F3	SGP	8.3182	+1.9 / -2.2	0.22000	A1-209
38910F3	SGP	7.9178	+1.3 / -1.7	0.22000	A1-212

[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 A1-215.

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.

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	200695
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________________　________________
Peter Gotseff, Technical Manager　　Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

200695 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 radiometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

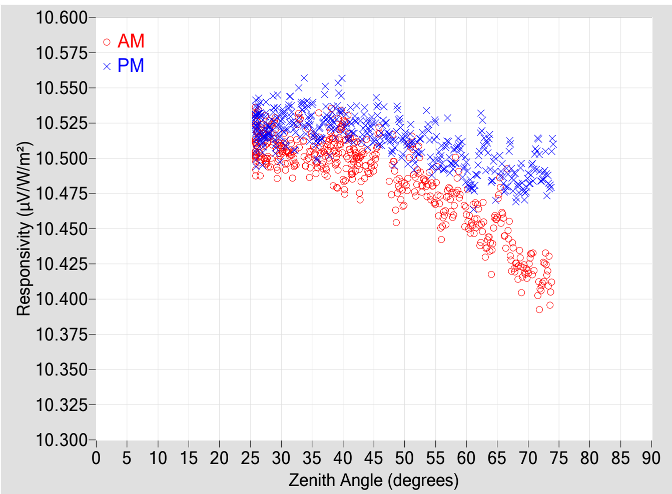


Figure 2. Responsivity vs Local Standard Time

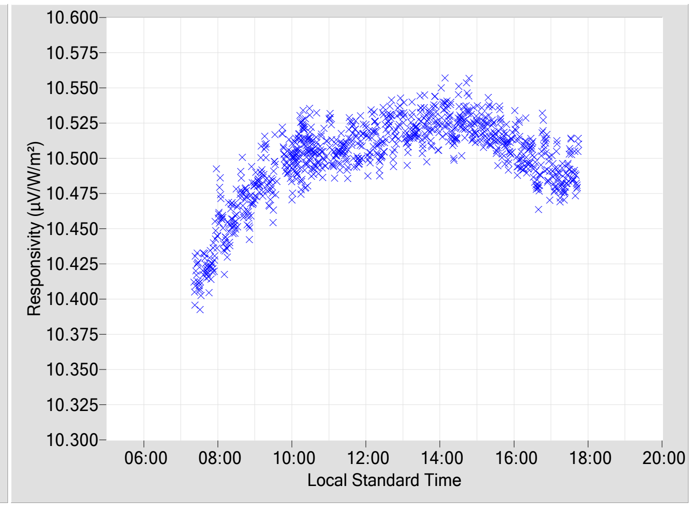


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.519	0.38	113.85	10.517	0.34	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.496	0.34	111.17	10.504	0.33	249.25
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.474	0.37	109.05	10.515	0.34	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.488	0.32	106.92	10.505	0.32	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.479	0.36	104.91	10.510	0.33	255.45
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.455	0.36	103.08	10.500	0.36	257.27
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.465	0.38	101.29	10.500	0.34	259.14
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.462	0.47	99.51	10.491	0.35	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.456	0.37	97.88	10.502	0.36	262.47
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.433	0.42	96.18	10.492	0.37	264.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.454	0.40	94.63	10.484	0.39	265.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.423	N/A	93.09	10.480	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	10.420	N/A	91.54	10.484	N/A	268.75
26	10.514	0.31	173.61	10.523	0.32	186.71	72	10.405	N/A	90.08	10.489	N/A	270.24
28	10.510	0.34	154.11	10.518	0.32	205.93	74	10.412	N/A	88.71	10.510	N/A	271.65
30	10.506	0.34	144.88	10.522	0.31	215.11	76	N/A	N/A	N/A	N/A	N/A	N/A
32	10.496	0.31	138.14	10.517	0.31	221.74	78	N/A	N/A	N/A	N/A	N/A	N/A
34	10.502	0.33	132.98	10.532	0.34	226.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	10.503	0.30	128.61	10.511	0.31	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	10.516	0.34	125.34	10.522	0.30	235.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	10.506	0.32	121.66	10.536	0.32	238.42	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.504	0.33	118.62	10.528	0.32	241.56	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.499	0.33	116.30	10.520	0.35	244.30	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

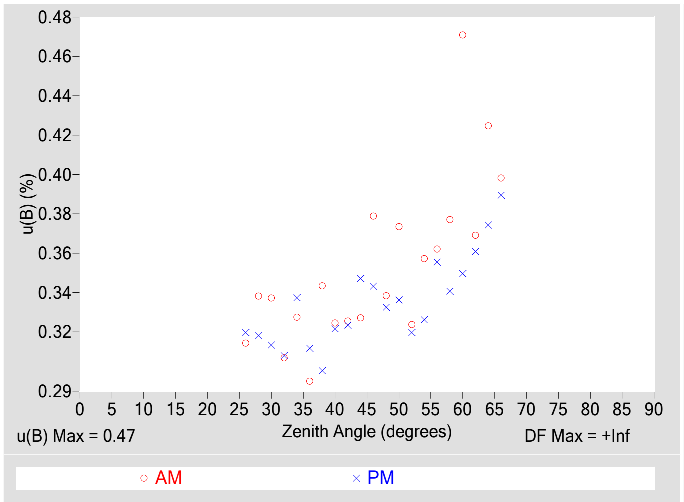


Figure 4. Residuals from Spline Interpolation

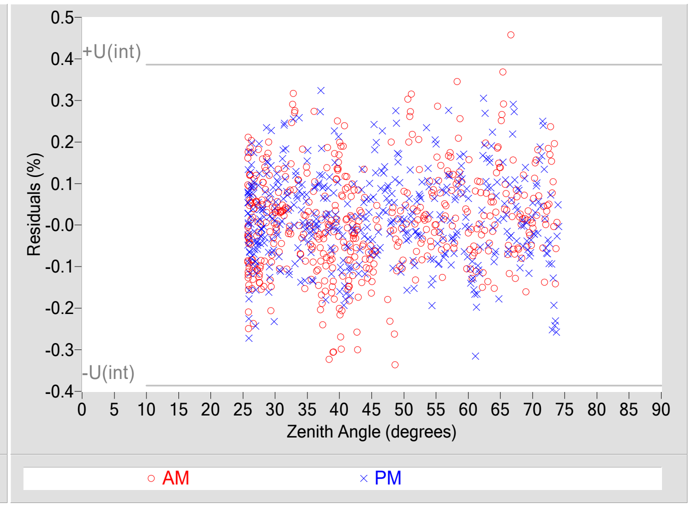


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.47
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	40513
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

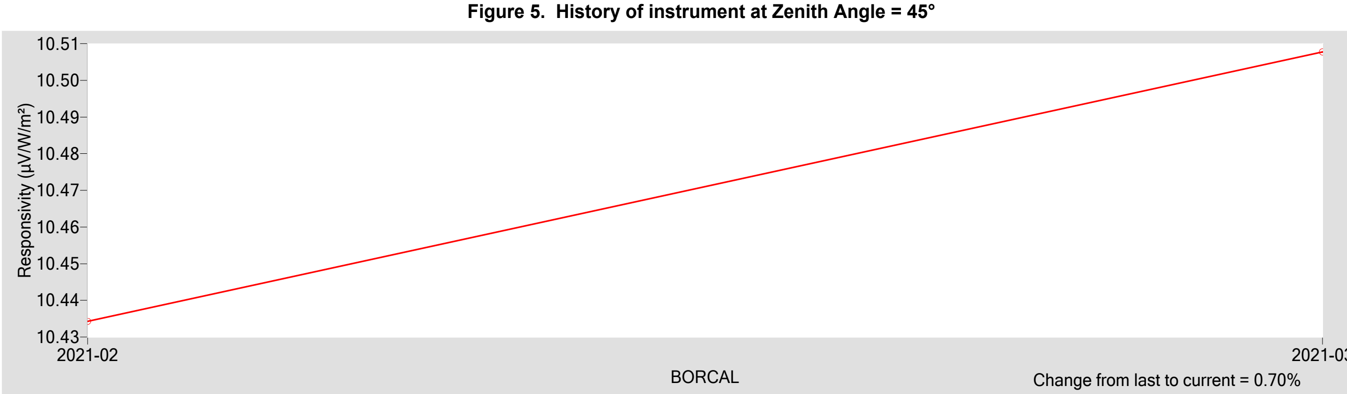
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
10.508	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.92
Offset Uncertainty, U(off) (%)	+0.27 / -0.50
Expanded Uncertainty, U (%)	+1.2 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	200710
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

__________________________________ ________________
Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

200710 Kipp & Zonen CMP22

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

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

where,

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

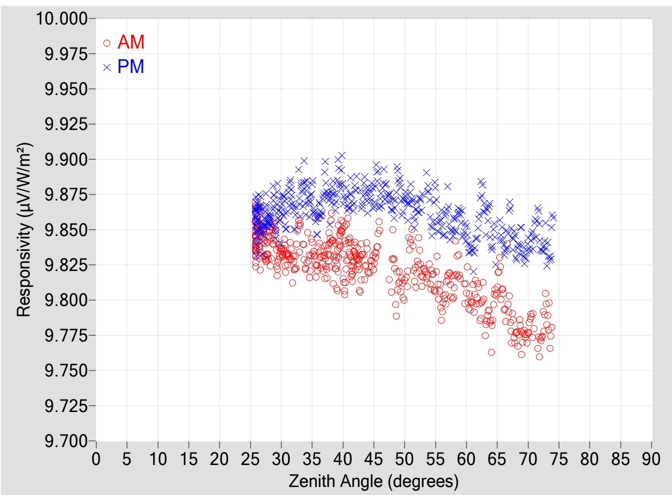


Figure 2. Responsivity vs Local Standard Time

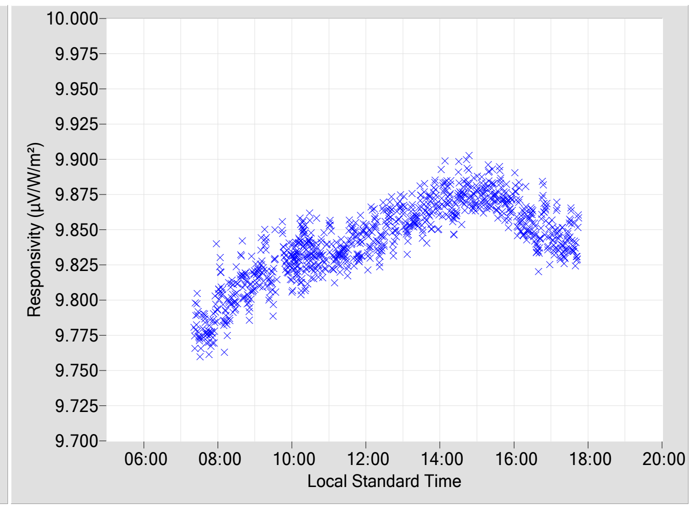


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.8508	0.38	113.85	9.8732	0.34	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8286	0.34	111.17	9.8643	0.33	249.25
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8081	0.37	109.05	9.8731	0.34	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8247	0.32	106.92	9.8647	0.32	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8157	0.36	104.91	9.8682	0.33	255.45
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7962	0.36	103.08	9.8550	0.36	257.27
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8073	0.38	101.29	9.8520	0.34	259.14
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8073	0.47	99.51	9.8469	0.35	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8011	0.37	97.88	9.8573	0.36	262.47
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7800	0.42	96.18	9.8450	0.37	264.08
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.8013	0.40	94.63	9.8400	0.39	265.68
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.7748	N/A	93.09	9.8381	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.7768	N/A	91.54	9.8382	N/A	268.75
26	9.8468	0.31	173.61	9.8565	0.32	186.71	72	9.7701	N/A	90.08	9.8405	N/A	270.24
28	9.8402	0.34	154.11	9.8565	0.32	205.93	74	9.7807	N/A	88.71	9.8568	N/A	271.65
30	9.8334	0.34	144.88	9.8629	0.31	215.11	76	N/A	N/A	N/A	N/A	N/A	N/A
32	9.8227	0.31	138.14	9.8599	0.31	221.74	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.8296	0.33	132.98	9.8762	0.34	226.93	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.8298	0.30	128.61	9.8582	0.31	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.8432	0.34	125.34	9.8705	0.30	235.12	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.8342	0.32	121.66	9.8839	0.32	238.42	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8324	0.33	118.62	9.8788	0.32	241.56	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8282	0.33	116.30	9.8734	0.35	244.30	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

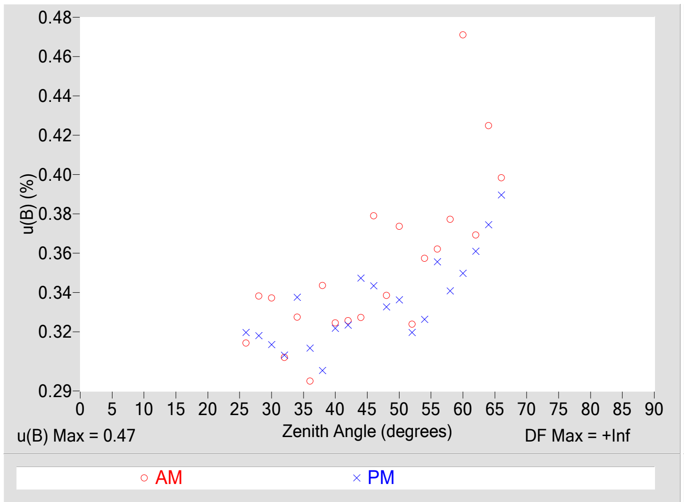


Figure 4. Residuals from Spline Interpolation

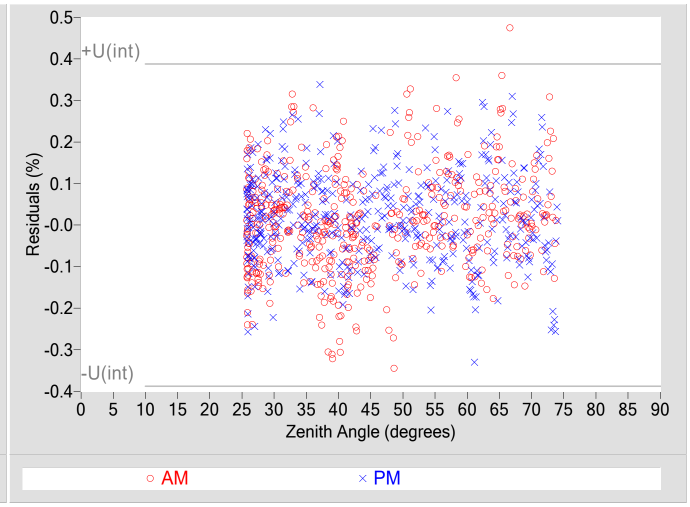


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.47
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	39959
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

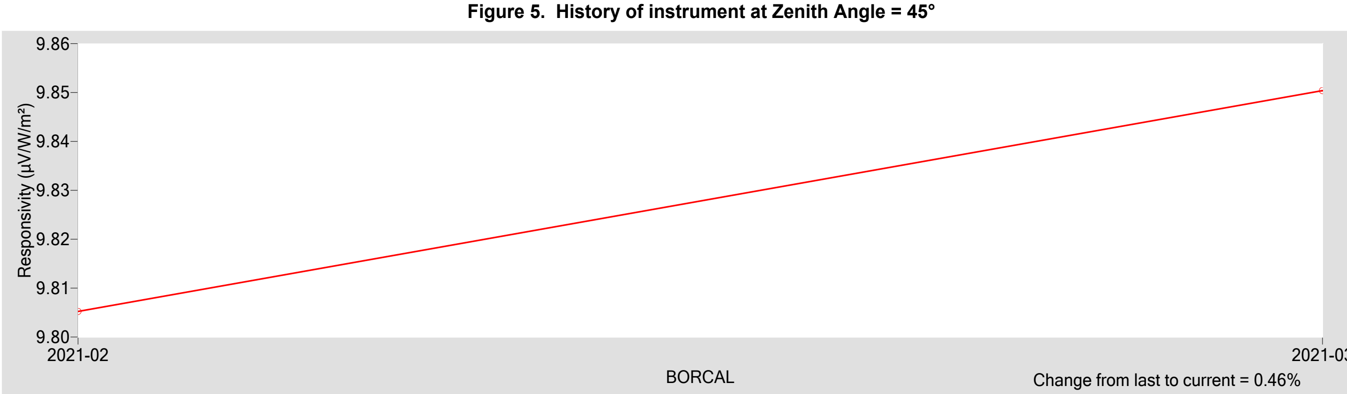
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.8504	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.92
Offset Uncertainty, U(off) (%)	+0.34 / -0.55
Expanded Uncertainty, U (%)	+1.3 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	200803
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____________________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

200803 Kipp & Zonen CHP1

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

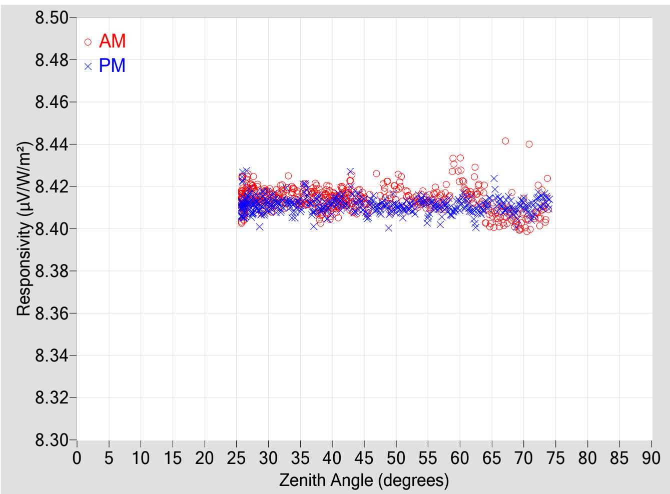


Figure 2. Responsivity vs Local Standard Time

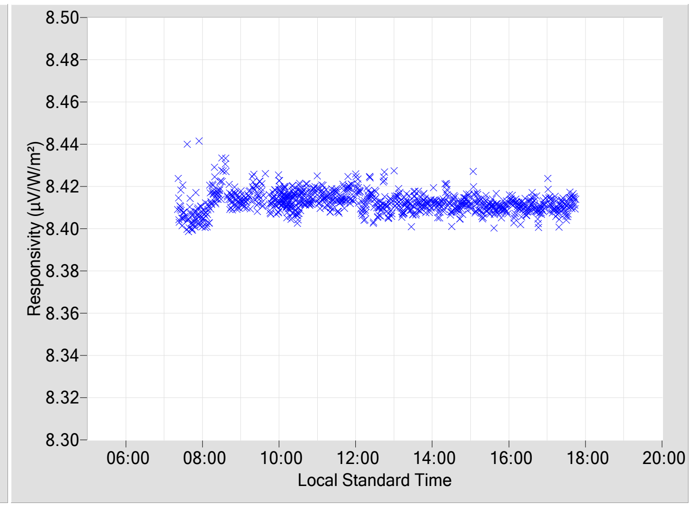


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4140	0.33	113.87	8.4120	0.32	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4162	0.31	111.26	8.4114	0.29	249.20
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4196	0.29	109.00	8.4099	0.29	251.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4157	0.31	107.00	8.4099	0.31	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4142	0.31	104.90	8.4129	0.29	255.41
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4156	0.31	103.04	8.4106	0.31	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4167	0.30	101.31	8.4111	0.30	259.10
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4244	0.30	99.42	8.4117	0.30	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4158	0.30	97.84	8.4092	0.30	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4108	0.30	96.25	8.4119	0.30	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4046	0.30	94.59	8.4119	0.30	265.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.4082	N/A	93.06	8.4096	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4079	N/A	91.56	8.4121	N/A	268.71
26	8.4132	0.30	173.34	8.4109	0.32	186.63	72	8.4097	N/A	90.05	8.4137	N/A	270.21
28	8.4154	0.28	153.81	8.4124	0.29	205.97	74	8.4164	N/A	88.72	8.4115	N/A	271.61
30	8.4145	0.31	144.79	8.4117	0.30	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.4172	0.33	138.29	8.4111	0.31	221.70	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4164	0.30	132.95	8.4095	0.31	226.96	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4144	0.31	128.54	8.4171	0.31	231.22	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4090	0.32	125.38	8.4105	0.33	235.24	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4127	0.31	121.71	8.4113	0.32	238.49	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4132	0.30	118.61	8.4113	0.29	241.60	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4134	0.31	116.17	8.4134	0.32	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

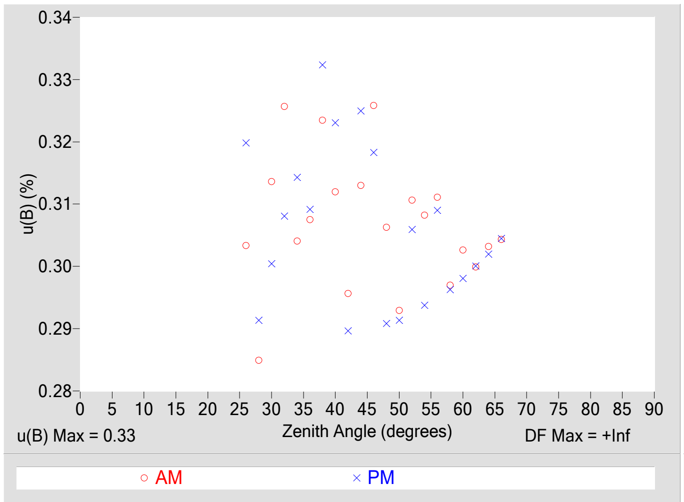


Figure 4. Residuals from Spline Interpolation

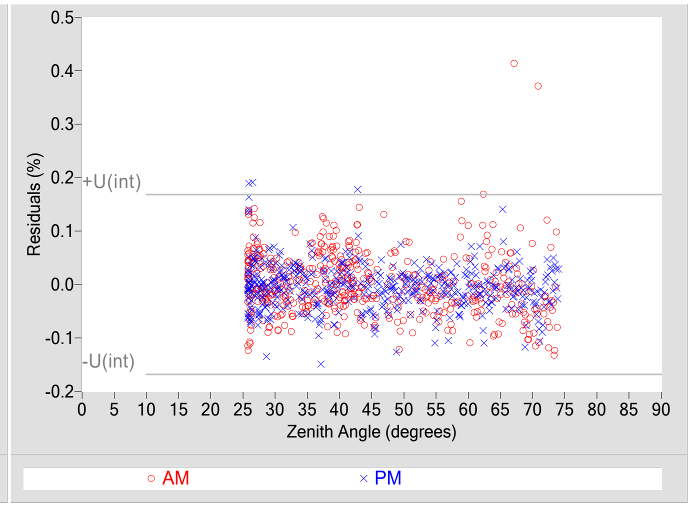


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.084
Combined Standard Uncertainty, u(c) (%)	±0.34
Effective degrees of freedom, DF(c)	233714
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.67
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

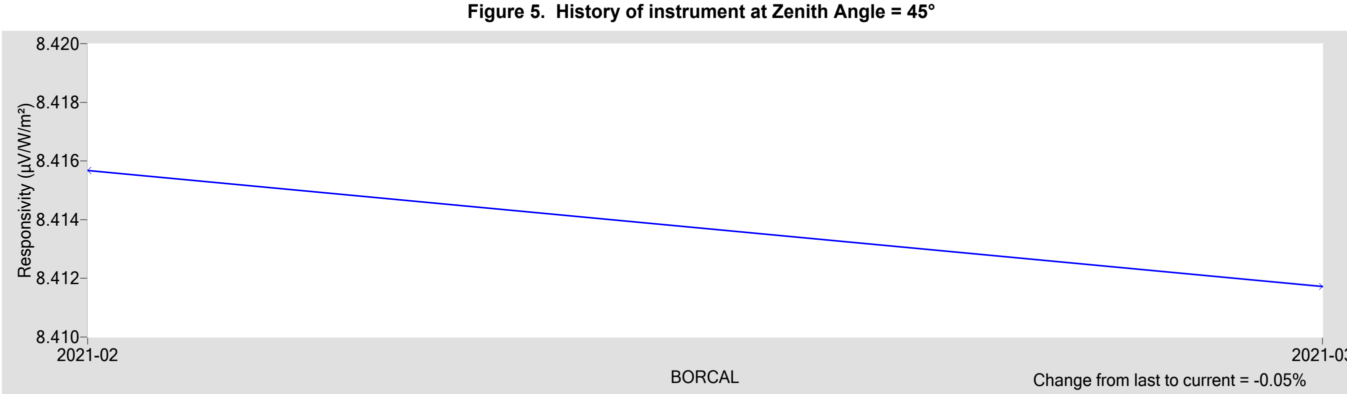
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4117	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.65
Offset Uncertainty, U(off) (%)	+0.15 / -0.033
Expanded Uncertainty, U (%)	+0.80 / -0.68
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	27973F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

27973F3 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

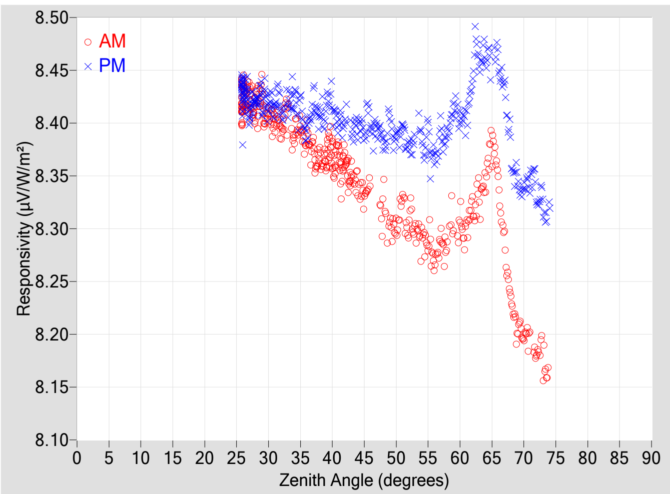


Figure 2. Responsivity vs Local Standard Time

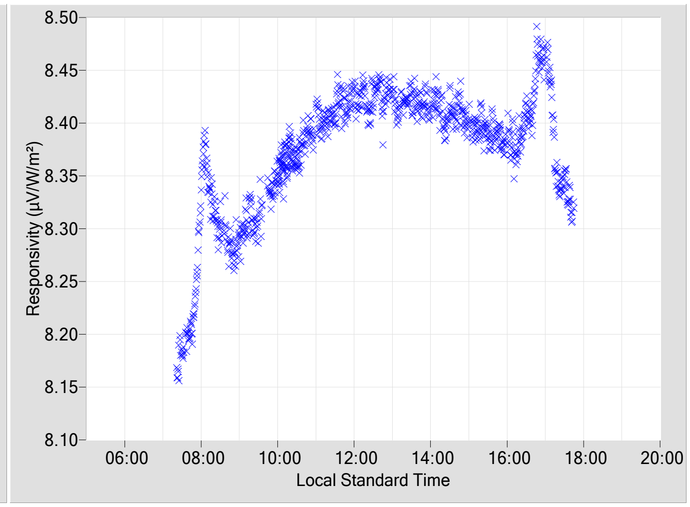


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3443	0.36	113.79	8.3976	0.39	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3187	0.44	111.29	8.3803	0.38	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2988	0.43	109.03	8.3890	0.43	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3078	0.38	106.87	8.3782	0.40	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2899	0.41	104.95	8.3835	0.41	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2696	0.48	103.09	8.3707	0.43	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2815	0.44	101.35	8.3913	0.46	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3057	0.46	99.52	8.4019	0.48	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3194	0.43	97.89	8.4449	0.48	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3466	0.49	96.19	8.4621	0.51	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3456	0.47	94.64	8.4565	0.54	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.2348	N/A	93.10	8.3718	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1975	N/A	91.51	8.3388	N/A	268.76
26	8.4217	0.36	173.51	8.4298	0.34	186.40	72	8.1823	N/A	90.04	8.3280	N/A	270.25
28	8.4156	0.34	154.05	8.4198	0.36	205.96	74	8.1684	N/A	88.72	8.3223	N/A	271.70
30	8.4066	0.33	144.99	8.4156	0.35	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3924	0.35	138.28	8.4092	0.35	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3866	0.37	133.04	8.4266	0.37	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3872	0.35	128.51	8.3911	0.36	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3683	0.38	125.51	8.4064	0.36	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3666	0.35	121.67	8.4173	0.38	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3646	0.36	118.64	8.4049	0.36	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3456	0.37	116.24	8.3964	0.40	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

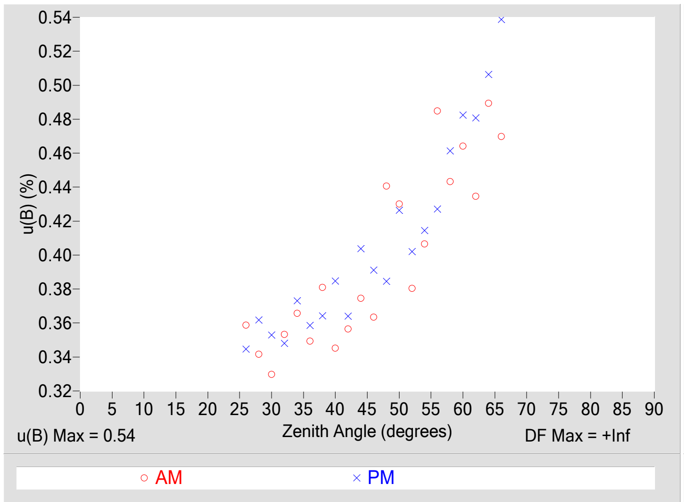


Figure 4. Residuals from Spline Interpolation

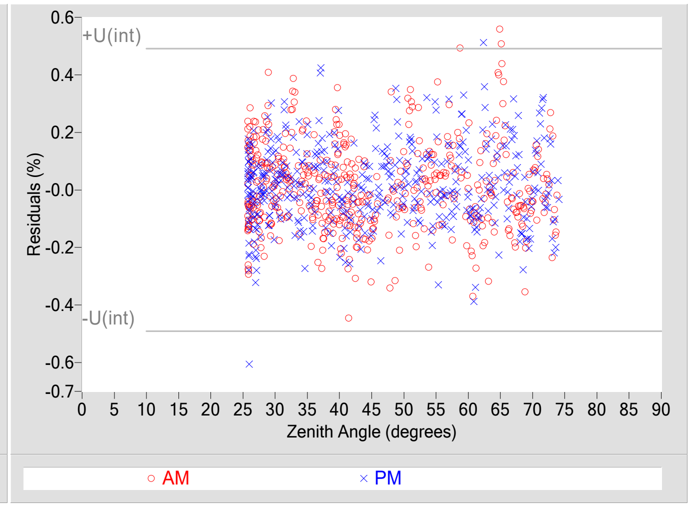


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.54
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	27799
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

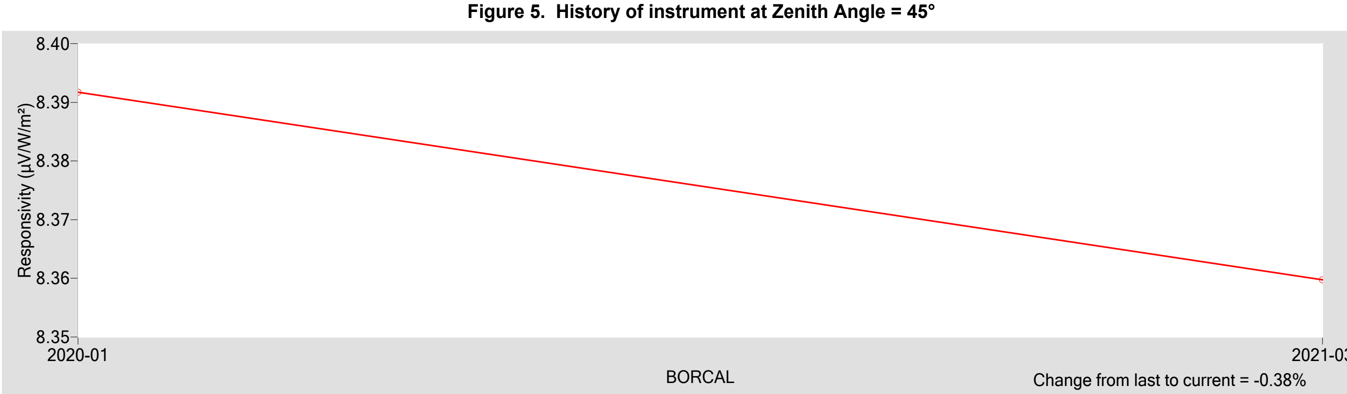
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3597	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+0.80 / -1.1
Expanded Uncertainty, U (%)	+1.8 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29554E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29554E6 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),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  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

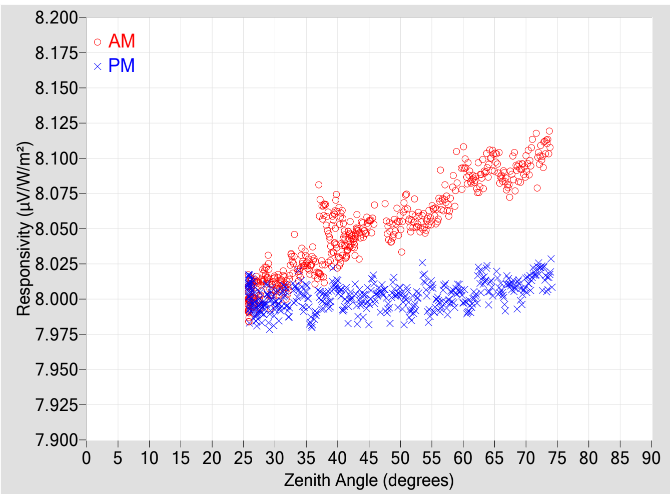


Figure 2. Responsivity vs Local Standard Time

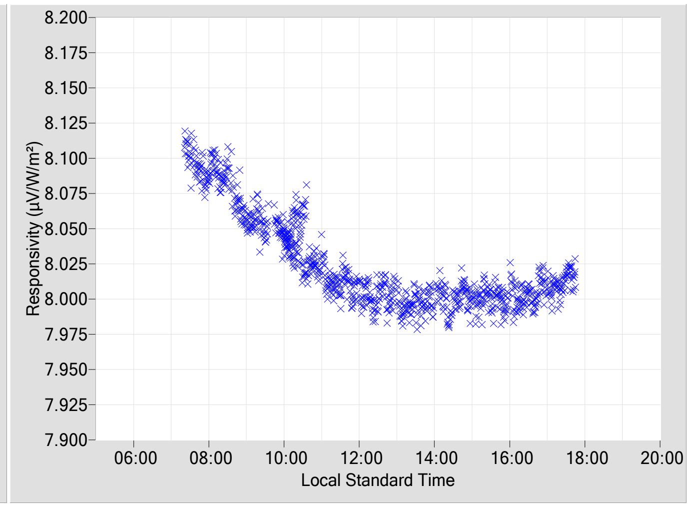


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0600	0.33	113.85	8.0029	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0501	0.32	111.24	7.9948	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0494	0.33	109.01	8.0034	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0586	0.29	106.92	7.9934	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0505	0.31	104.94	8.0102	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0633	0.33	103.03	7.9977	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0643	0.30	101.40	8.0009	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0931	0.34	99.56	8.0021	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0817	0.32	97.82	8.0040	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0970	0.36	96.23	8.0084	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0853	0.30	94.58	8.0070	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.0912	N/A	93.04	8.0095	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0939	N/A	91.55	8.0100	N/A	268.70
26	8.0008	0.30	173.43	8.0041	0.31	187.00	72	8.0961	N/A	90.03	8.0220	N/A	270.20
28	8.0118	0.31	153.85	7.9922	0.30	206.02	74	8.1136	N/A	88.71	8.0185	N/A	271.65
30	8.0116	0.30	144.62	7.9952	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.0078	0.30	138.25	7.9938	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0222	0.30	132.92	8.0106	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0269	0.29	128.49	7.9821	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0470	0.32	125.32	7.9999	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0435	0.30	121.60	8.0093	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0432	0.31	118.63	8.0004	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0494	0.32	116.23	7.9977	0.29	244.38	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

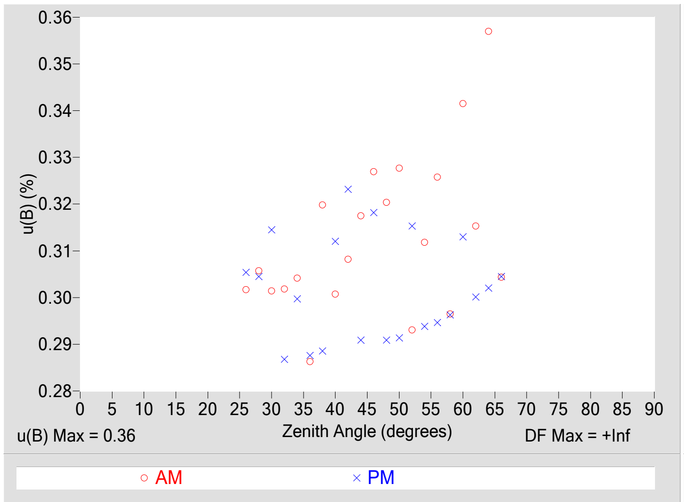


Figure 4. Residuals from Spline Interpolation

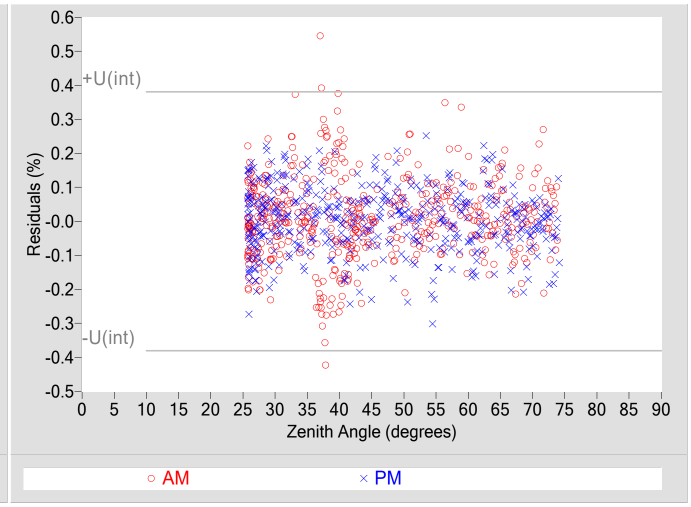


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	17295
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.79
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

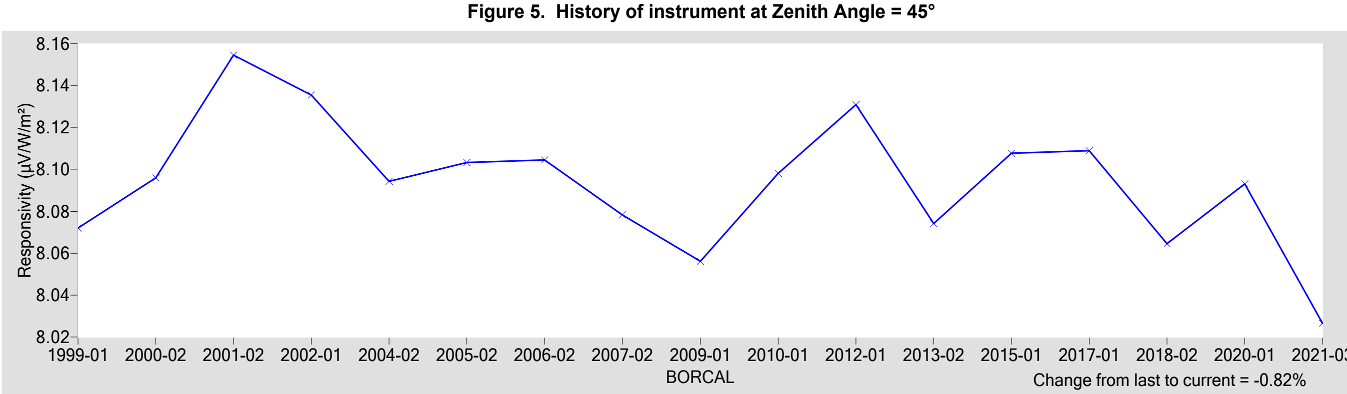
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0265	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.83 / -0.55
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	29619F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29619F3 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

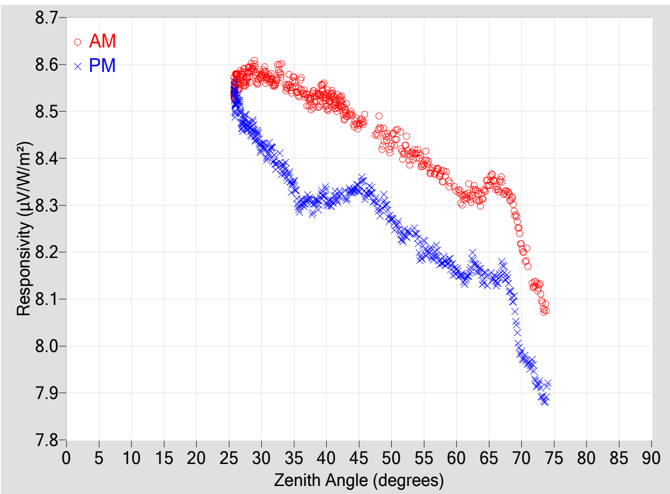


Figure 2. Responsivity vs Local Standard Time

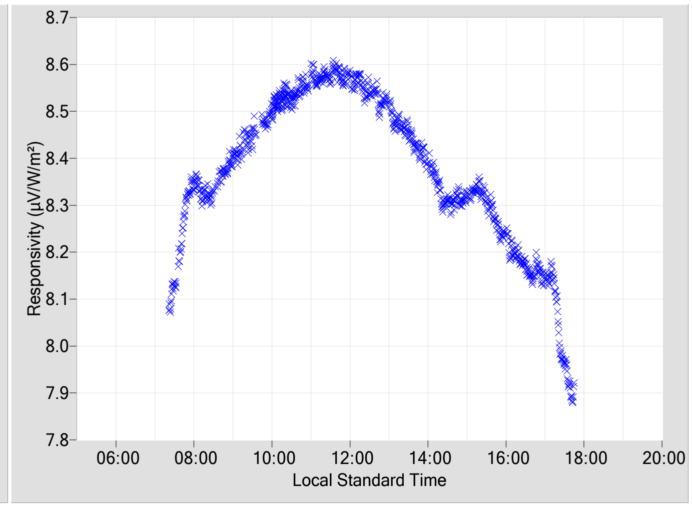


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4856	0.37	113.88	8.3224	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4636	0.37	111.27	8.2901	0.36	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4348	0.40	108.97	8.2728	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4149	0.34	106.95	8.2352	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4080	0.36	104.90	8.2247	0.40	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3725	0.38	103.11	8.1982	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3588	0.36	101.23	8.1791	0.39	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3319	0.38	99.43	8.1613	0.38	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3216	0.39	97.85	8.1566	0.40	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3167	0.45	96.25	8.1439	0.42	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3424	0.42	94.60	8.1386	0.44	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.3221	N/A	93.07	8.1330	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2168	N/A	91.57	7.9799	N/A	268.72
26	8.5547	0.34	173.17	8.5271	0.31	186.81	72	8.1306	N/A	90.05	7.9350	N/A	270.22
28	8.5800	0.31	153.91	8.4659	0.31	205.99	74	8.0824	N/A	88.74	7.9089	N/A	271.62
30	8.5768	0.34	144.87	8.4247	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.5592	0.34	138.31	8.3927	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5555	0.30	132.96	8.3654	0.34	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5522	0.32	128.62	8.3001	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5286	0.34	125.32	8.2977	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5232	0.35	121.70	8.3155	0.34	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5207	0.35	118.55	8.3203	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4850	0.36	116.20	8.3309	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

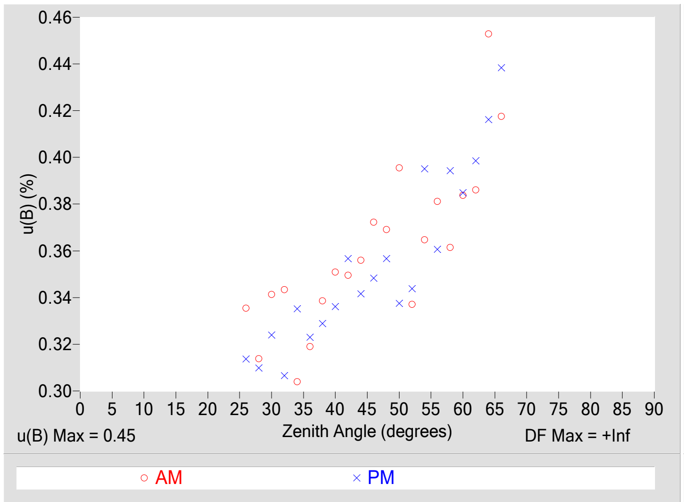


Figure 4. Residuals from Spline Interpolation

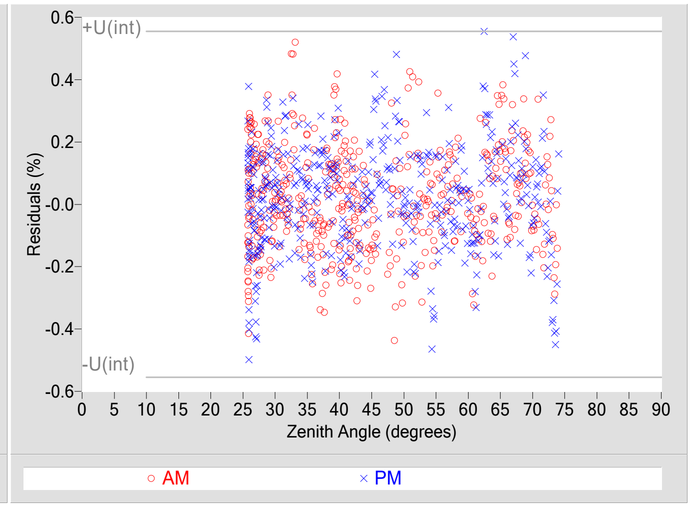


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	11120
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

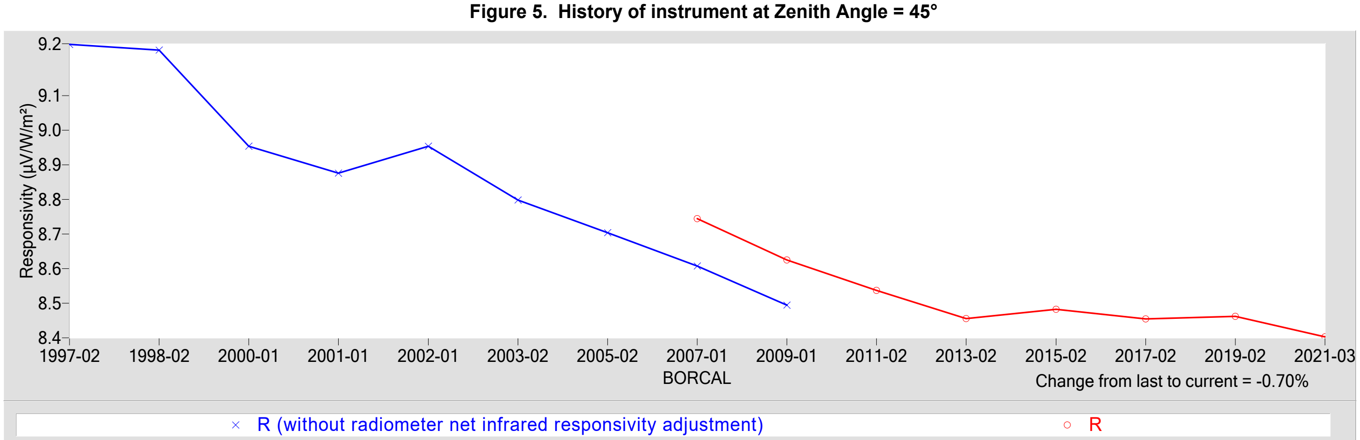
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4031	0.69050

† Rnet determination date: 04/24/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+2.1 / -2.9
Expanded Uncertainty, U (%)	+2.8 / -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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29743E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29743E6 Eppley NIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

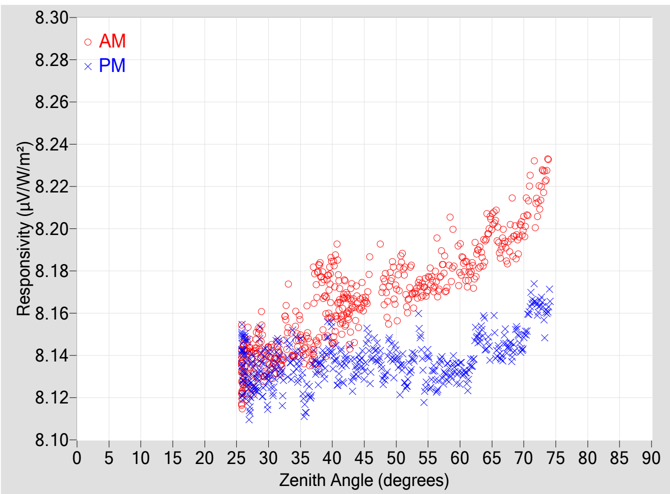


Figure 2. Responsivity vs Local Standard Time

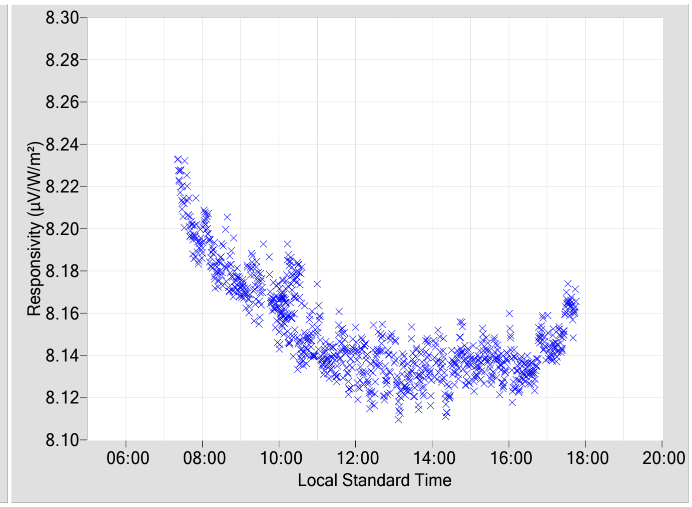


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.1825	0.33	113.85	8.1355	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1715	0.32	111.24	8.1295	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1663	0.33	109.01	8.1396	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1694	0.29	106.92	8.1314	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1707	0.31	104.94	8.1424	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1739	0.33	103.03	8.1303	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1709	0.30	101.40	8.1320	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1830	0.34	99.56	8.1335	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1788	0.32	97.82	8.1387	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1951	0.36	96.23	8.1465	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1926	0.30	94.58	8.1422	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.1975	N/A	93.04	8.1421	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1998	N/A	91.55	8.1471	N/A	268.70
26	8.1334	0.30	173.43	8.1373	0.31	187.00	72	8.2090	N/A	90.03	8.1629	N/A	270.20
28	8.1416	0.31	153.85	8.1266	0.30	206.02	74	8.2329	N/A	88.71	8.1651	N/A	271.65
30	8.1400	0.30	144.62	8.1282	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1367	0.30	138.25	8.1290	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1448	0.30	132.92	8.1425	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1482	0.29	128.49	8.1184	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1679	0.32	125.32	8.1332	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1647	0.30	121.60	8.1437	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1651	0.31	118.63	8.1359	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1643	0.32	116.23	8.1352	0.29	244.38	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

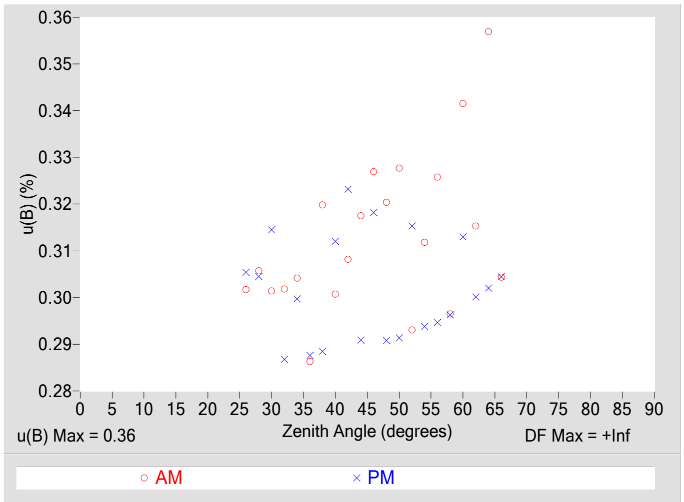


Figure 4. Residuals from Spline Interpolation

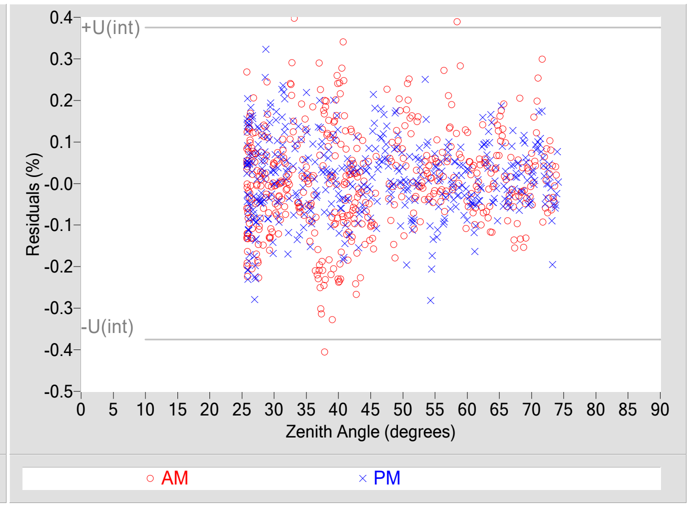


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	18044
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.79
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

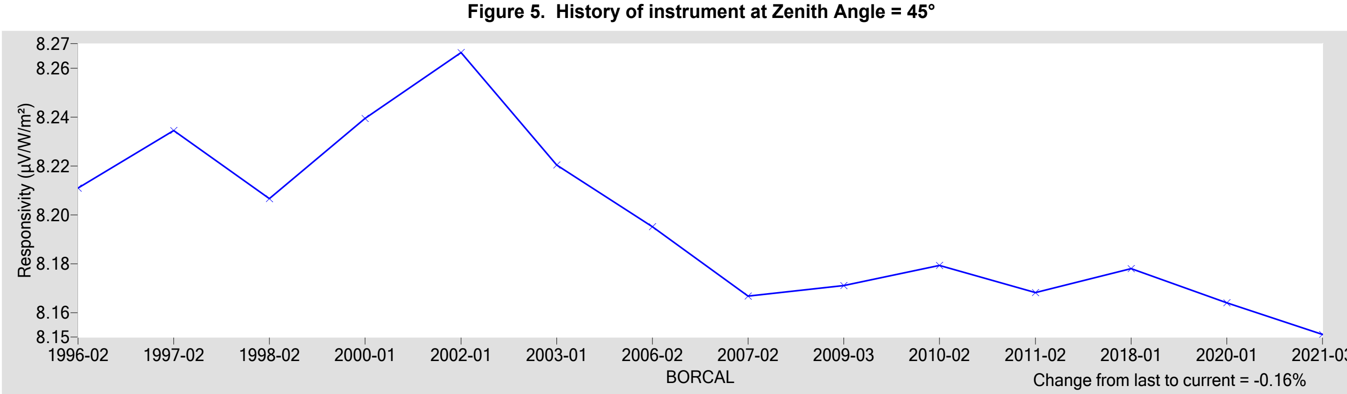
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1510	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.39 / -0.40
Expanded Uncertainty, U (%)	+1.1 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29856E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29856E6 Eppley NIP

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

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

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

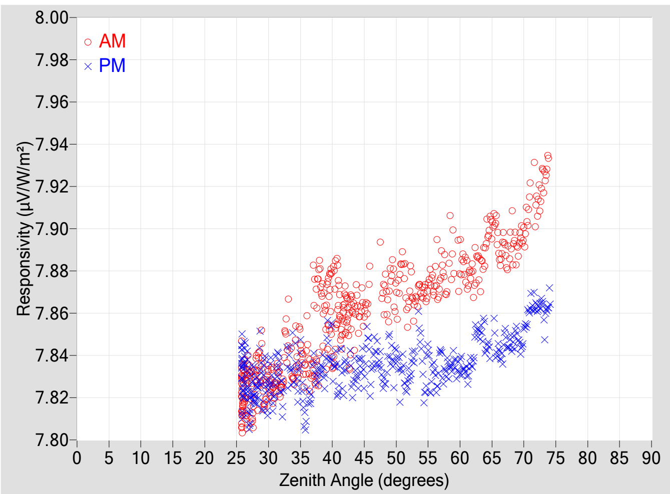


Figure 2. Responsivity vs Local Standard Time

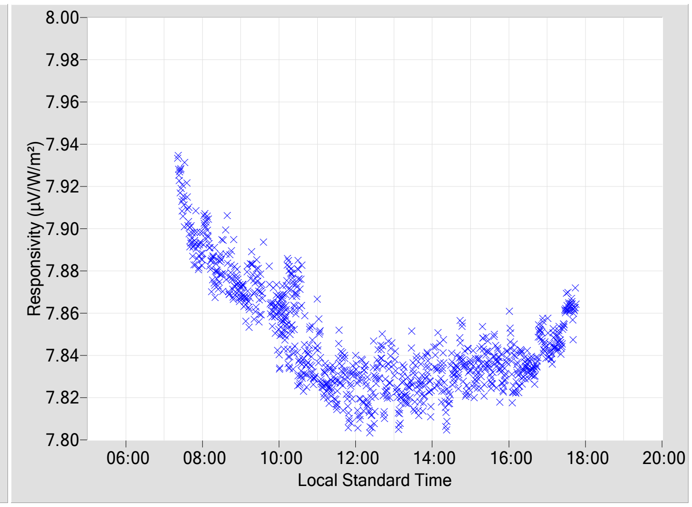


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8780	0.33	113.85	7.8319	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8684	0.32	111.24	7.8278	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8655	0.33	109.01	7.8388	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8669	0.29	106.92	7.8296	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8692	0.31	104.94	7.8417	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8733	0.33	103.03	7.8310	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8694	0.30	101.40	7.8334	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8833	0.34	99.56	7.8357	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8767	0.32	97.82	7.8389	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8923	0.36	96.23	7.8455	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8894	0.30	94.58	7.8423	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.8932	N/A	93.04	7.8456	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8954	N/A	91.55	7.8502	N/A	268.70
26	7.8228	0.30	173.43	7.8314	0.31	187.00	72	7.9095	N/A	90.03	7.8626	N/A	270.20
28	7.8299	0.31	153.85	7.8219	0.30	206.02	74	7.9341	N/A	88.71	7.8654	N/A	271.65
30	7.8290	0.30	144.62	7.8235	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.8261	0.30	138.25	7.8232	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.8353	0.30	132.92	7.8388	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8404	0.29	128.49	7.8137	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8624	0.32	125.32	7.8318	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8580	0.30	121.60	7.8408	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8617	0.31	118.63	7.8328	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8628	0.32	116.23	7.8323	0.29	244.38	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

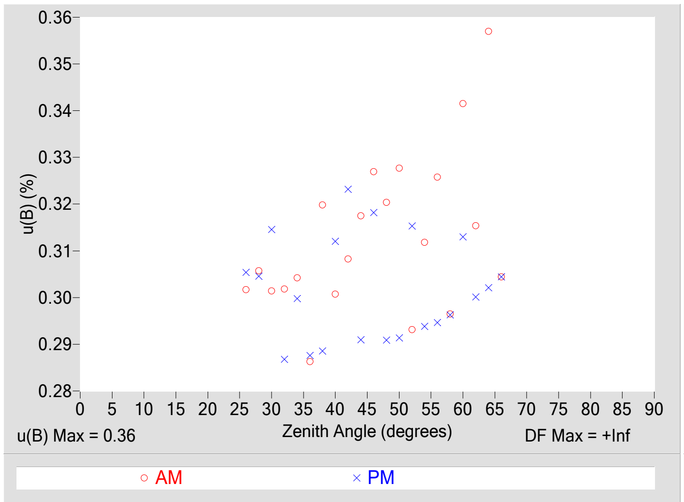


Figure 4. Residuals from Spline Interpolation

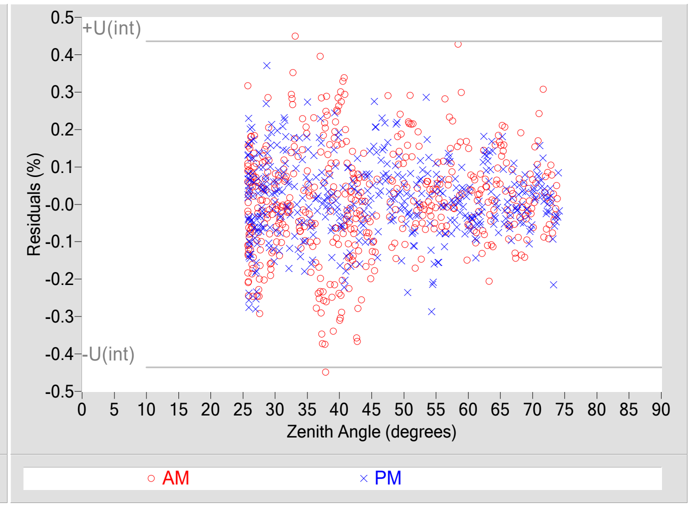


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.42
Effective degrees of freedom, DF(c)	11467
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.82
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

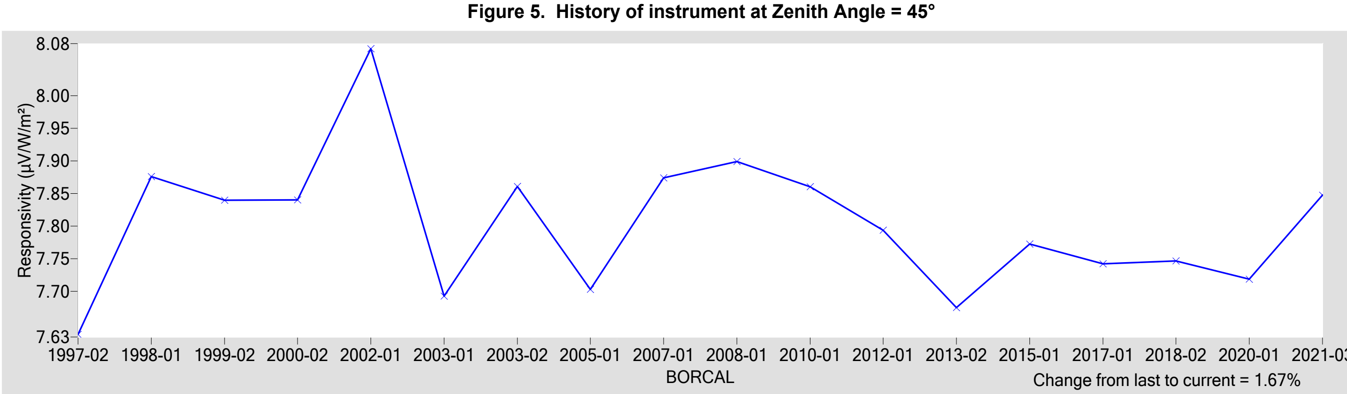
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8478	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.45 / -0.43
Expanded Uncertainty, U (%)	+1.1 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 29869E6
Calibration Date: 8/25/2021
Due Date: 8/25/2022
Customer: TWP
Environmental Conditions: see page 4
Test Dates: 8/24-25

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ______________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29869E6 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),
  - = $Win - Wout$ = $Win - \sigma * Tc^4$
  - 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

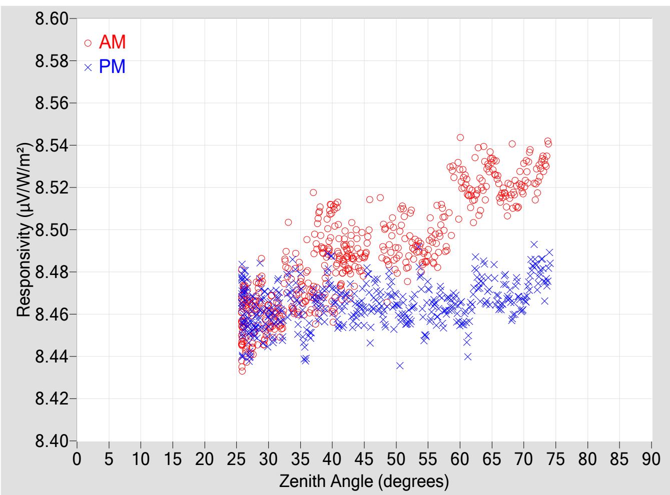


Figure 2. Responsivity vs Local Standard Time

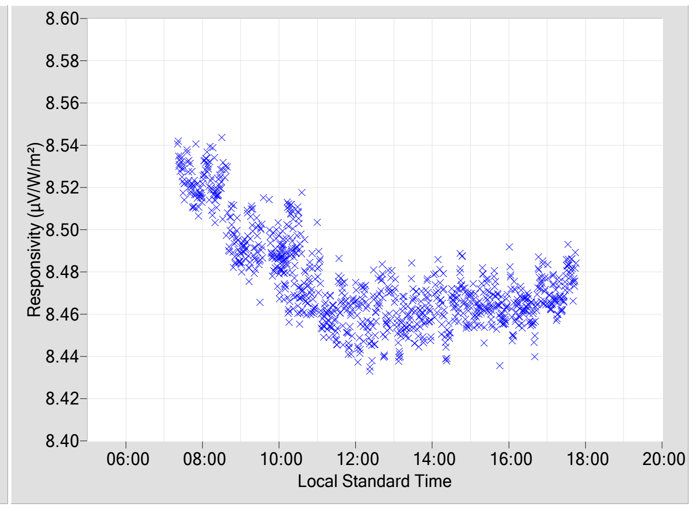


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5070	0.33	113.85	8.4591	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4943	0.32	111.24	8.4596	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4847	0.33	109.01	8.4653	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4901	0.29	106.92	8.4576	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4853	0.31	104.94	8.4698	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4894	0.33	103.03	8.4631	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4906	0.30	101.40	8.4639	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5263	0.34	99.56	8.4613	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5132	0.32	97.82	8.4700	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5270	0.36	96.23	8.4701	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5199	0.30	94.58	8.4658	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5157	N/A	93.07	8.4630	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5220	N/A	91.55	8.4649	N/A	268.70
26	8.4575	0.30	173.43	8.4639	0.31	187.00	72	8.5210	N/A	90.03	8.4798	N/A	270.20
28	8.4624	0.31	153.85	8.4547	0.30	206.02	74	8.5412	N/A	88.71	8.4826	N/A	271.65
30	8.4603	0.30	144.62	8.4574	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.4553	0.30	138.25	8.4570	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4692	0.30	132.92	8.4753	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4759	0.29	128.49	8.4449	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4905	0.32	125.32	8.4623	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4870	0.30	121.60	8.4731	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4900	0.31	118.63	8.4654	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4910	0.32	116.23	8.4612	0.29	244.38	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

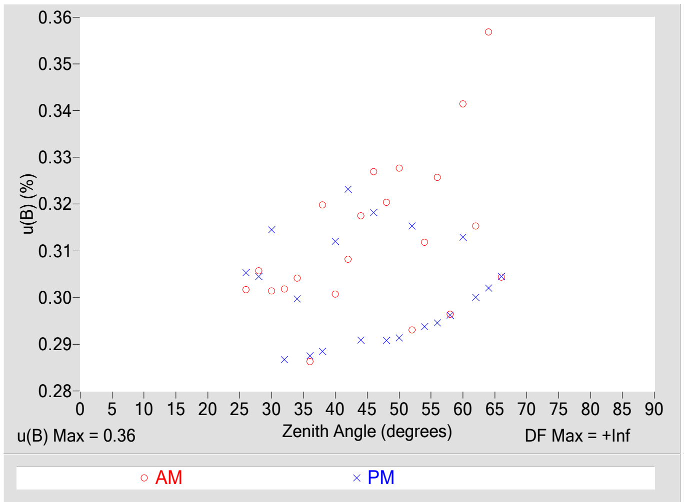


Figure 4. Residuals from Spline Interpolation

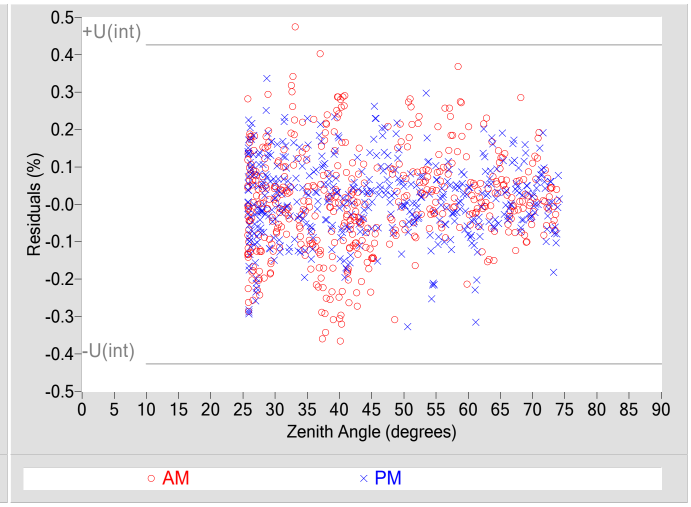


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.42
Effective degrees of freedom, DF(c)	12234
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.81
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

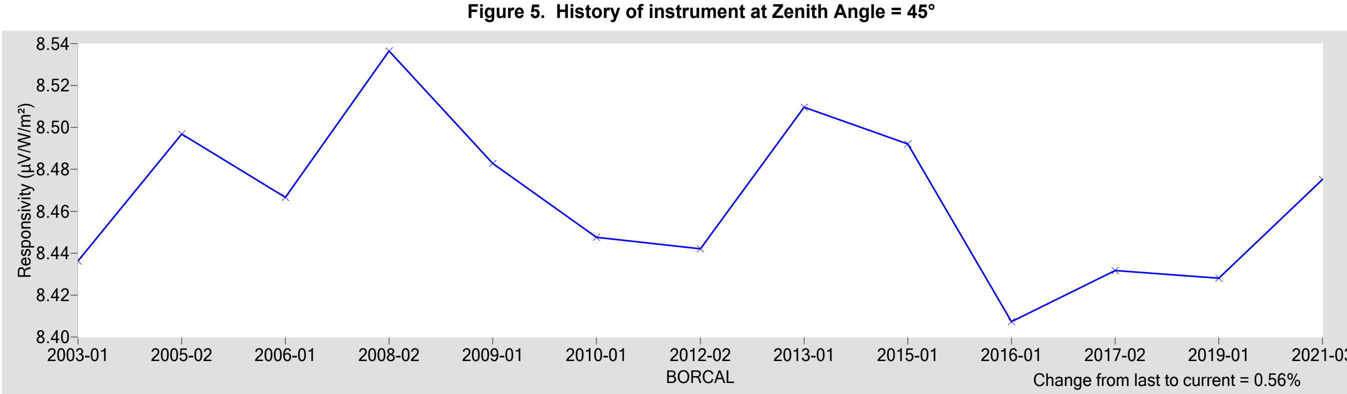
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4751	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.60 / -0.36
Expanded Uncertainty, U (%)	+1.3 / -1.0
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	29913F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29913F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

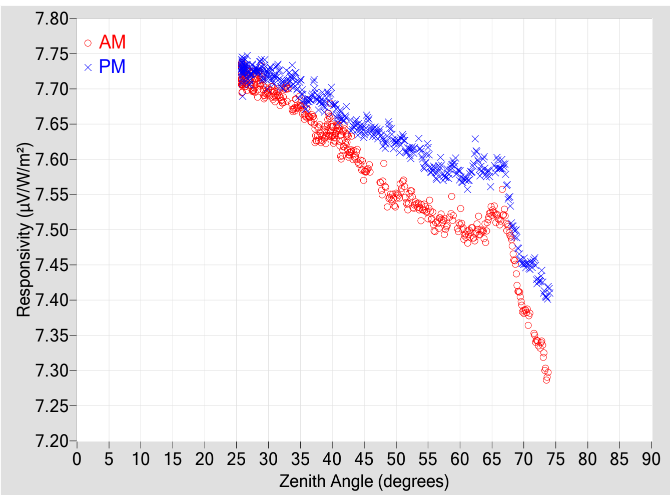


Figure 2. Responsivity vs Local Standard Time

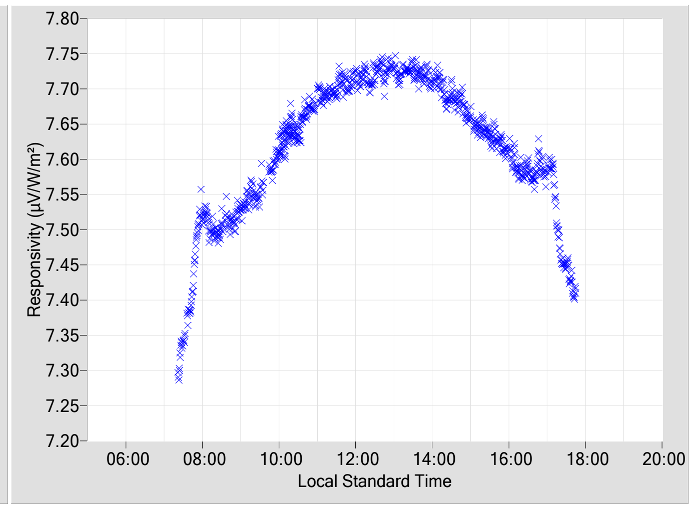


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	7.5870	0.33	113.79	7.6424	0.34	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5660	0.41	111.29	7.6233	0.33	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5427	0.40	109.03	7.6251	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5437	0.34	106.87	7.6108	0.34	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5270	0.37	104.95	7.6039	0.35	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5076	0.45	103.09	7.5834	0.36	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5036	0.40	101.35	7.5787	0.39	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5106	0.42	99.52	7.5760	0.41	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4956	0.39	97.89	7.5911	0.40	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4970	0.44	96.19	7.5853	0.41	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5158	0.42	94.64	7.5926	0.43	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.4878	N/A	93.10	7.5200	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.3842	N/A	91.51	7.4518	N/A	268.76
26	7.7163	0.33	173.51	7.7282	0.32	186.40	72	7.3421	N/A	90.04	7.4314	N/A	270.25
28	7.7070	0.32	154.05	7.7261	0.33	205.96	74	7.2974	N/A	88.72	7.4151	N/A	271.65
30	7.6951	0.30	144.99	7.7189	0.32	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.6828	0.33	138.28	7.7069	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6725	0.34	133.04	7.7174	0.34	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6682	0.32	128.51	7.6789	0.32	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6373	0.35	125.51	7.6819	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6387	0.31	121.67	7.6822	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6309	0.32	118.64	7.6625	0.32	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6034	0.34	116.24	7.6456	0.36	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

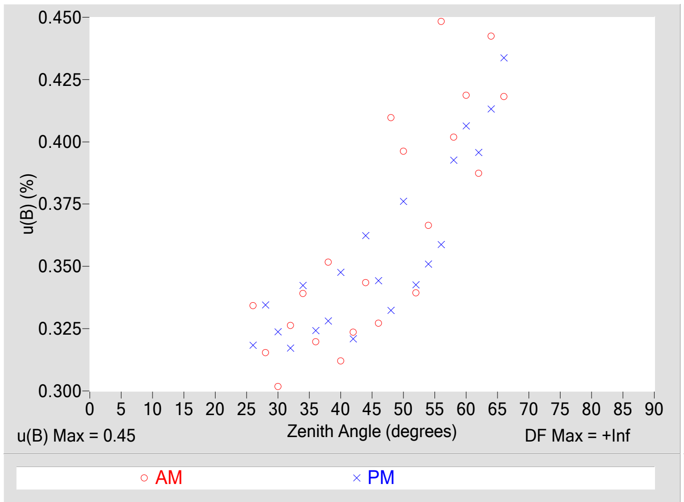


Figure 4. Residuals from Spline Interpolation

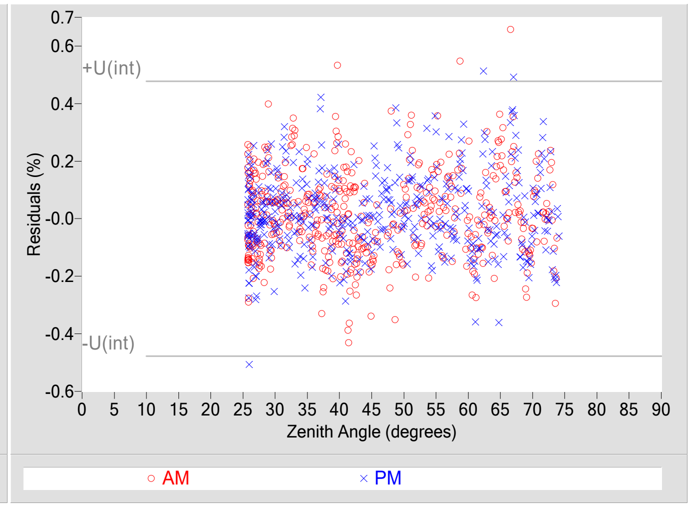


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	16921
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

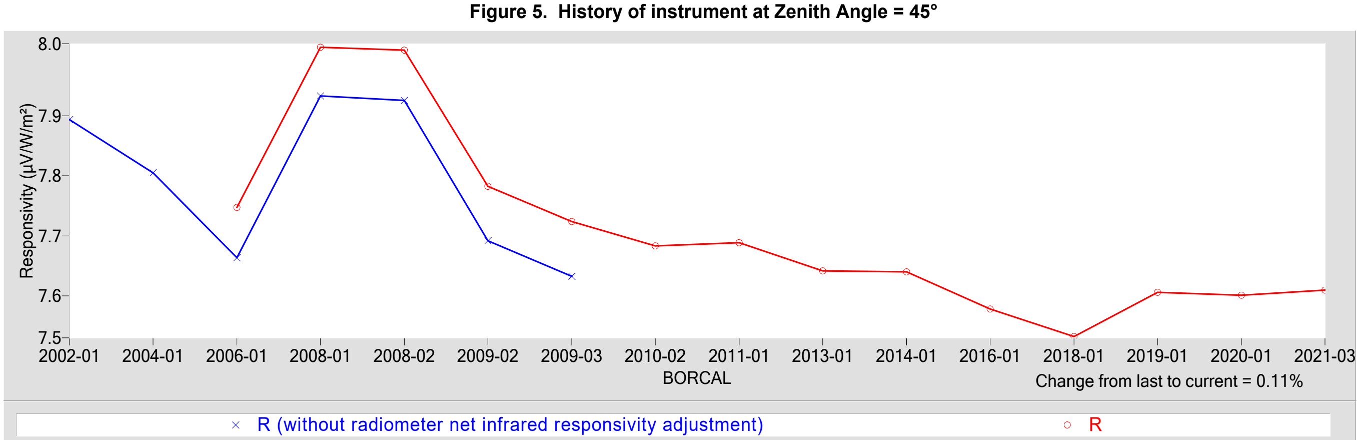
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6097	0.53900

† Rnet determination date: 03/31/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+1.4 / -1.4
Expanded Uncertainty, U (%)	+2.3 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	29915F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29915F3 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

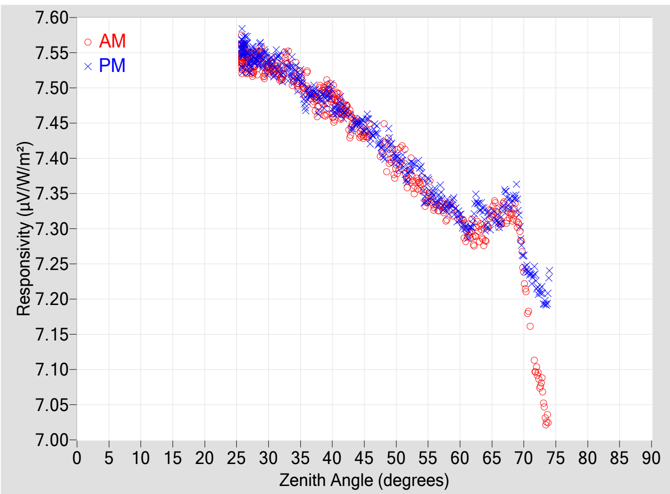


Figure 2. Responsivity vs Local Standard Time

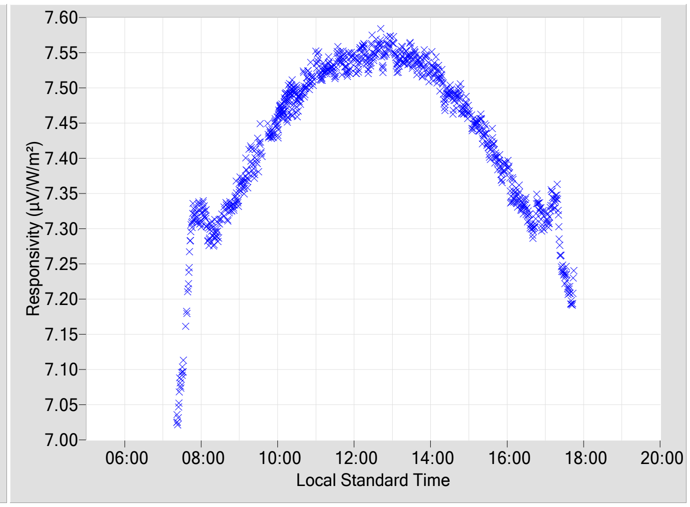


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.4419	0.37	113.88	7.4308	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4216	0.37	111.27	7.4048	0.36	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3876	0.40	108.97	7.4031	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3729	0.34	106.95	7.3801	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3616	0.37	104.90	7.3760	0.40	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3311	0.38	103.11	7.3463	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3231	0.36	101.23	7.3310	0.40	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3135	0.39	99.43	7.3178	0.39	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2899	0.39	97.85	7.3094	0.40	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2895	0.45	96.25	7.3093	0.42	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3149	0.42	94.60	7.3099	0.44	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.3176	N/A	93.07	7.3383	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.2373	N/A	91.57	7.2542	N/A	268.72
26	7.5467	0.34	173.17	7.5540	0.31	186.81	72	7.0969	N/A	90.05	7.2198	N/A	270.22
28	7.5372	0.31	153.91	7.5416	0.31	205.99	74	7.0302	N/A	88.74	7.2262	N/A	271.62
30	7.5292	0.34	144.87	7.5331	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.5155	0.34	138.31	7.5231	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.5149	0.30	132.96	7.5219	0.34	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5056	0.32	128.62	7.4847	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.4866	0.34	125.32	7.4794	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4779	0.35	121.70	7.4802	0.34	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4703	0.35	118.55	7.4654	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4447	0.36	116.20	7.4504	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

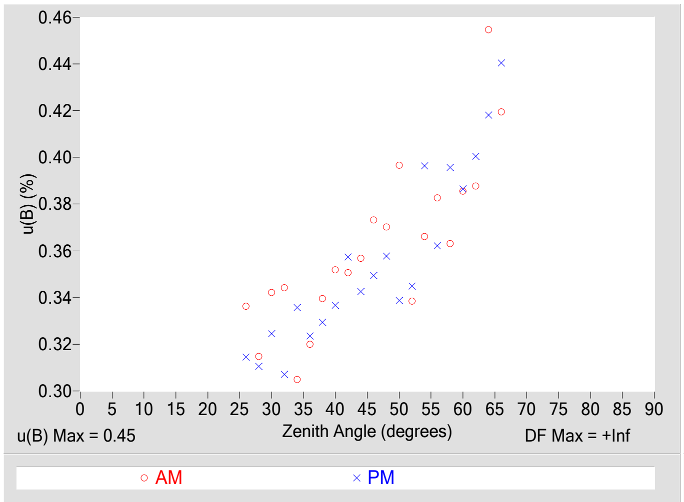


Figure 4. Residuals from Spline Interpolation

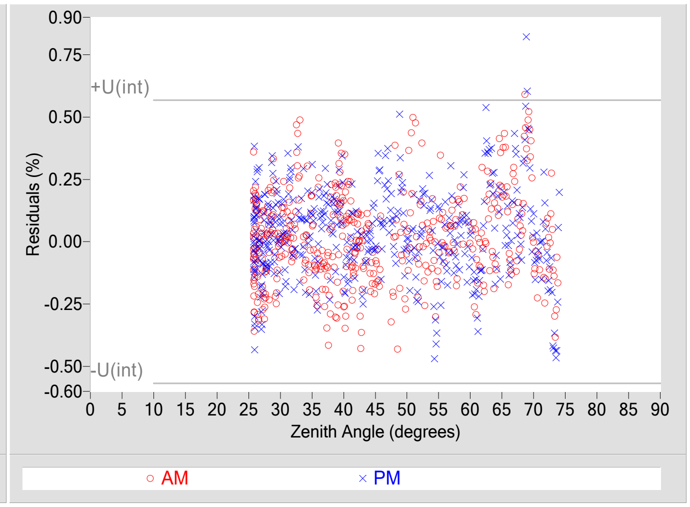


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	10455
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

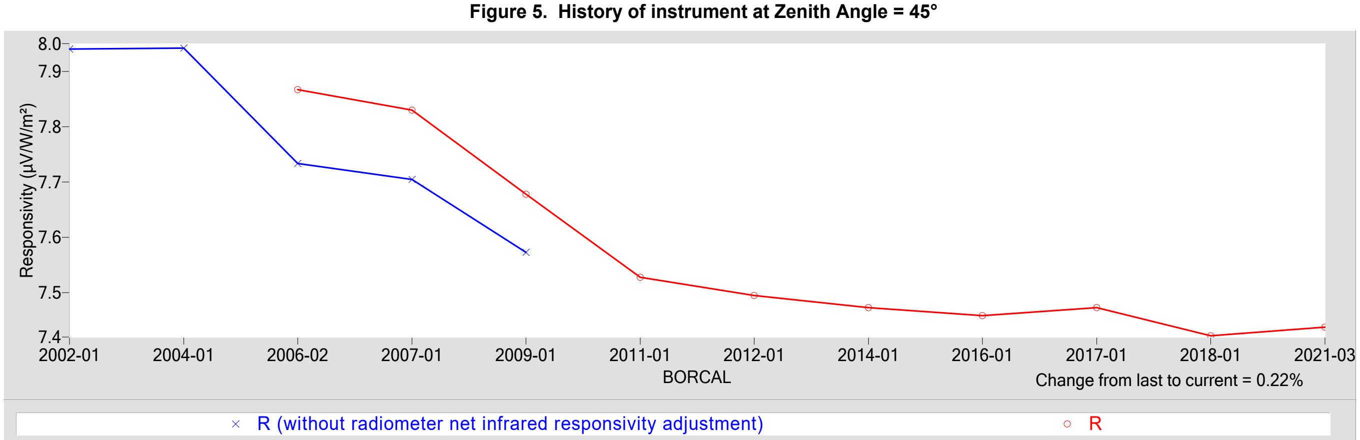
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.4381	0.63274

† Rnet determination date: 06/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.3 / -1.7
Expanded Uncertainty, U (%)	+2.1 / -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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29934E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29934E6 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),	*I*	=	reference irradiance (W/m²), beam (B) or global (G)
Rnet	=	radiometer net infrared responsivity (μV/W/m²), see Table 4,	where,		*G* = *B * COS(Z) + D,*
Wnet	=	effective net infrared measured by pyrgeometer (W/m²),			*Z* = zenith angle (degrees),
	=	*Win - Wout* = *Win - σ * Tc^4*			*D* = reference diffuse irradiance (W/m²).

where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

Figure 1. Responsivity vs Zenith Angle

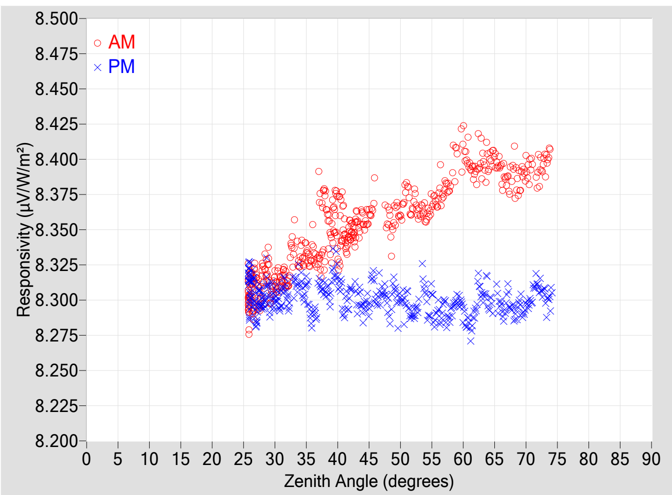


Figure 2. Responsivity vs Local Standard Time

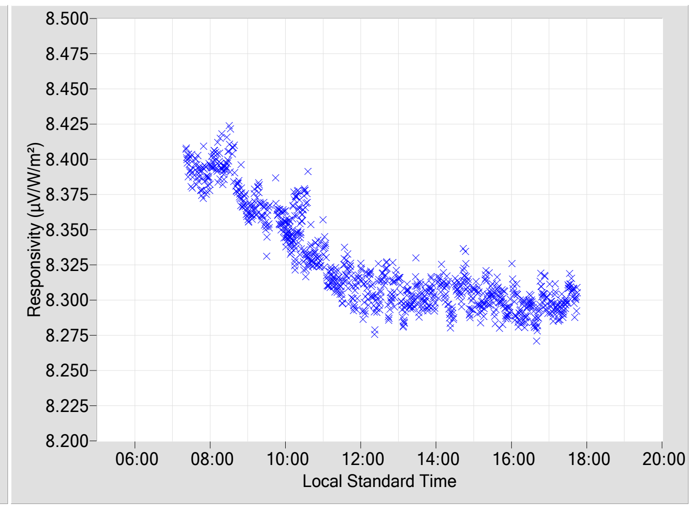


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3777	0.33	113.85	8.3029	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3577	0.32	111.24	8.2963	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3590	0.33	109.01	8.3005	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3678	0.29	106.92	8.2897	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3594	0.31	104.94	8.3055	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3720	0.33	103.03	8.2919	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3785	0.30	101.40	8.2901	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4106	0.34	99.56	8.2933	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3902	0.32	97.82	8.2969	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4001	0.36	96.23	8.3002	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3891	0.30	94.58	8.2965	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.3909	N/A	93.04	8.2912	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3911	N/A	91.55	8.2956	N/A	268.70
26	8.3045	0.30	173.43	8.3095	0.31	187.00	72	8.3893	N/A	90.03	8.3106	N/A	270.20
28	8.3149	0.31	153.85	8.2978	0.30	206.02	74	8.4075	N/A	88.71	8.3022	N/A	271.65
30	8.3129	0.30	144.62	8.3001	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3126	0.30	138.25	8.2990	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3306	0.30	132.92	8.3159	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3325	0.29	128.49	8.2869	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3579	0.32	125.32	8.3060	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3506	0.30	121.60	8.3178	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3496	0.31	118.63	8.3044	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3592	0.32	116.23	8.2934	0.29	244.38	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

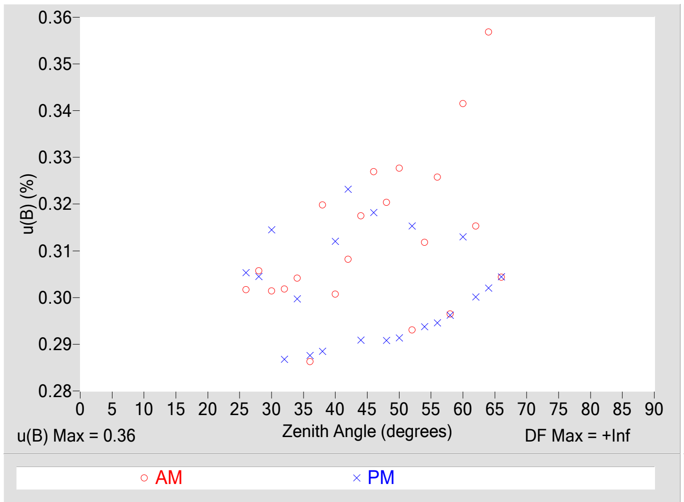


Figure 4. Residuals from Spline Interpolation

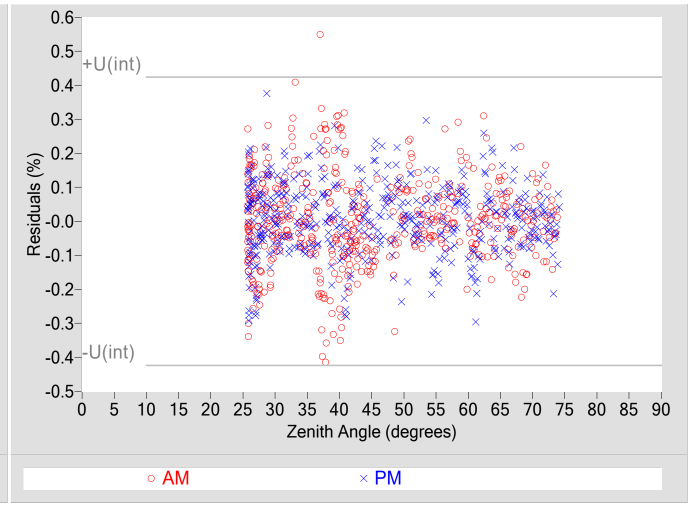


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	12451
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.81
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

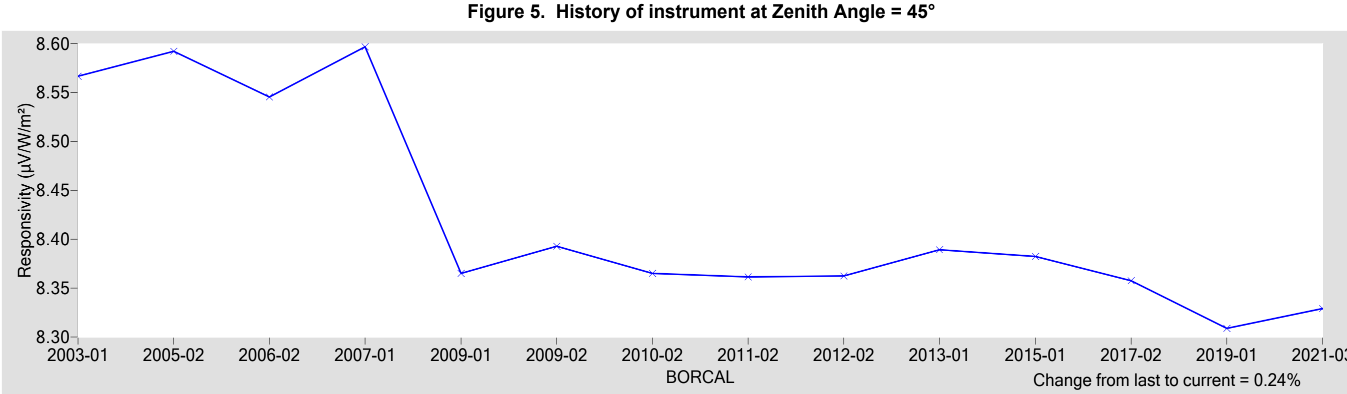
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3291	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.98 / -0.51
Expanded Uncertainty, U (%)	+1.6 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29938E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ __________________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

29938E6 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),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  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

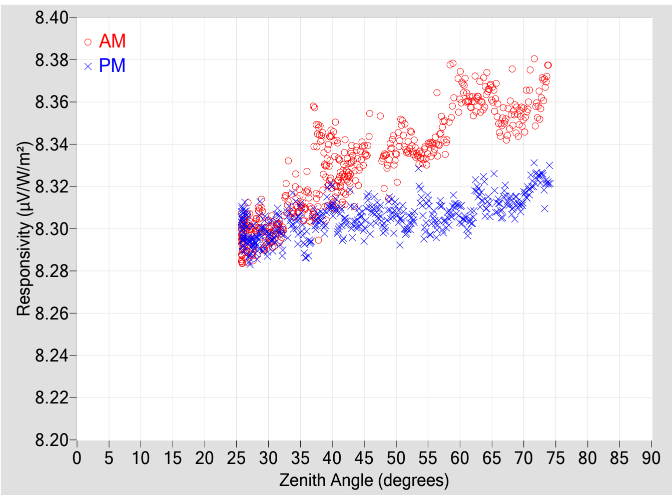


Figure 2. Responsivity vs Local Standard Time

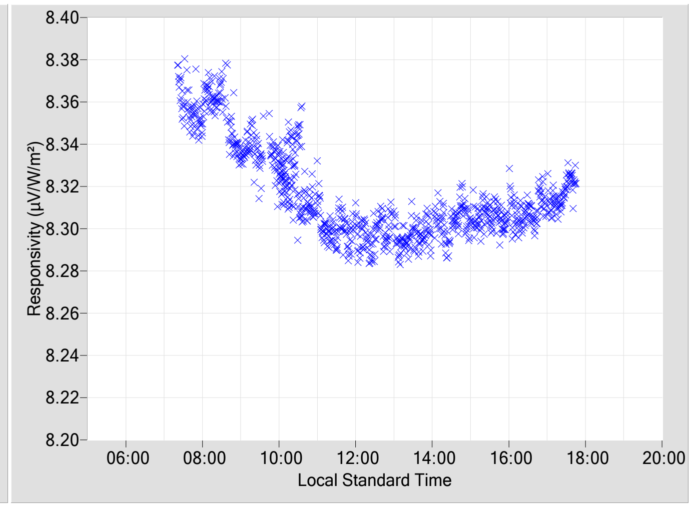


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3491	0.33	113.85	8.3056	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3308	0.32	111.24	8.3013	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3313	0.33	109.01	8.3079	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3395	0.29	106.92	8.3018	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3332	0.31	104.94	8.3126	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3393	0.33	103.03	8.3030	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3393	0.30	101.40	8.3036	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3643	0.34	99.56	8.3083	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3587	0.32	97.82	8.3074	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3668	0.36	96.23	8.3120	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3502	0.30	94.58	8.3117	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.3572	N/A	93.04	8.3115	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3511	N/A	91.55	8.3149	N/A	268.70
26	8.2949	0.30	173.43	8.3004	0.31	187.00	72	8.3553	N/A	90.03	8.3245	N/A	270.20
28	8.2996	0.31	153.85	8.2924	0.30	206.02	74	8.3775	N/A	88.71	8.3237	N/A	271.65
30	8.2990	0.30	144.62	8.2949	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.2986	0.30	138.25	8.2955	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3115	0.30	132.92	8.3073	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3162	0.29	128.49	8.2896	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3330	0.32	125.32	8.3050	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3270	0.30	121.60	8.3133	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3258	0.31	118.63	8.3024	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3314	0.32	116.23	8.3047	0.29	244.38	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

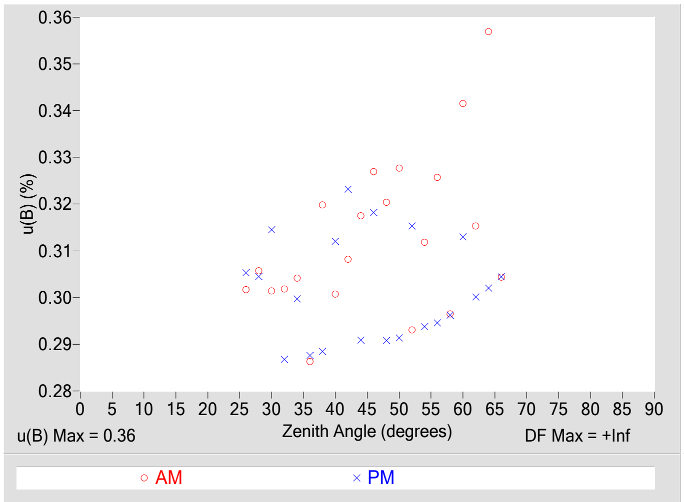


Figure 4. Residuals from Spline Interpolation

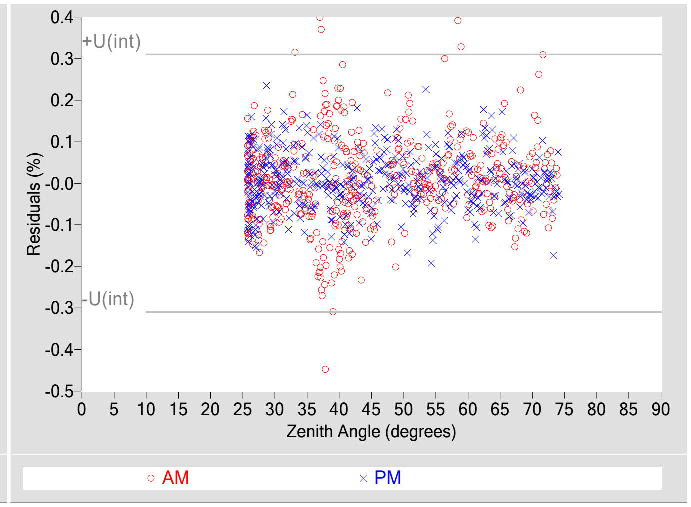


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	33627
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.76
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

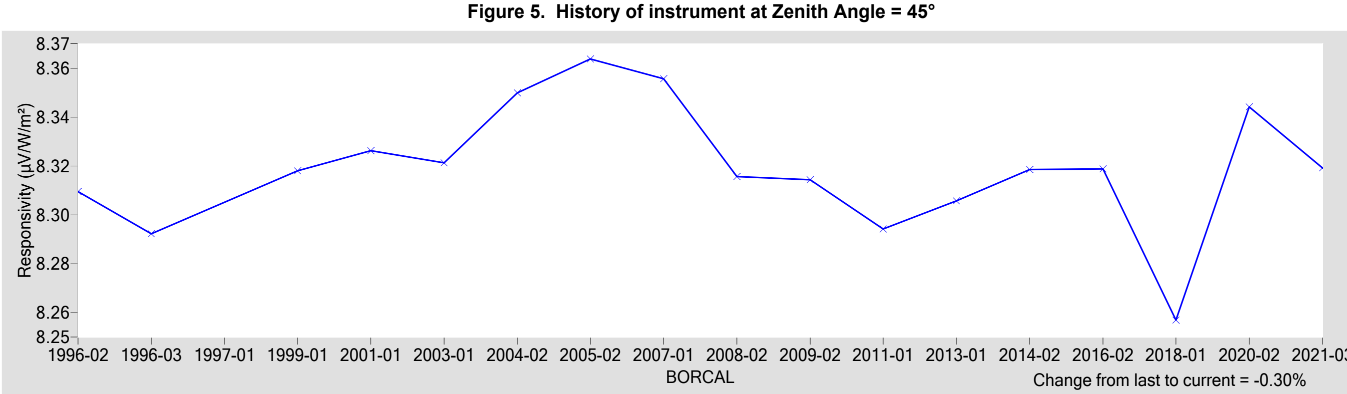
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3191	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.54 / -0.35
Expanded Uncertainty, U (%)	+1.2 / -1.0
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated)
Manufacturer: Eppley
Model: PSP
Serial Number: 30617F3
Calibration Date: 8/25/2021
Due Date: 8/25/2022
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 8/24-25

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ______________
Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30617F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

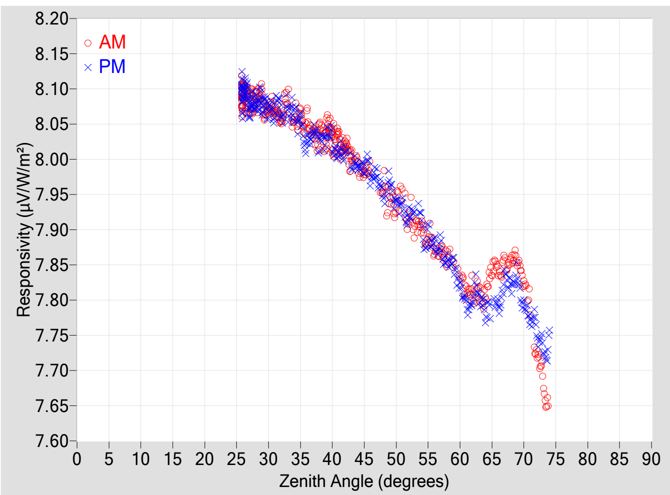


Figure 2. Responsivity vs Local Standard Time

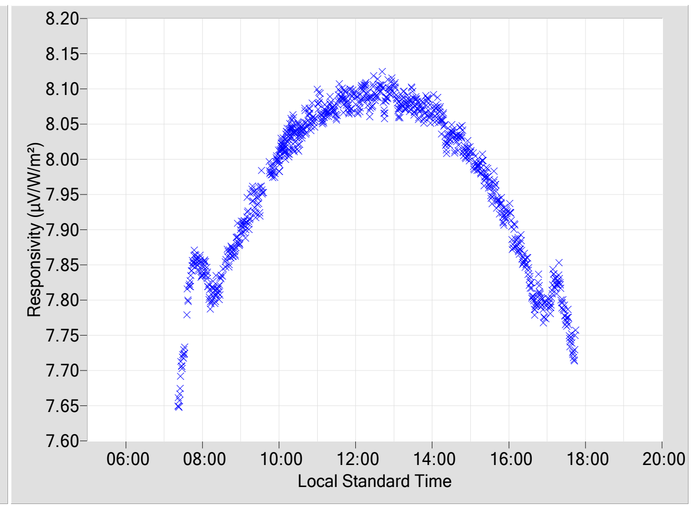


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	7.9902	0.37	113.88	7.9725	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9611	0.37	111.27	7.9472	0.36	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9363	0.40	108.97	7.9426	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9145	0.34	106.95	7.9189	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9027	0.37	104.90	7.9103	0.40	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8678	0.38	103.11	7.8791	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8573	0.36	101.23	7.8557	0.39	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8346	0.38	99.43	7.8235	0.39	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8043	0.39	97.82	7.7994	0.40	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8058	0.45	96.25	7.7814	0.42	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8419	0.42	94.60	7.7916	0.44	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.8568	N/A	93.07	7.8231	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8249	N/A	91.57	7.7918	N/A	268.72
26	8.0914	0.34	173.17	8.0937	0.31	186.81	72	7.7236	N/A	90.05	7.7538	N/A	270.22
28	8.0848	0.31	153.91	8.0784	0.31	205.99	74	7.6554	N/A	88.74	7.7455	N/A	271.62
30	8.0720	0.34	144.87	8.0698	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.0561	0.34	138.31	8.0633	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0581	0.30	132.96	8.0661	0.34	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0559	0.32	128.62	8.0234	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0371	0.34	125.32	8.0240	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0283	0.35	121.70	8.0228	0.34	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0205	0.35	118.55	8.0095	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9918	0.36	116.20	7.9899	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

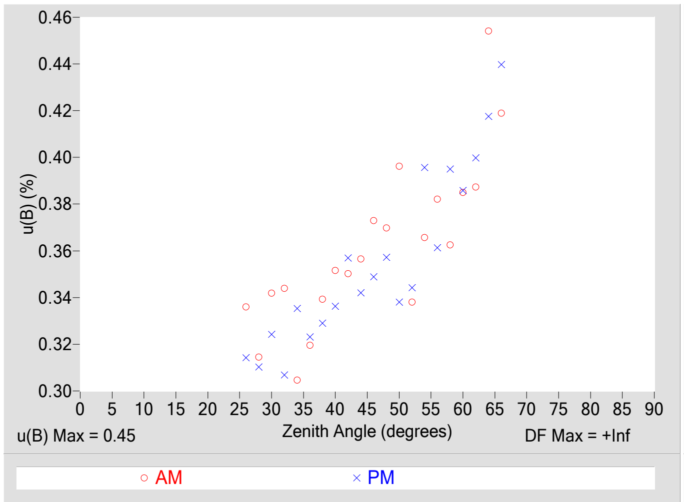


Figure 4. Residuals from Spline Interpolation

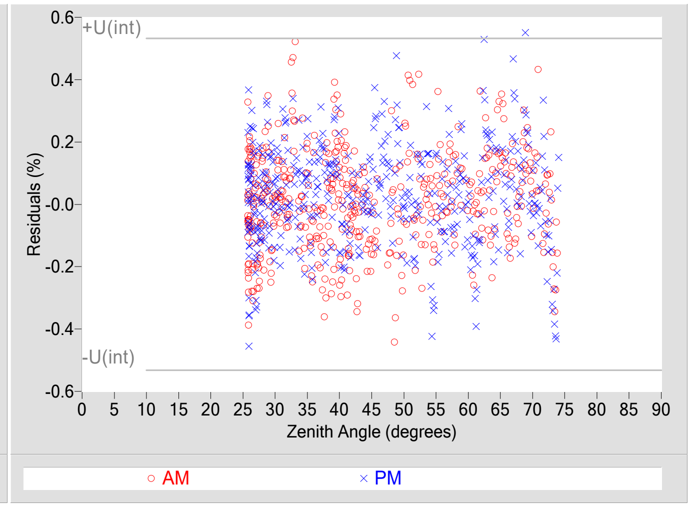


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	12622
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

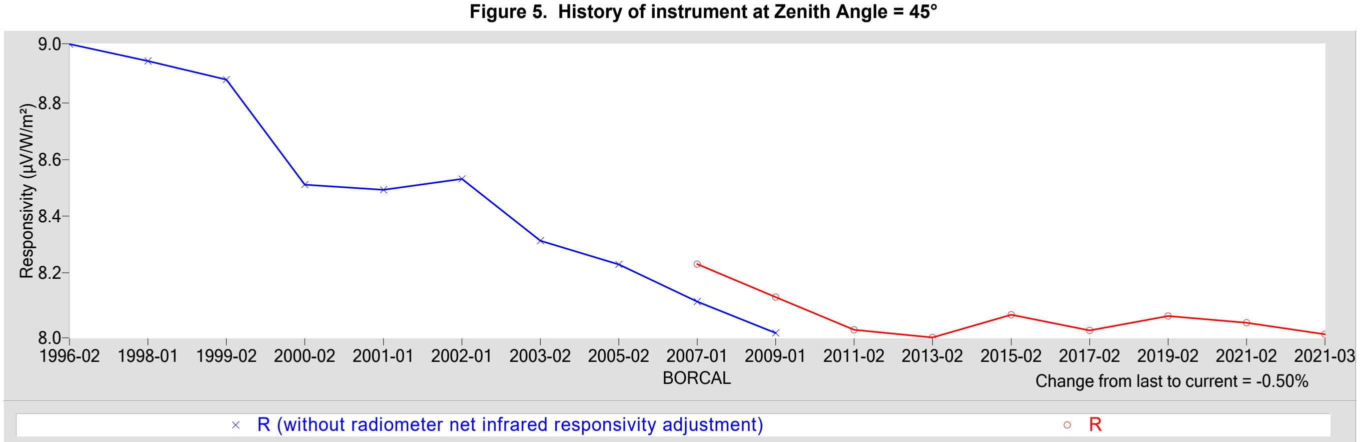
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9826	0.67027

† Rnet determination date: 04/24/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.1 / -2.0
Expanded Uncertainty, U (%)	+1.9 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30653F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

__________________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30653F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

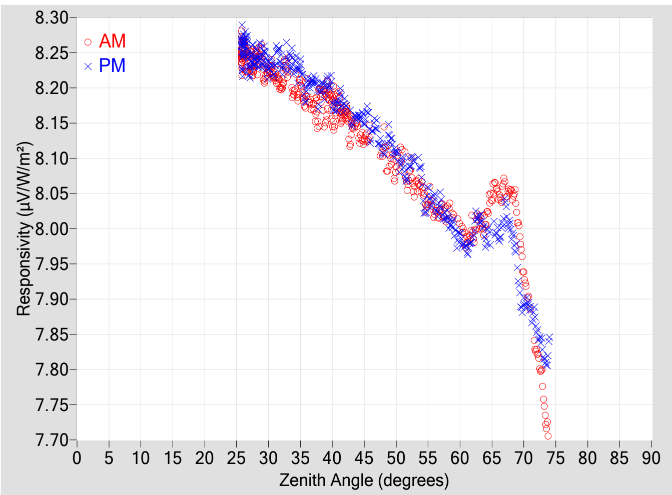


Figure 2. Responsivity vs Local Standard Time

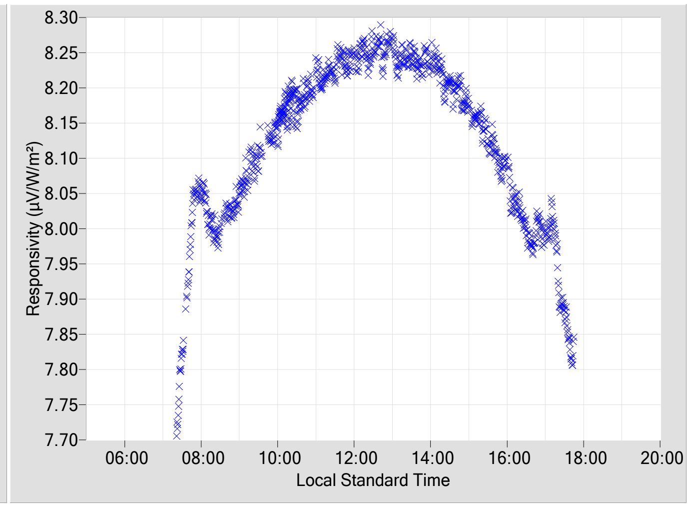


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.1386	0.37	113.88	8.1332	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1171	0.37	111.27	8.1092	0.35	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0897	0.39	108.97	8.1096	0.33	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0700	0.34	106.95	8.0862	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0574	0.36	104.90	8.0696	0.39	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0222	0.38	103.11	8.0374	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0212	0.36	101.23	8.0138	0.39	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0055	0.38	99.43	7.9895	0.38	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9956	0.38	97.85	7.9874	0.39	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0091	0.45	96.25	7.9860	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0490	0.41	94.60	7.9902	0.43	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.0511	N/A	93.07	7.9995	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9376	N/A	91.57	7.8908	N/A	268.72
26	8.2512	0.33	173.17	8.2562	0.31	186.81	72	7.8254	N/A	90.05	7.8575	N/A	270.22
28	8.2385	0.31	153.91	8.2411	0.31	205.99	74	7.7154	N/A	88.74	7.8352	N/A	271.62
30	8.2241	0.34	144.87	8.2291	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.2023	0.34	138.31	8.2330	0.30	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1966	0.30	132.96	8.2349	0.33	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1928	0.32	128.62	8.1981	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1798	0.34	125.32	8.1901	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1724	0.35	121.70	8.1885	0.33	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1658	0.35	118.55	8.1755	0.35	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1393	0.35	116.20	8.1592	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

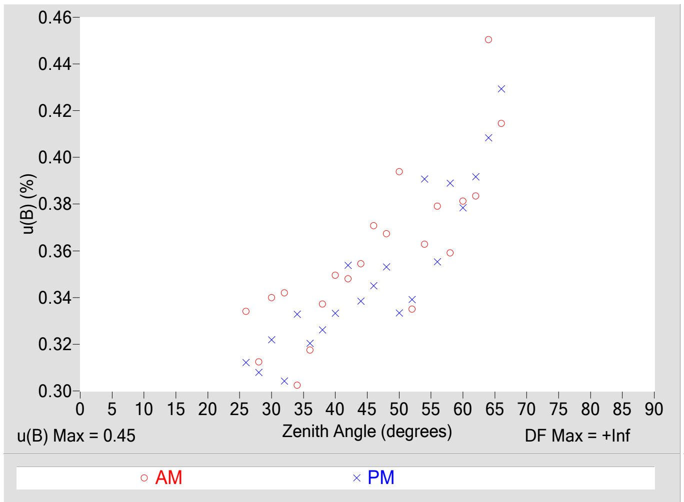


Figure 4. Residuals from Spline Interpolation

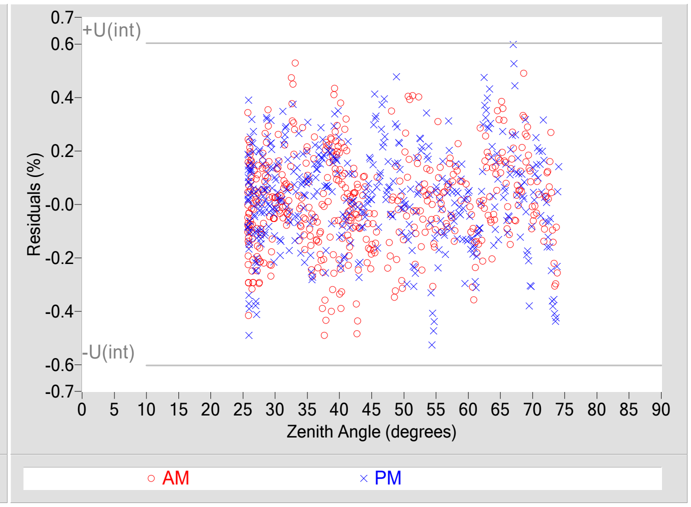


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	8616
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

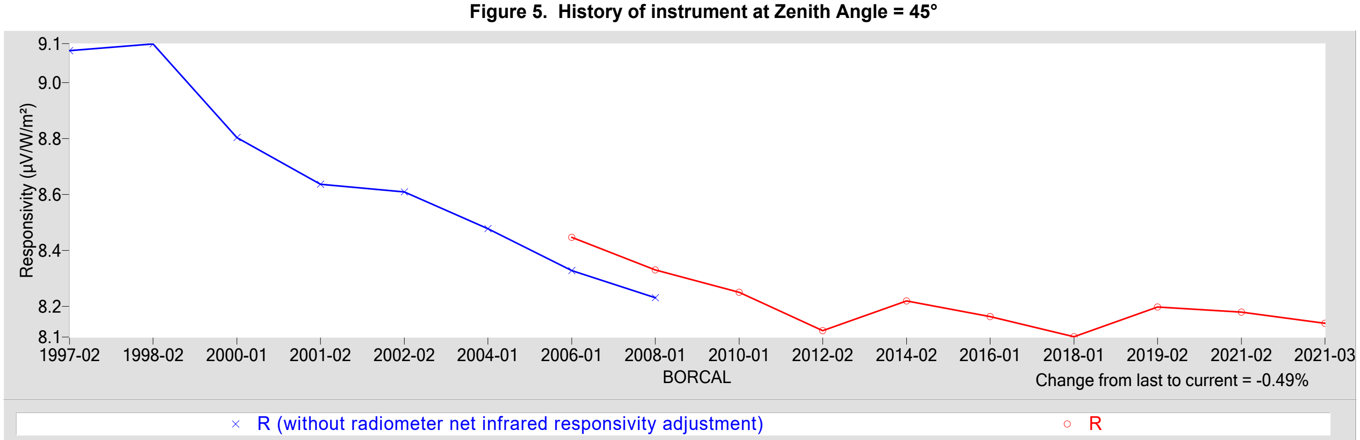
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1393	0.61000

† Rnet determination date: 04/18/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.77
Offset Uncertainty, U(off) (%)	+1.2 / -1.8
Expanded Uncertainty, U (%)	+1.9 / -2.6
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30665F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30665F3 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 - 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

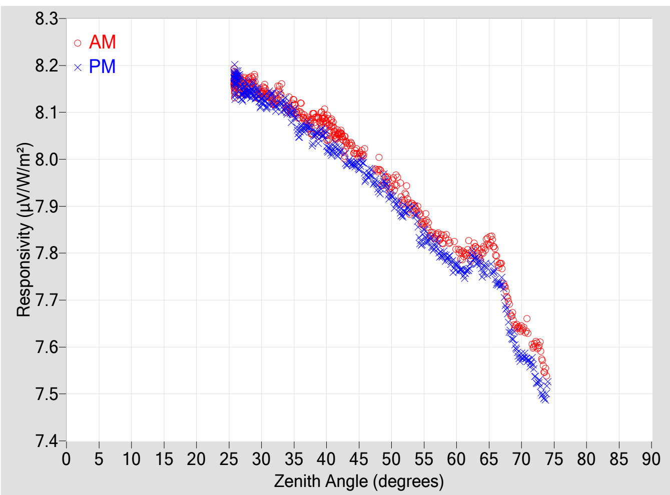


Figure 2. Responsivity vs Local Standard Time

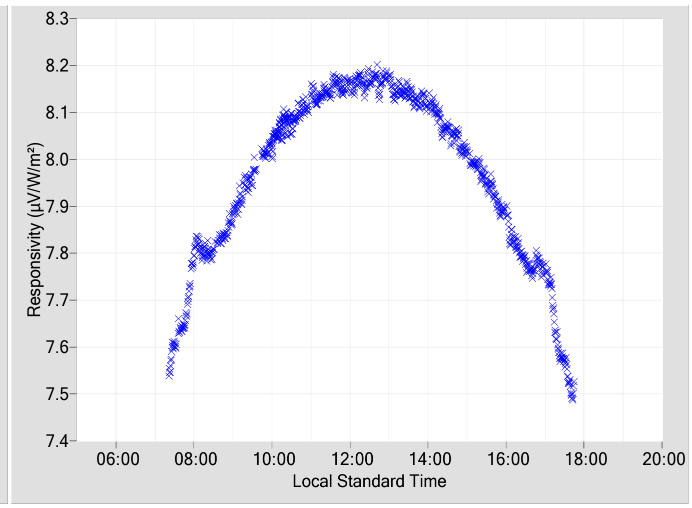


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0157	0.37	113.88	7.9621	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9819	0.37	111.27	7.9349	0.36	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9451	0.40	108.97	7.9226	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9150	0.34	106.95	7.8888	0.35	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8895	0.37	104.90	7.8635	0.40	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8417	0.38	103.11	7.8239	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8278	0.36	101.23	7.7936	0.40	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8084	0.39	99.43	7.7735	0.39	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8013	0.39	97.85	7.7700	0.40	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8015	0.45	96.25	7.7625	0.42	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7988	0.42	94.60	7.7470	0.44	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.6941	N/A	93.07	7.6547	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.6386	N/A	91.57	7.5771	N/A	268.72
26	8.1668	0.33	173.13	8.1683	0.31	186.81	72	7.6037	N/A	90.05	7.5428	N/A	270.22
28	8.1585	0.31	153.91	8.1438	0.31	205.99	74	7.5468	N/A	88.74	7.5145	N/A	271.62
30	8.1429	0.34	144.87	8.1223	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1211	0.34	138.31	8.1164	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1121	0.30	132.96	8.1084	0.34	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1048	0.32	128.62	8.0606	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0811	0.34	125.32	8.0464	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0718	0.35	121.71	8.0358	0.34	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0550	0.35	118.55	8.0169	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0250	0.36	116.20	7.9902	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

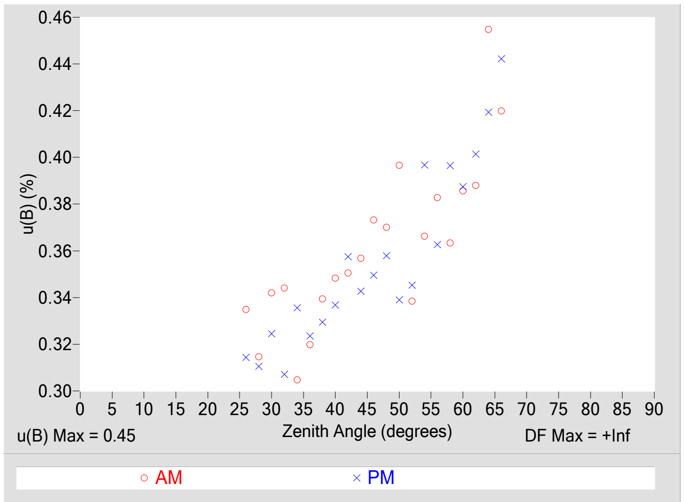


Figure 4. Residuals from Spline Interpolation

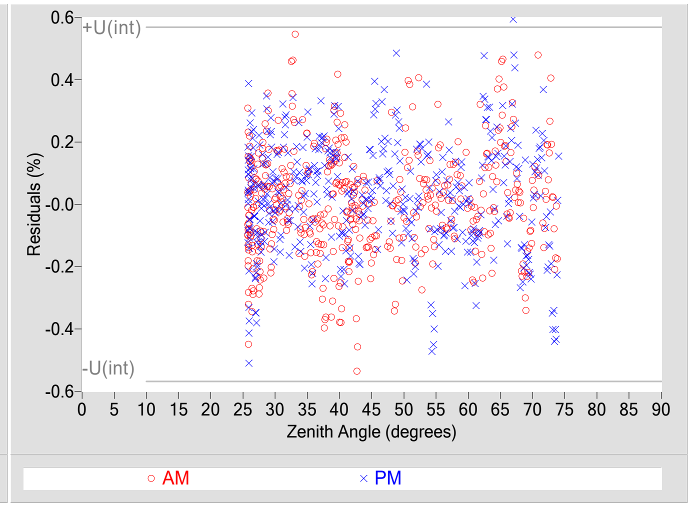


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	10508
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

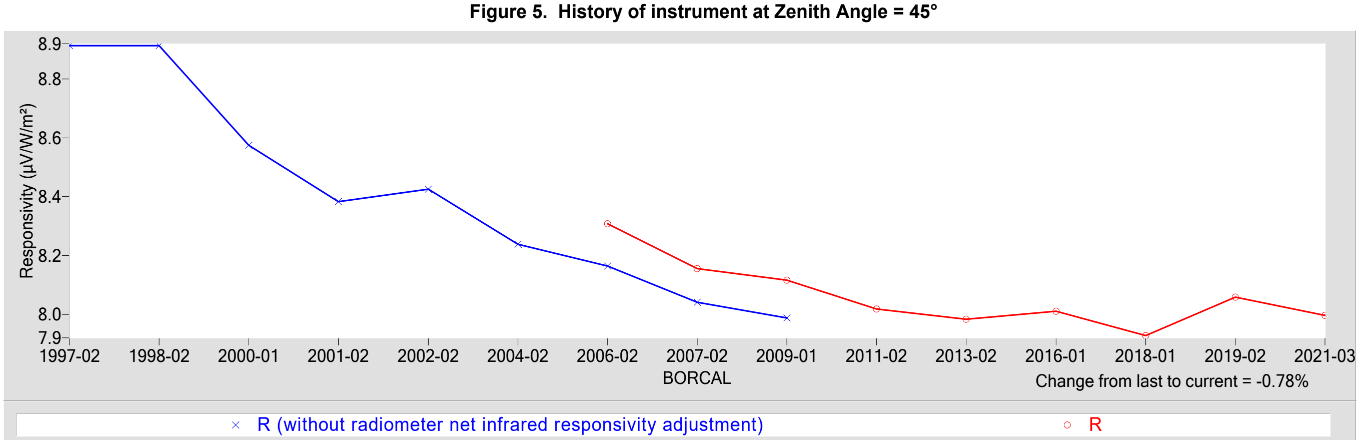
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9960	0.68202

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.8 / -2.8
Expanded Uncertainty, U (%)	+2.6 / -3.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30673F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30673F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

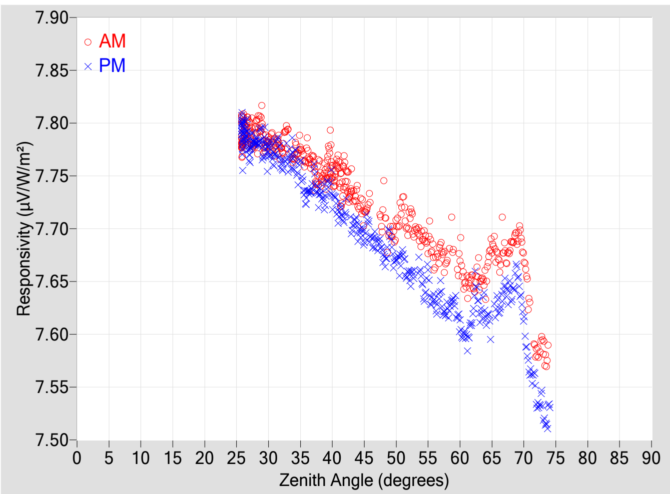


Figure 2. Responsivity vs Local Standard Time

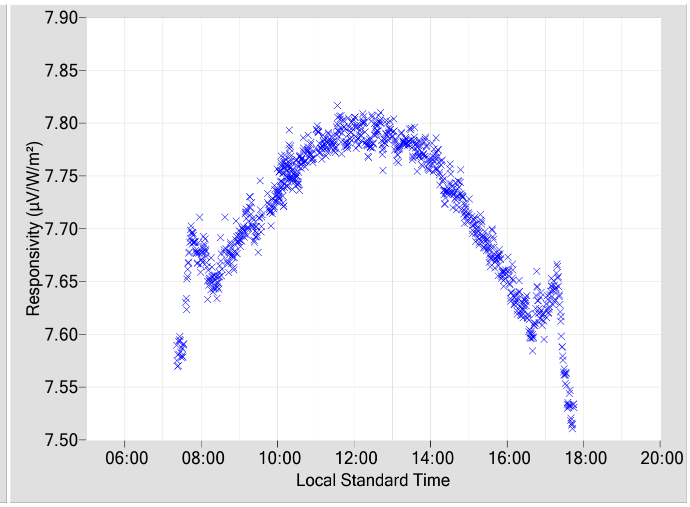


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7291	0.33	113.79	7.6921	0.35	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7145	0.41	111.29	7.6722	0.33	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6993	0.40	109.03	7.6713	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7076	0.34	106.87	7.6551	0.35	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6906	0.37	104.95	7.6490	0.35	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6710	0.45	103.09	7.6309	0.36	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6682	0.40	101.35	7.6222	0.40	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6716	0.42	99.52	7.6074	0.41	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6501	0.39	97.89	7.6200	0.40	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.6509	0.44	96.19	7.6204	0.42	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.6712	0.42	94.64	7.6268	0.44	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.6836	N/A	93.10	7.6408	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.6704	N/A	91.51	7.6073	N/A	268.76
26	7.7888	0.34	173.51	7.7913	0.32	186.40	72	7.5833	N/A	90.04	7.5363	N/A	270.25
28	7.7893	0.32	154.05	7.7816	0.34	205.96	74	7.5897	N/A	88.72	7.5326	N/A	271.65
30	7.7818	0.30	144.99	7.7722	0.32	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.7739	0.33	138.28	7.7609	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7685	0.34	133.04	7.7697	0.34	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7708	0.32	128.51	7.7304	0.33	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7535	0.35	125.51	7.7320	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7538	0.31	121.67	7.7354	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7506	0.32	118.64	7.7157	0.32	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7295	0.34	116.24	7.6995	0.36	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

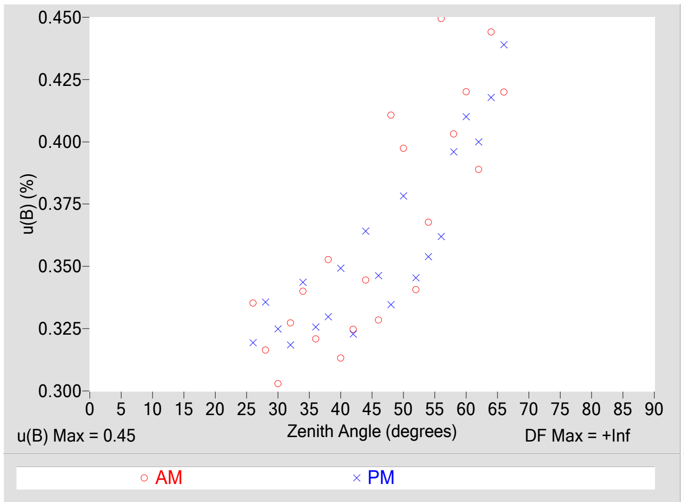


Figure 4. Residuals from Spline Interpolation

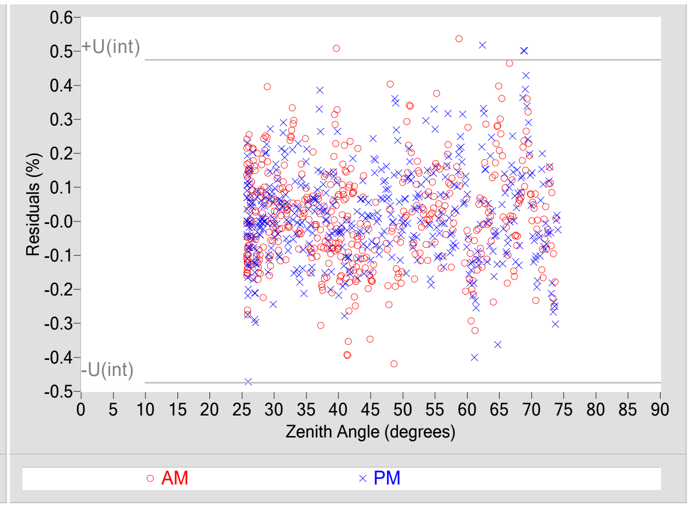


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	17359
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

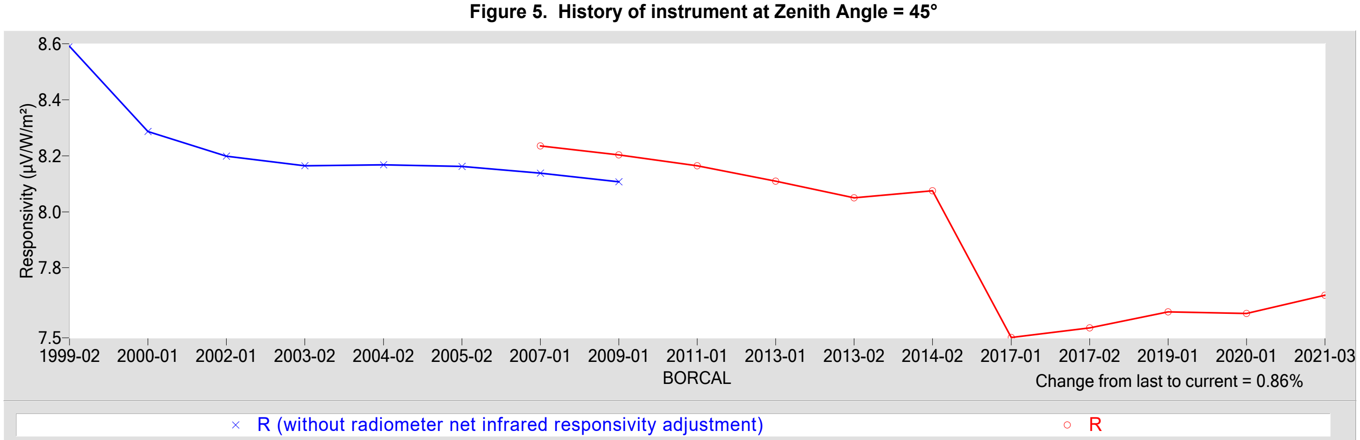
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.7023	0.57412

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+1.0 / -1.2
Expanded Uncertainty, U (%)	+1.9 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30709F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30709F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

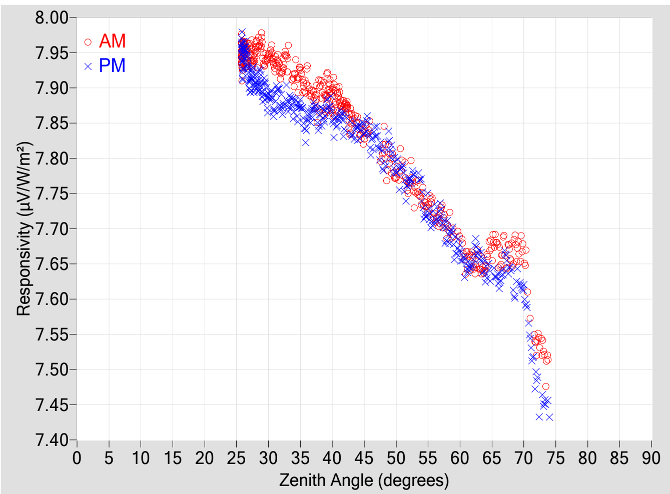


Figure 2. Responsivity vs Local Standard Time

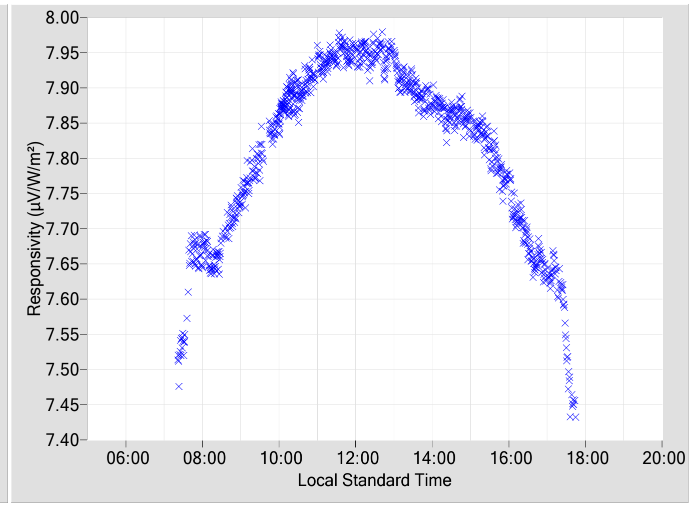


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.8467	0.37	113.88	7.8215	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8156	0.37	111.27	7.7933	0.35	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7762	0.41	109.04	7.7907	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7600	0.34	106.95	7.7673	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7444	0.36	104.90	7.7520	0.39	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7155	0.38	103.11	7.7208	0.36	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6971	0.36	101.23	7.6935	0.39	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6876	0.38	99.43	7.6704	0.38	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6554	0.39	97.85	7.6526	0.39	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.6471	0.45	96.25	7.6369	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.6646	0.42	94.60	7.6257	0.43	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.6619	N/A	93.07	7.6437	N/A	267.08
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.6611	N/A	91.57	7.6074	N/A	268.72
26	7.9501	0.33	173.13	7.9478	0.31	186.81	72	7.5380	N/A	90.05	7.4856	N/A	270.17
28	7.9511	0.31	153.91	7.9066	0.31	205.99	74	7.5170	N/A	88.74	7.4443	N/A	271.62
30	7.9451	0.34	144.87	7.8838	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.9237	0.34	138.31	7.8740	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9180	0.30	132.96	7.8748	0.33	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9119	0.32	128.62	7.8485	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8927	0.34	125.32	7.8551	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8854	0.35	121.70	7.8570	0.33	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8757	0.35	118.55	7.8469	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8468	0.36	116.20	7.8387	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

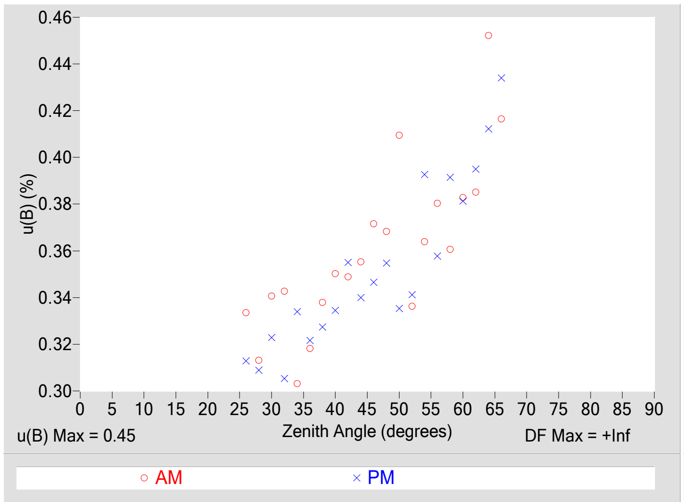


Figure 4. Residuals from Spline Interpolation

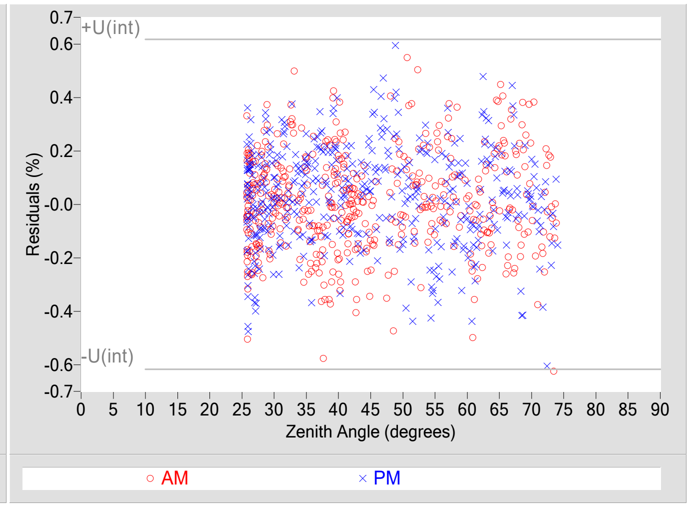


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.55
Effective degrees of freedom, DF(c)	8133
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

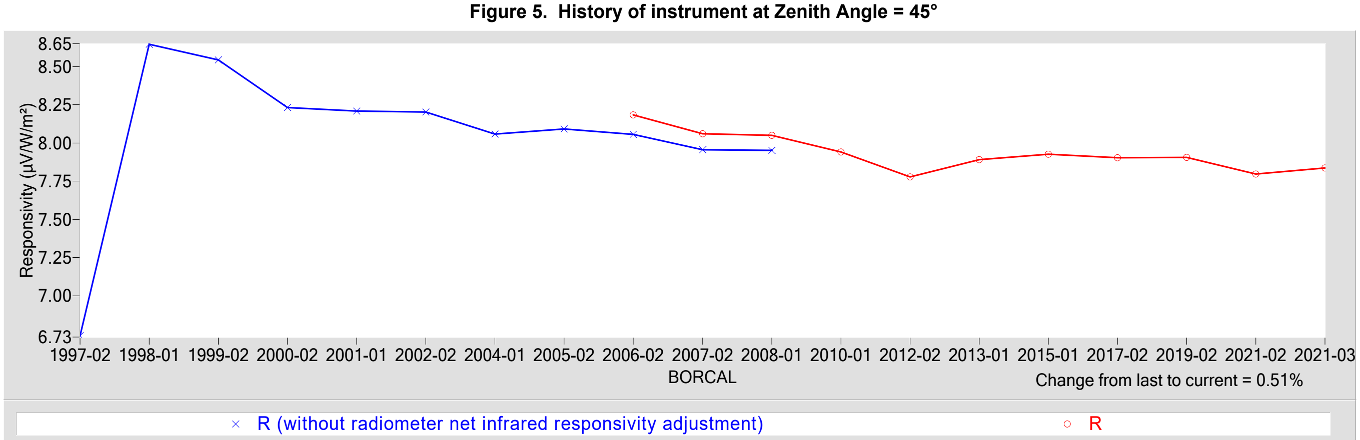
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8371	0.61495

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+1.4 / -2.1
Expanded Uncertainty, U (%)	+2.2 / -2.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer
Manufacturer: Eppley
Model: NIP
Serial Number: 30717E6
Calibration Date: 8/25/2021
Due Date: 8/25/2022
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 8/24-25

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30717E6 Eppley NIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

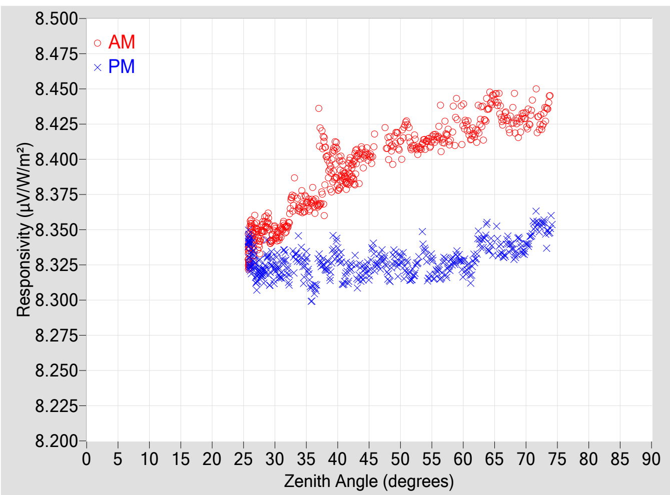


Figure 2. Responsivity vs Local Standard Time

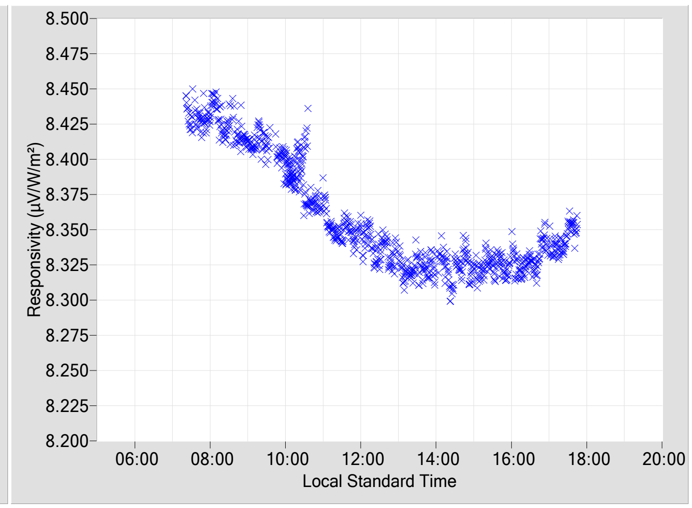


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.4134	0.33	113.85	8.3257	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4085	0.32	111.24	8.3183	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4080	0.33	109.01	8.3289	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4102	0.29	106.92	8.3175	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4118	0.31	104.94	8.3332	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4168	0.33	103.03	8.3205	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4121	0.30	101.40	8.3258	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4266	0.34	99.56	8.3245	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4173	0.32	97.82	8.3324	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4396	0.36	96.23	8.3403	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4302	0.30	94.58	8.3354	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.4307	N/A	93.04	8.3343	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4271	N/A	91.55	8.3374	N/A	268.70
26	8.3381	0.30	173.43	8.3341	0.31	187.00	72	8.4250	N/A	90.03	8.3530	N/A	270.20
28	8.3499	0.31	153.85	8.3181	0.30	206.02	74	8.4450	N/A	88.71	8.3531	N/A	271.65
30	8.3481	0.30	144.62	8.3223	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3525	0.30	138.25	8.3189	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3683	0.30	132.92	8.3344	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3709	0.29	128.49	8.3033	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3955	0.32	125.32	8.3224	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3911	0.30	121.60	8.3354	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3914	0.31	118.63	8.3219	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4029	0.32	116.23	8.3188	0.29	244.38	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

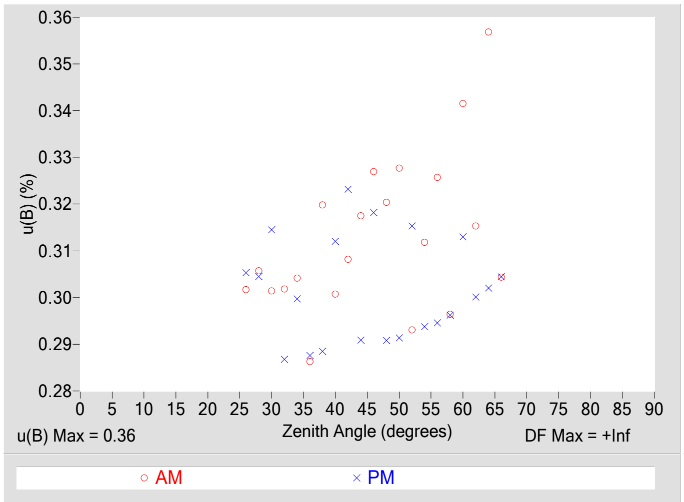


Figure 4. Residuals from Spline Interpolation

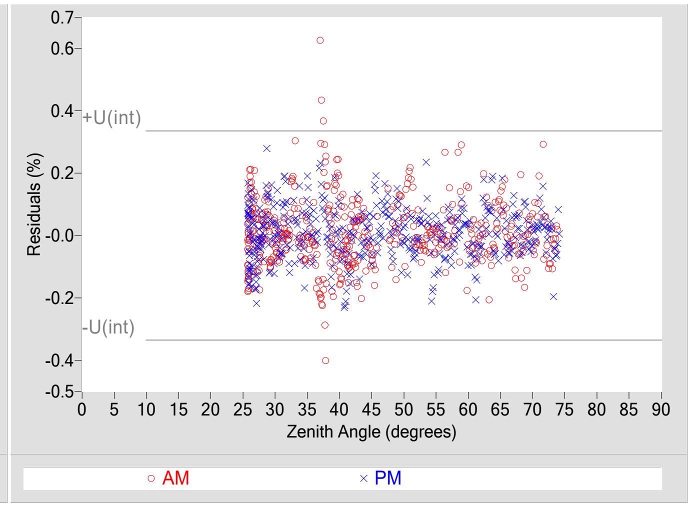


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	25865
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.77
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

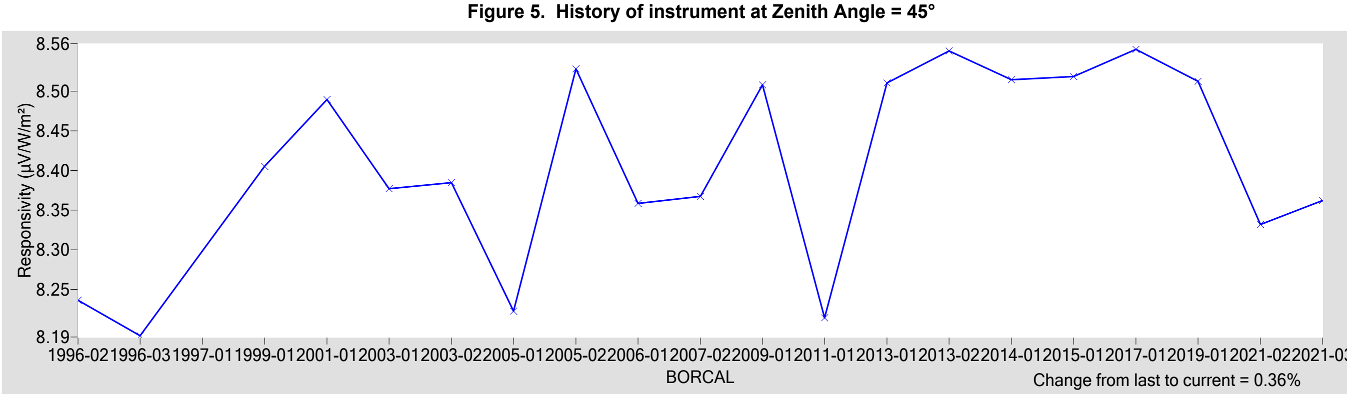
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3620	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.77 / -0.70
Expanded Uncertainty, U (%)	+1.4 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	30718E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager — Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30718E6 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

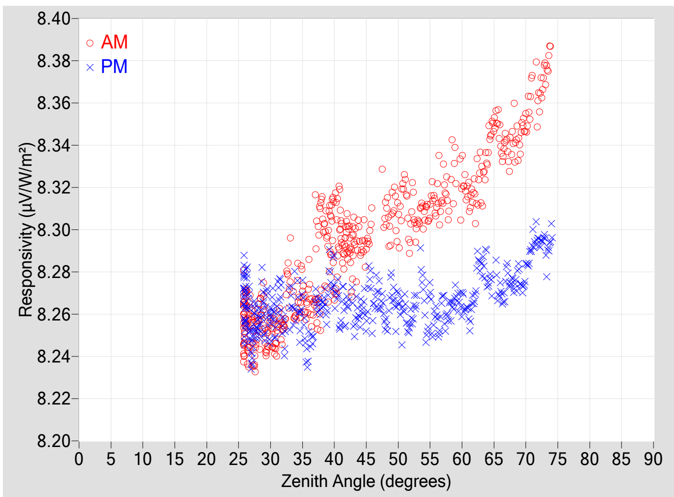


Figure 2. Responsivity vs Local Standard Time

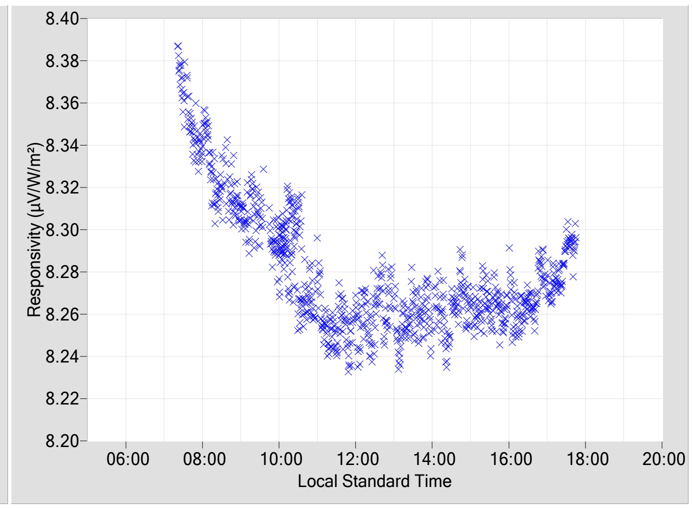


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3065	0.33	113.85	8.2620	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3063	0.32	111.24	8.2563	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3014	0.33	109.01	8.2656	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3033	0.29	106.92	8.2571	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3062	0.31	104.94	8.2702	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3118	0.33	103.03	8.2579	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3091	0.30	101.40	8.2609	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3227	0.34	99.56	8.2665	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3148	0.32	97.82	8.2707	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3369	0.36	96.23	8.2776	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3402	0.30	94.58	8.2707	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.3429	N/A	93.04	8.2741	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3486	N/A	91.55	8.2801	N/A	268.70
26	8.2577	0.30	173.43	8.2667	0.31	187.00	72	8.3590	N/A	90.03	8.2941	N/A	270.20
28	8.2559	0.31	153.85	8.2543	0.30	206.02	74	8.3869	N/A	88.71	8.2968	N/A	271.65
30	8.2538	0.30	144.62	8.2579	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.2535	0.30	138.25	8.2524	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.2652	0.30	132.92	8.2687	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2692	0.29	128.49	8.2422	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2934	0.32	125.32	8.2635	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2917	0.30	121.60	8.2753	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2970	0.31	118.63	8.2638	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2955	0.32	116.23	8.2607	0.29	244.38	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

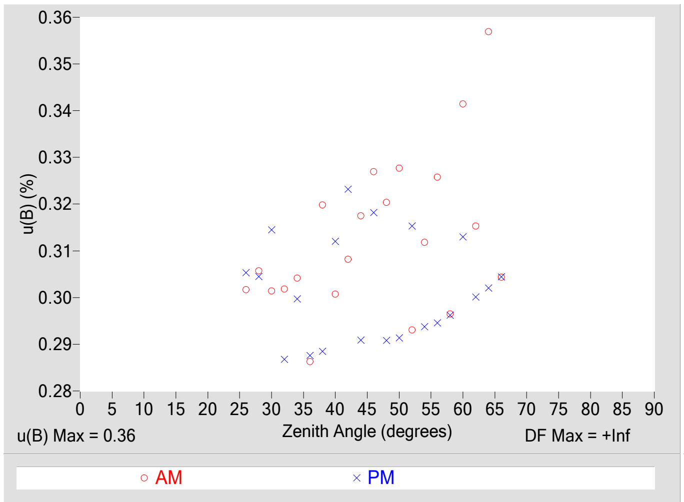


Figure 4. Residuals from Spline Interpolation

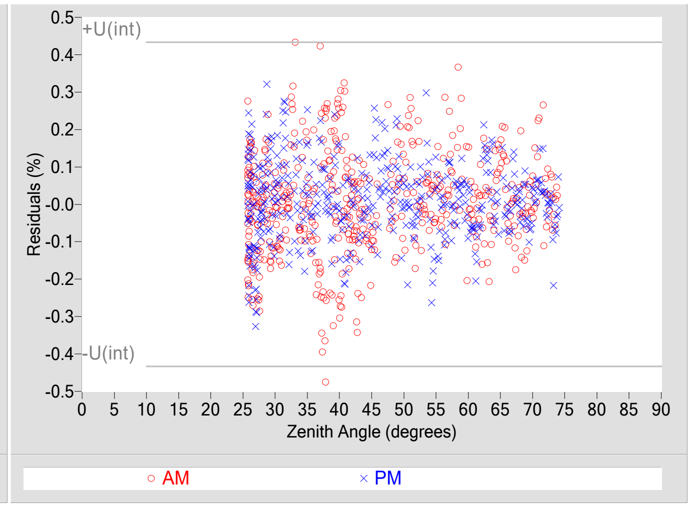


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.42
Effective degrees of freedom, DF(c)	11667
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.82
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

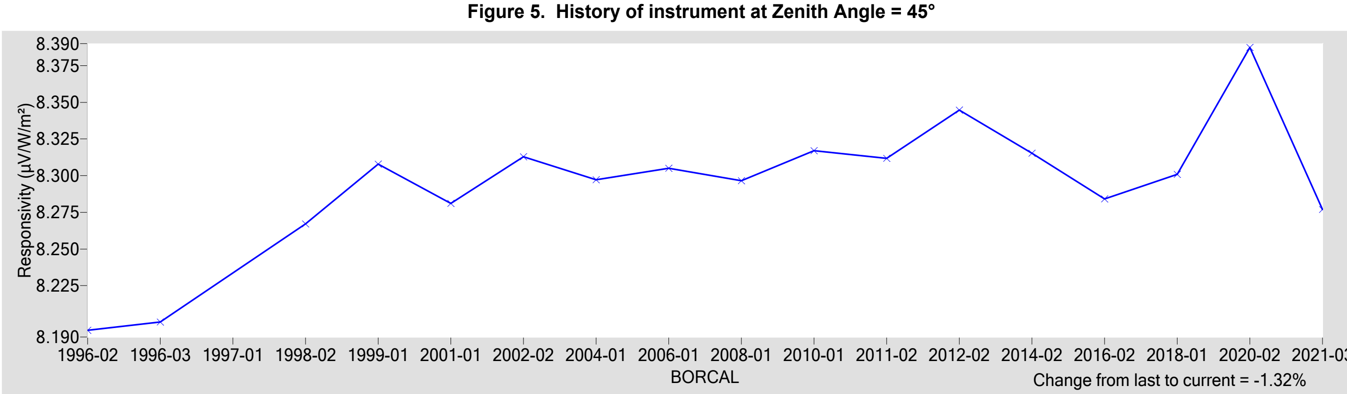
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.2769	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.55 / -0.42
Expanded Uncertainty, U (%)	+1.2 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	30722E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____________________________________ __________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30722E6 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),
  = $Win - Wout$ = $Win - \sigma * Tc^4$
  - 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

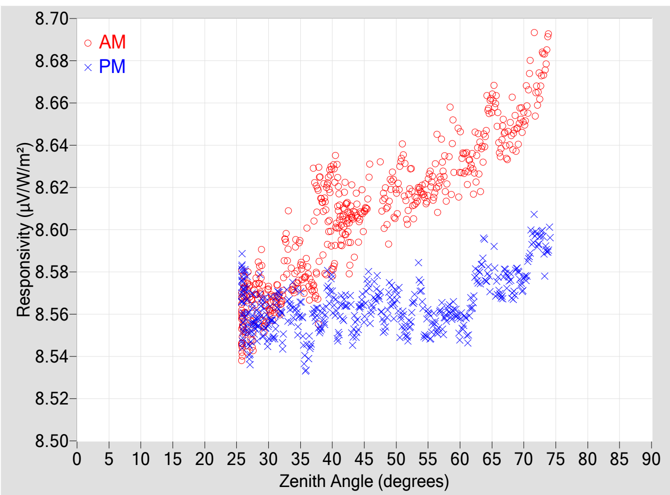


Figure 2. Responsivity vs Local Standard Time

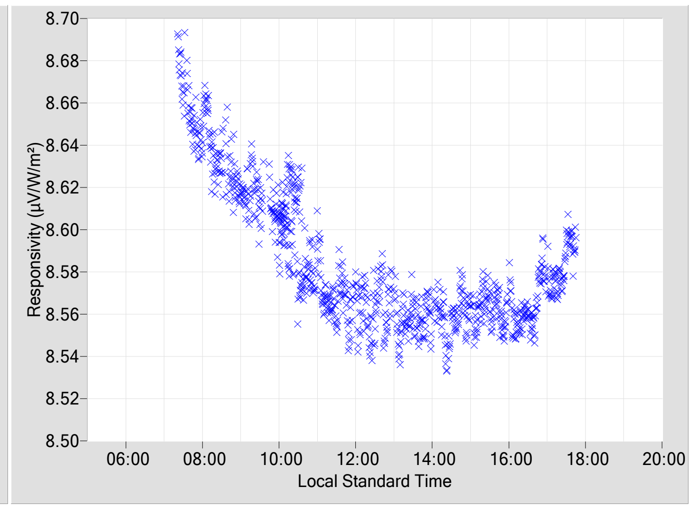


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6279	0.33	113.85	8.5628	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6110	0.32	111.24	8.5557	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6123	0.33	109.01	8.5676	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6153	0.29	106.92	8.5529	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6183	0.31	104.94	8.5691	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6195	0.33	103.03	8.5557	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6177	0.30	101.40	8.5606	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6328	0.34	99.56	8.5551	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6278	0.32	97.82	8.5674	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6478	0.36	96.23	8.5804	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6433	0.30	94.58	8.5727	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.6472	N/A	93.04	8.5733	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6508	N/A	91.55	8.5750	N/A	268.70
26	8.5598	0.30	173.43	8.5668	0.31	187.00	72	8.6622	N/A	90.03	8.5958	N/A	270.20
28	8.5699	0.31	153.85	8.5547	0.30	206.02	74	8.6920	N/A	88.71	8.5943	N/A	271.65
30	8.5669	0.30	144.62	8.5543	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.5664	0.30	138.25	8.5564	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5789	0.30	132.92	8.5662	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5824	0.29	128.49	8.5378	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6039	0.32	125.32	8.5528	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6033	0.30	121.60	8.5698	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6081	0.31	118.63	8.5641	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6066	0.32	116.23	8.5576	0.29	244.38	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

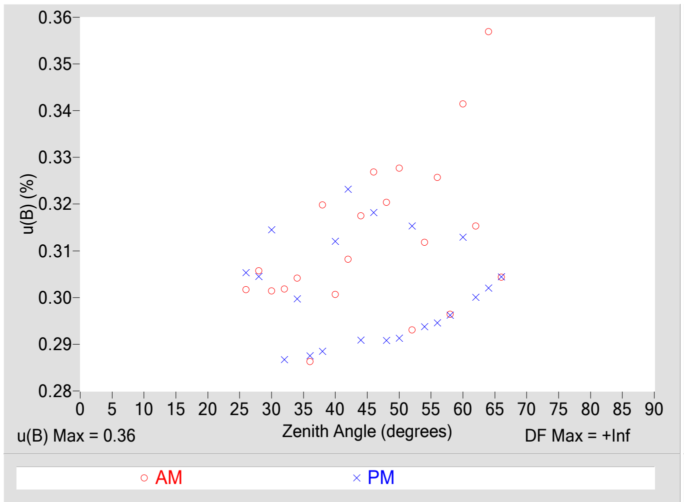


Figure 4. Residuals from Spline Interpolation

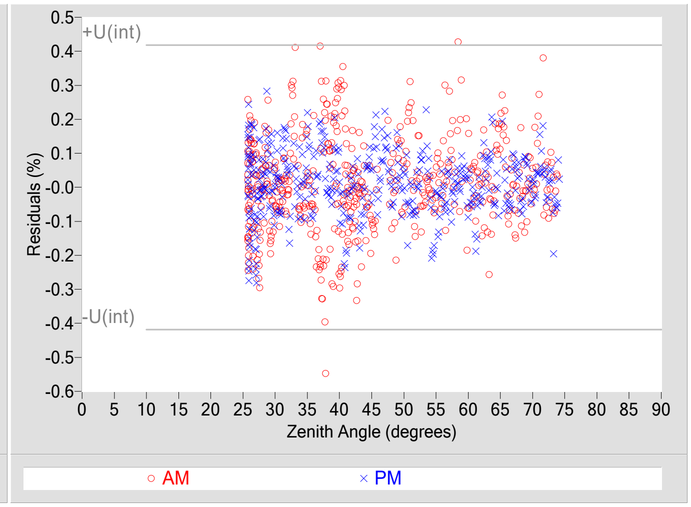


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	12924
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.81
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

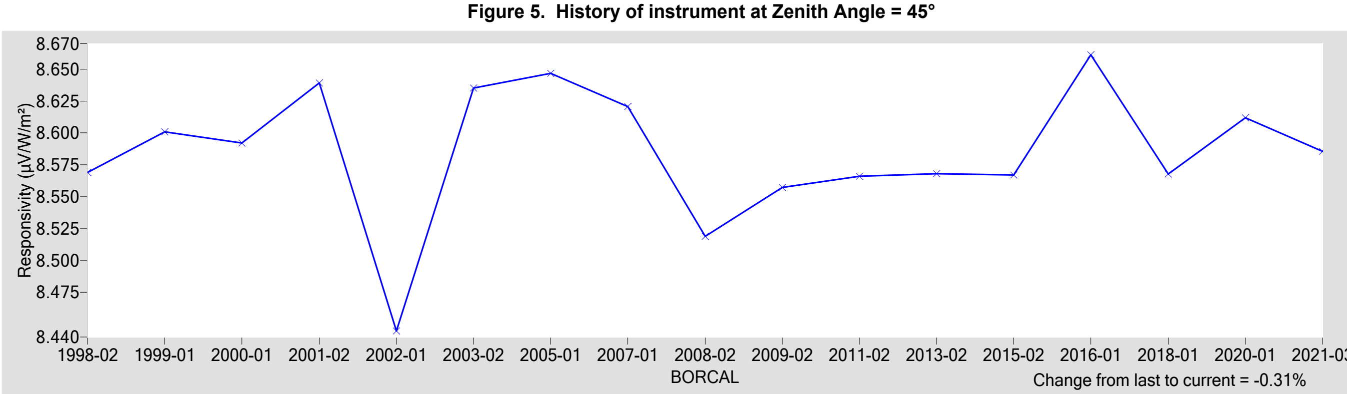
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5855	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.55 / -0.56
Expanded Uncertainty, U (%)	+1.2 / -1.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30776F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30776F3 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

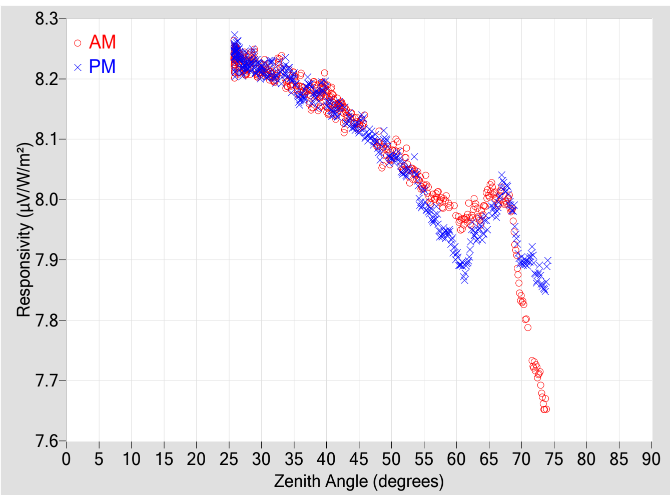


Figure 2. Responsivity vs Local Standard Time

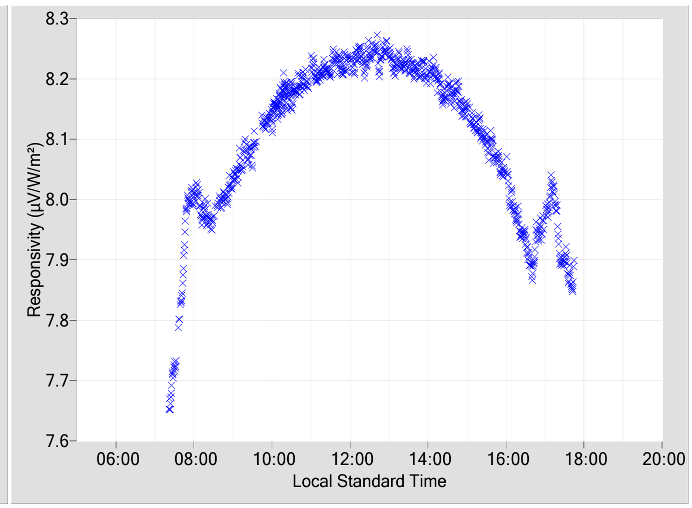


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1333	0.37	113.88	8.1076	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0956	0.37	111.27	8.0811	0.36	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0724	0.40	108.97	8.0714	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0585	0.34	106.95	8.0473	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0373	0.36	104.90	8.0275	0.39	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9984	0.38	103.11	7.9749	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9931	0.36	101.23	7.9430	0.39	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9725	0.38	99.43	7.9095	0.38	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9713	0.39	97.85	7.9092	0.40	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9755	0.45	96.25	7.9489	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0044	0.42	94.60	7.9820	0.43	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.9978	N/A	93.07	8.0085	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8357	N/A	91.57	7.8959	N/A	268.72
26	8.2371	0.33	173.13	8.2411	0.31	186.81	72	7.7236	N/A	90.05	7.8836	N/A	270.22
28	8.2263	0.31	153.91	8.2224	0.31	205.99	74	7.6614	N/A	88.74	7.8837	N/A	271.62
30	8.2146	0.34	144.87	8.2128	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1997	0.34	138.31	8.2043	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1947	0.30	132.96	8.2140	0.33	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1920	0.32	128.62	8.1669	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1783	0.34	125.32	8.1718	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1720	0.35	121.71	8.1713	0.33	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1573	0.35	118.55	8.1520	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1352	0.36	116.20	8.1231	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

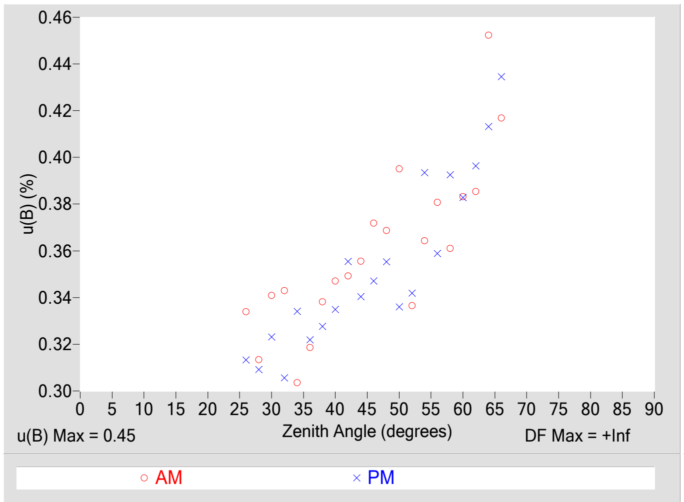


Figure 4. Residuals from Spline Interpolation

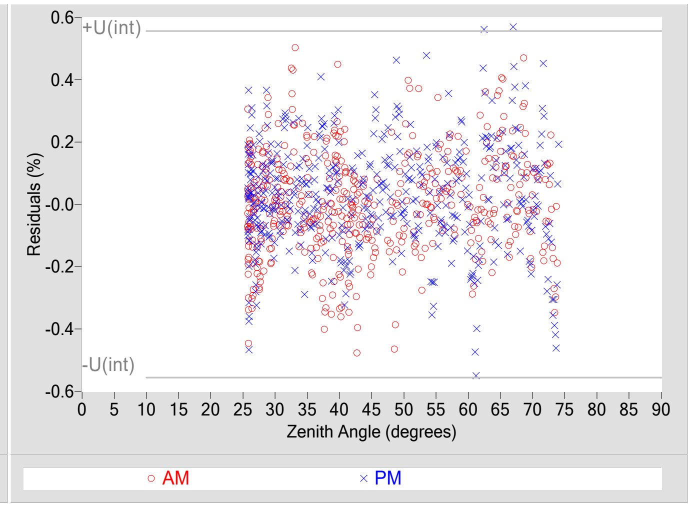


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	10989
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

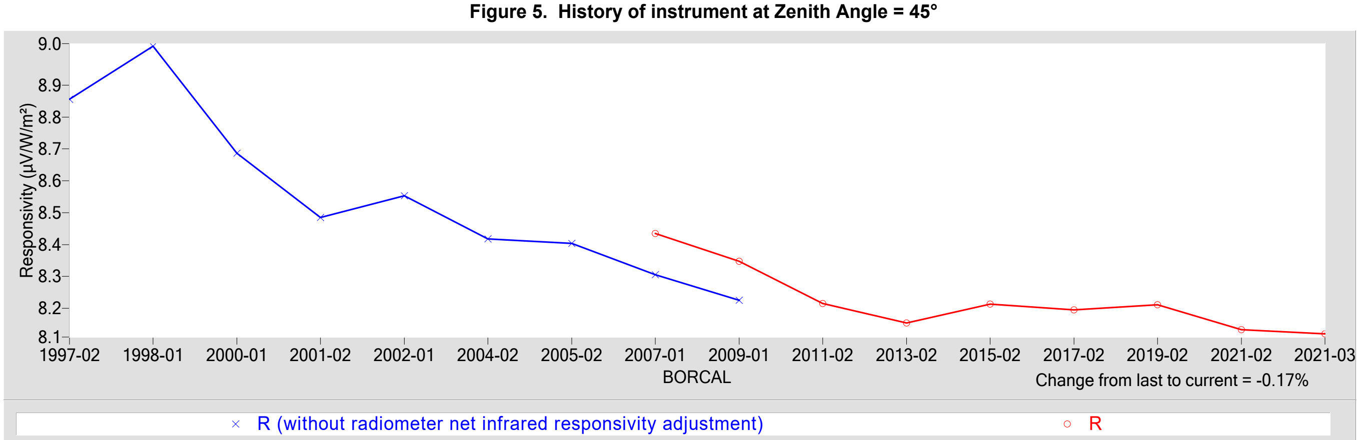
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1196	0.64865

† Rnet determination date: 04/24/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.77
Offset Uncertainty, U(off) (%)	+1.2 / -2.6
Expanded Uncertainty, U (%)	+1.9 / -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 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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30820F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30820F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

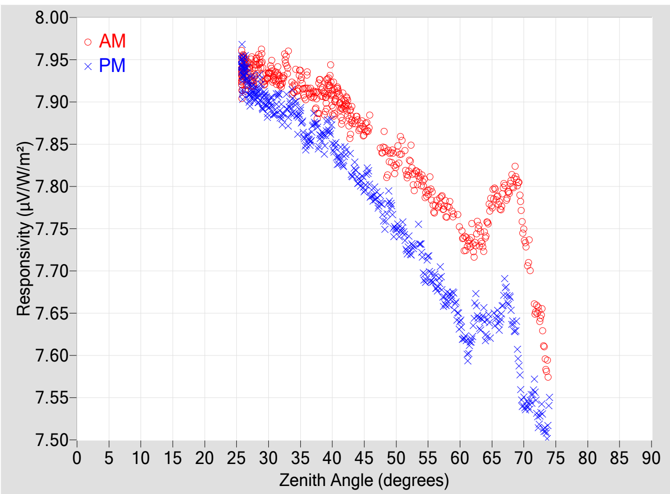


Figure 2. Responsivity vs Local Standard Time

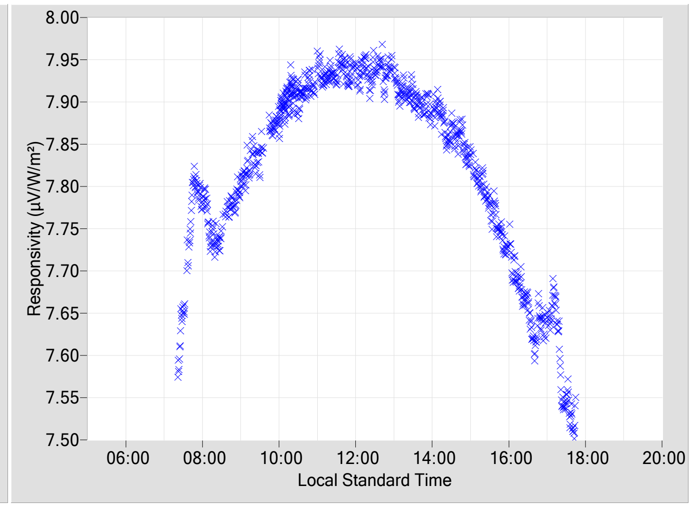


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8768	0.37	113.88	7.7925	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8475	0.37	111.27	7.7635	0.36	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8303	0.40	108.97	7.7513	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8206	0.34	106.95	7.7266	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8062	0.36	104.90	7.7199	0.39	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7735	0.38	103.11	7.6869	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7699	0.36	101.23	7.6660	0.39	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7499	0.38	99.43	7.6391	0.38	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7334	0.39	97.85	7.6274	0.40	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7415	0.45	96.25	7.6322	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7820	0.42	94.60	7.6415	0.44	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.8031	N/A	93.07	7.6542	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7444	N/A	91.57	7.5409	N/A	268.72
26	7.9383	0.33	173.13	7.9372	0.31	186.81	72	7.6533	N/A	90.05	7.5354	N/A	270.22
28	7.9389	0.31	153.91	7.9083	0.31	205.99	74	7.5844	N/A	88.74	7.5360	N/A	271.62
30	7.9330	0.34	144.87	7.8946	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.9235	0.34	138.31	7.8847	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9186	0.30	132.96	7.8960	0.33	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9198	0.32	128.62	7.8530	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9104	0.34	125.32	7.8567	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9054	0.35	121.70	7.8573	0.34	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8981	0.35	118.55	7.8375	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8758	0.36	116.20	7.8087	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

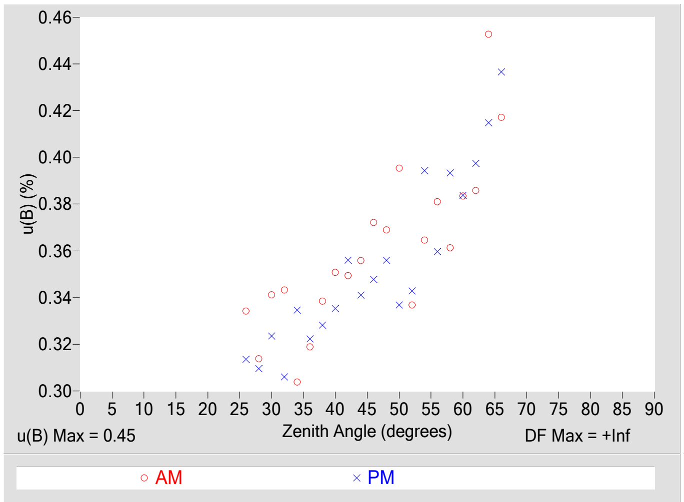


Figure 4. Residuals from Spline Interpolation

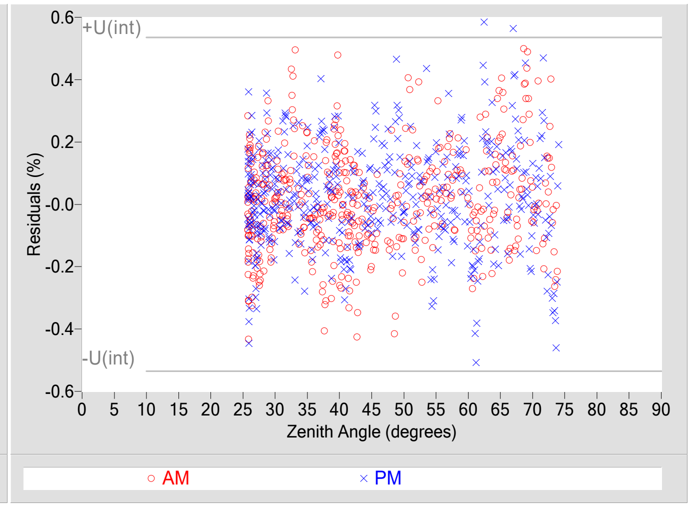


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	12347
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

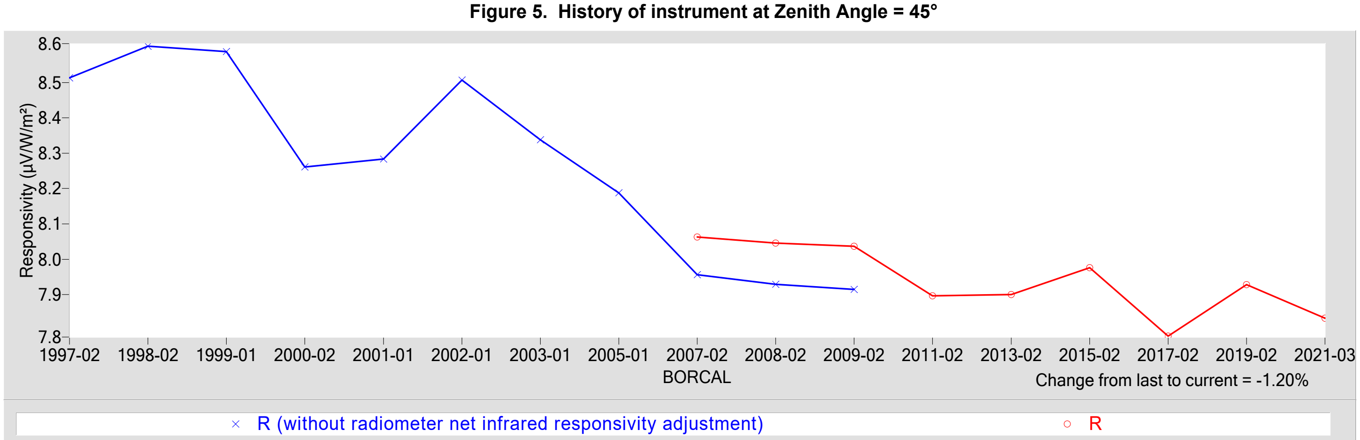
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8334	0.63499

† Rnet determination date: 05/09/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.77
Offset Uncertainty, U(off) (%)	+1.3 / -2.5
Expanded Uncertainty, U (%)	+2.0 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30891F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30891F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

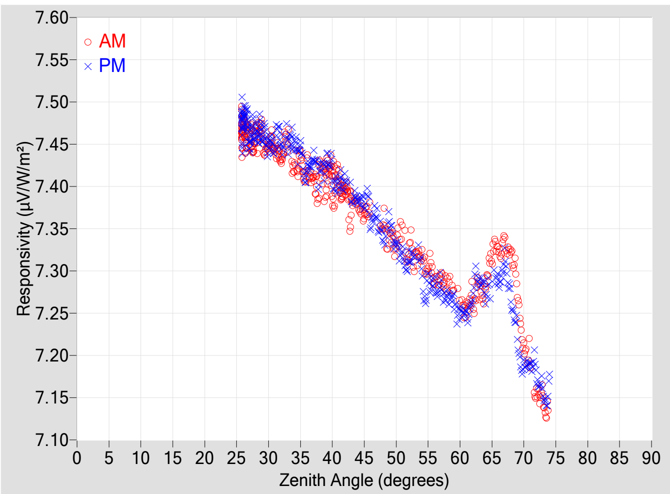


Figure 2. Responsivity vs Local Standard Time

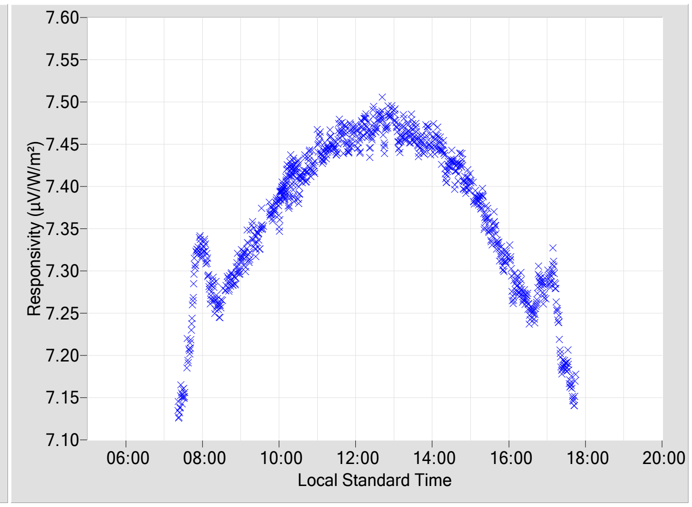


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	7.3752	0.37	113.88	7.3582	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3564	0.37	111.27	7.3372	0.35	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3338	0.39	108.97	7.3335	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3219	0.34	106.95	7.3112	0.34	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3161	0.36	104.90	7.3006	0.39	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2884	0.38	103.11	7.2828	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2831	0.36	101.23	7.2693	0.39	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2655	0.38	99.43	7.2525	0.38	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2657	0.38	97.85	7.2687	0.39	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2802	0.45	96.25	7.2726	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3246	0.42	94.60	7.2885	0.43	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.3193	N/A	93.07	7.2671	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.2099	N/A	91.57	7.1856	N/A	268.72
26	7.4698	0.33	173.13	7.4770	0.31	186.80	72	7.1544	N/A	90.05	7.1745	N/A	270.22
28	7.4594	0.31	153.91	7.4632	0.31	205.99	74	7.1401	N/A	88.74	7.1662	N/A	271.62
30	7.4490	0.34	144.87	7.4474	0.32	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.4334	0.34	138.31	7.4493	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.4246	0.30	132.96	7.4519	0.33	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.4219	0.32	128.62	7.4172	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.4126	0.34	125.32	7.4142	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4070	0.35	121.71	7.4143	0.33	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3970	0.35	118.55	7.4056	0.35	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3787	0.36	116.20	7.3840	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

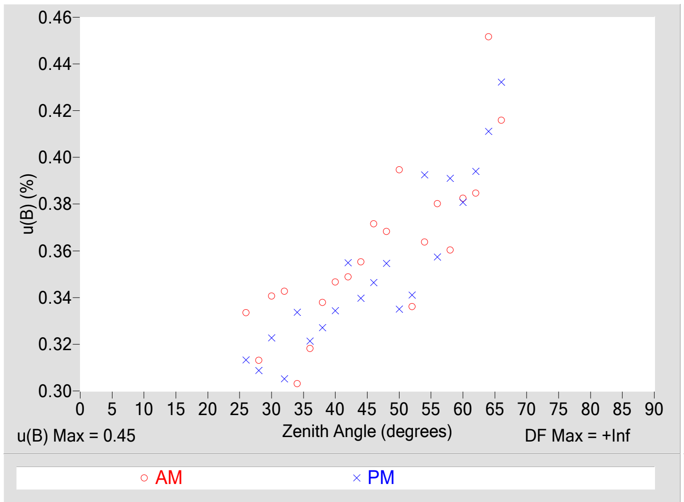


Figure 4. Residuals from Spline Interpolation

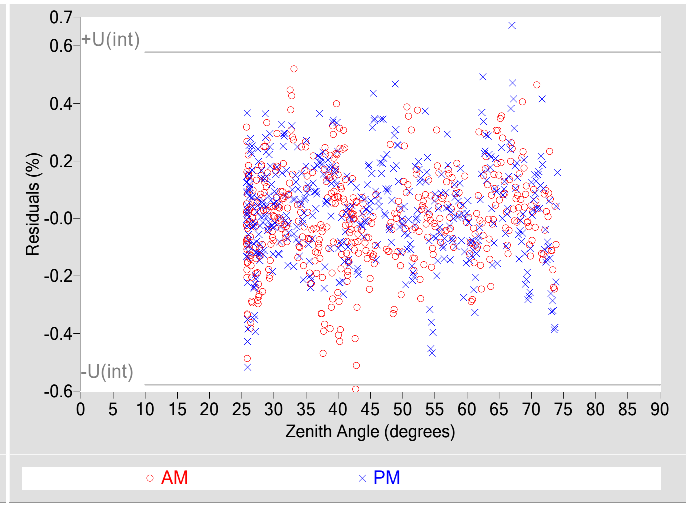


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	9806
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

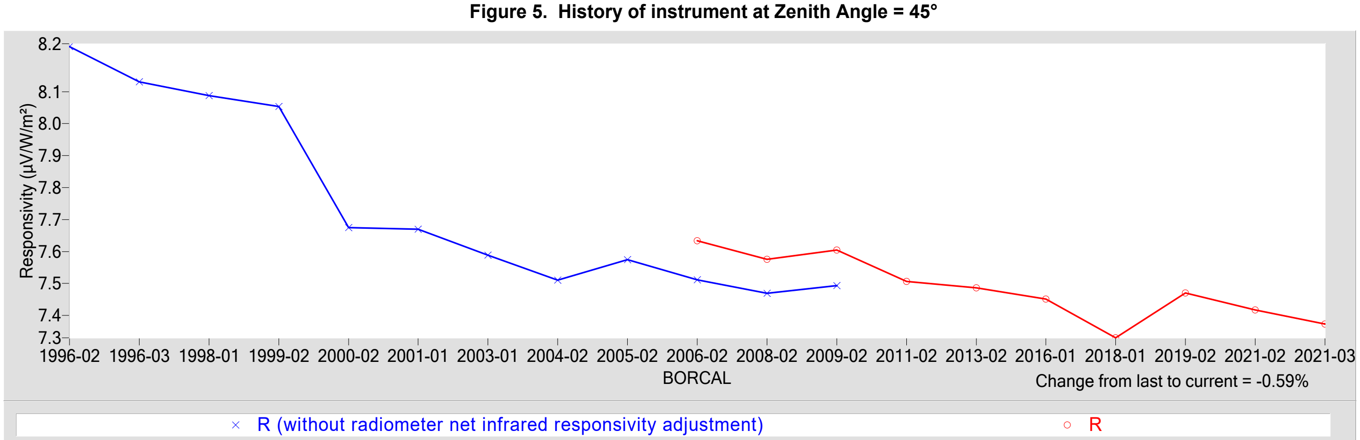
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.3728	0.57550

† Rnet determination date: 06/08/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.77
Offset Uncertainty, U(off) (%)	+1.1 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30900F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ____________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30900F3 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

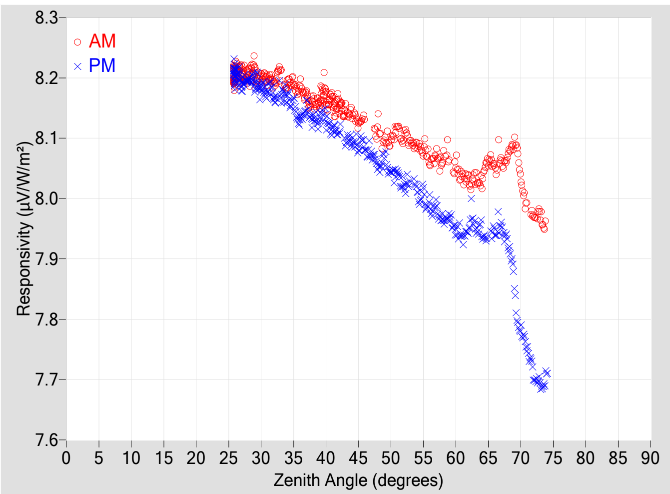


Figure 2. Responsivity vs Local Standard Time

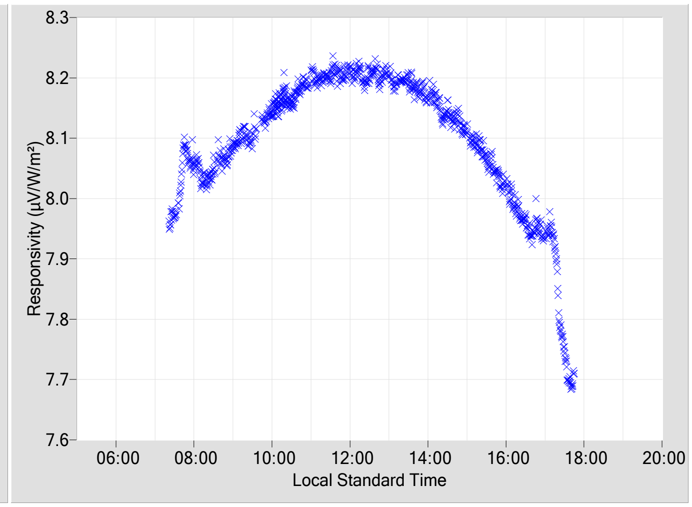


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1345	0.33	113.79	8.0823	0.35	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1136	0.41	111.29	8.0516	0.34	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0959	0.40	109.03	8.0446	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1042	0.34	106.87	8.0207	0.35	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0882	0.37	104.95	8.0114	0.36	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0635	0.45	103.09	7.9889	0.37	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0630	0.43	101.30	7.9646	0.40	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0546	0.42	99.52	7.9473	0.41	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0309	0.39	97.89	7.9511	0.40	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0304	0.45	96.19	7.9455	0.42	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0522	0.42	94.64	7.9446	0.44	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.0693	N/A	93.10	7.9252	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0301	N/A	91.51	7.7786	N/A	268.76
26	8.2040	0.34	173.51	8.2060	0.32	186.43	72	7.9716	N/A	90.04	7.7030	N/A	270.25
28	8.2050	0.32	154.05	8.1954	0.34	205.96	74	7.9626	N/A	88.72	7.7113	N/A	271.65
30	8.2026	0.30	144.99	8.1815	0.33	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1914	0.33	138.28	8.1653	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1878	0.34	133.04	8.1715	0.34	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1840	0.32	128.51	8.1308	0.33	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1618	0.35	125.51	8.1303	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1654	0.31	121.67	8.1321	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1584	0.33	118.64	8.1121	0.32	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1423	0.35	116.24	8.0944	0.37	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

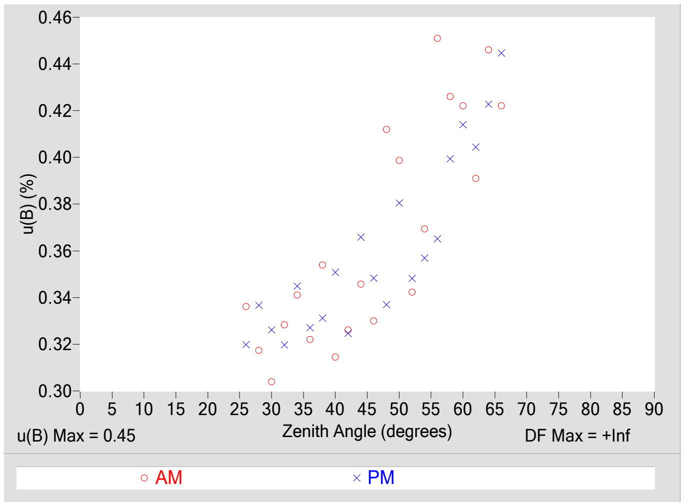


Figure 4. Residuals from Spline Interpolation

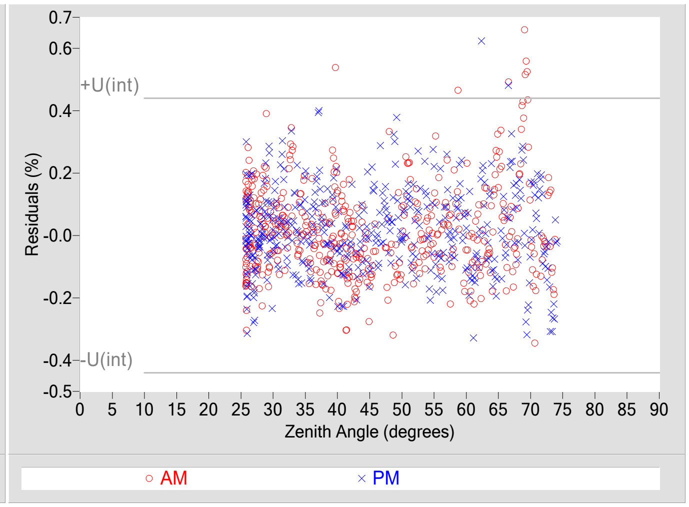


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	22319
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

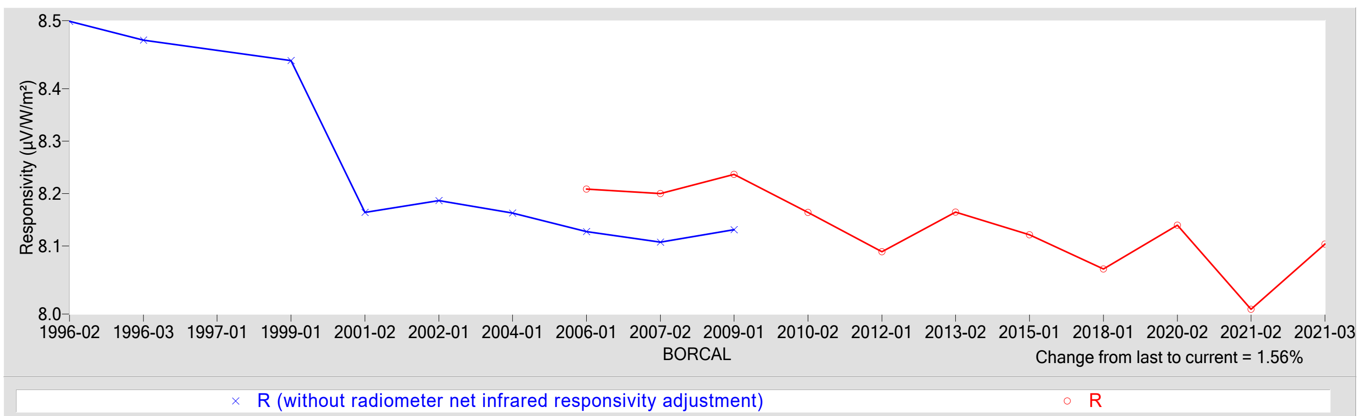
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1037	0.63379

† Rnet determination date: 05/08/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+1.2 / -1.9
Expanded Uncertainty, U (%)	+2.1 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 30951F3

Calibration Date: 8/25/2021

Due Date: 8/25/2022

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 8/24-25

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30951F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

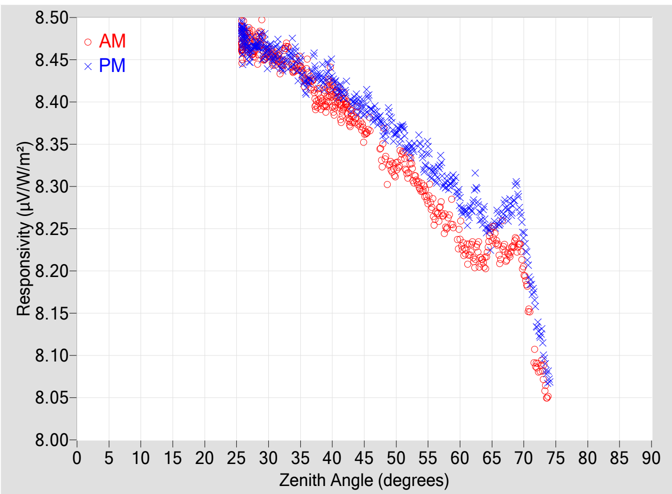


Figure 2. Responsivity vs Local Standard Time

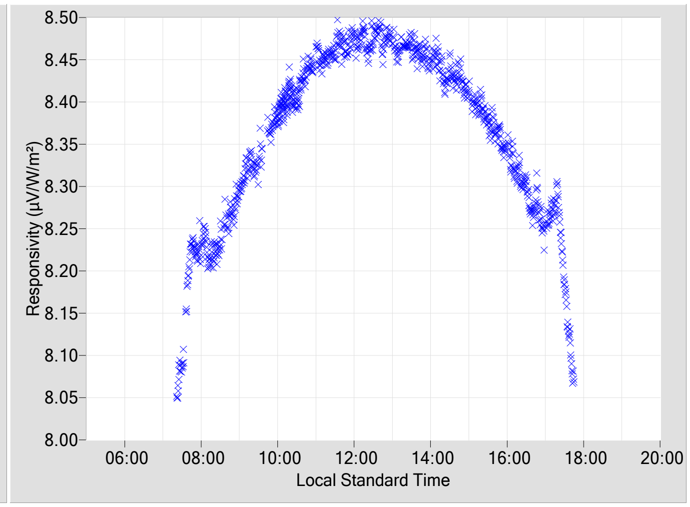


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3738	0.33	113.79	8.3915	0.35	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3412	0.41	111.29	8.3649	0.34	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3202	0.40	109.03	8.3641	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3242	0.34	106.87	8.3434	0.35	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2970	0.37	104.95	8.3372	0.36	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2669	0.45	103.09	8.3160	0.36	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2539	0.43	101.30	8.3028	0.40	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2403	0.42	99.52	8.2808	0.41	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2230	0.39	97.89	8.2806	0.40	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2124	0.45	96.19	8.2568	0.42	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2250	0.42	94.64	8.2611	0.44	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.2229	N/A	93.10	8.2754	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1968	N/A	91.51	8.2372	N/A	268.76
26	8.4731	0.34	173.51	8.4784	0.32	186.40	72	8.0901	N/A	90.04	8.1387	N/A	270.25
28	8.4652	0.32	154.05	8.4666	0.34	205.96	74	8.0515	N/A	88.72	8.0740	N/A	271.65
30	8.4576	0.30	144.99	8.4574	0.33	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.4431	0.33	138.28	8.4445	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4403	0.34	133.04	8.4574	0.34	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4332	0.32	128.51	8.4189	0.33	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4055	0.35	125.51	8.4276	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4056	0.31	121.67	8.4311	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3995	0.33	118.64	8.4134	0.32	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3824	0.35	116.24	8.3975	0.37	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

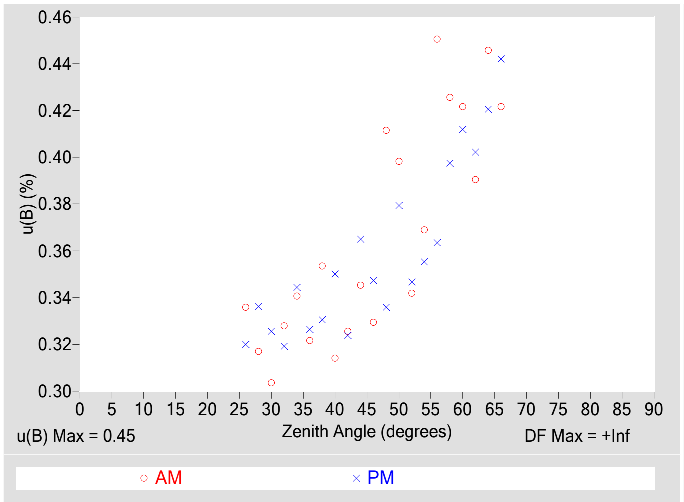


Figure 4. Residuals from Spline Interpolation

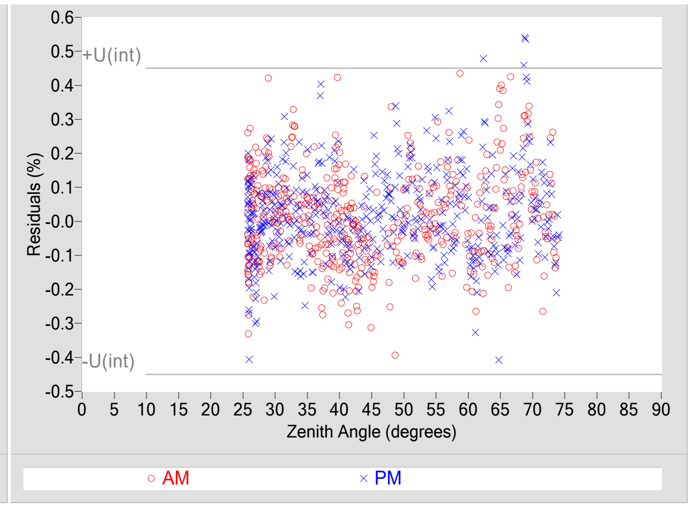


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	20627
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

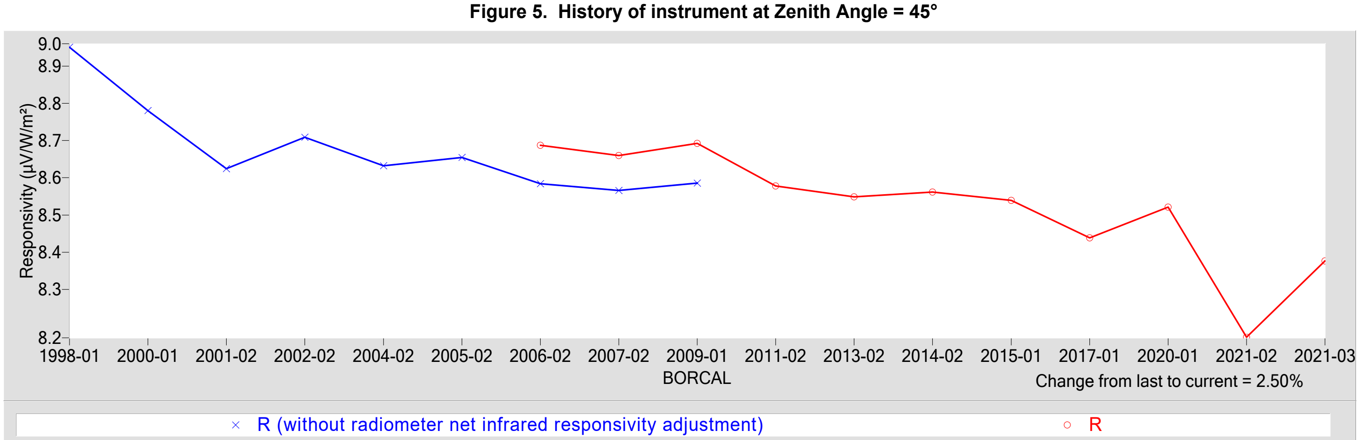
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3762	0.64270

† Rnet determination date: 07/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+0.97 / -1.6
Expanded Uncertainty, U (%)	+1.9 / -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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30953F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

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

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

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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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

30953F3 Eppley PSP

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

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

where,

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

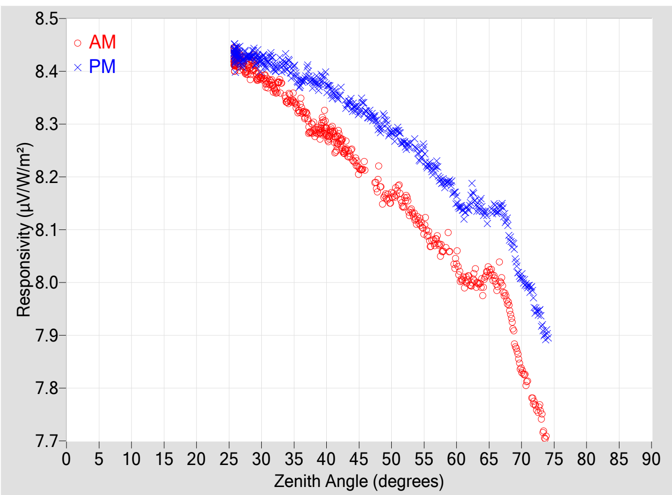


Figure 2. Responsivity vs Local Standard Time

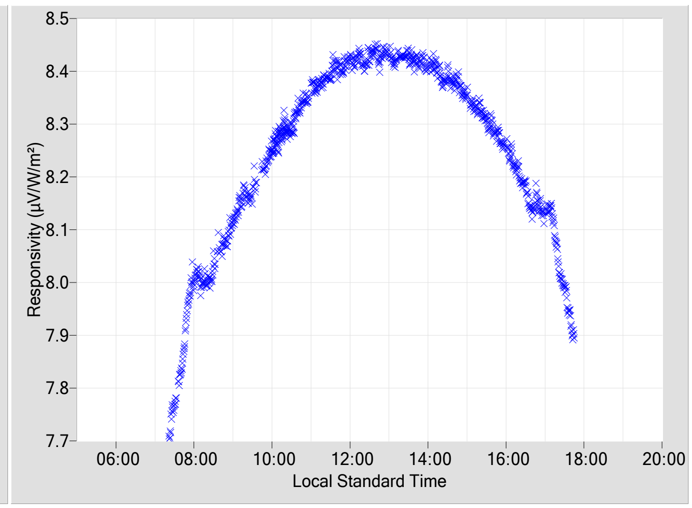


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2209	0.33	113.79	8.3244	0.35	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1894	0.41	111.29	8.2925	0.34	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1600	0.40	109.03	8.2844	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1532	0.34	106.87	8.2615	0.35	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1168	0.37	104.95	8.2456	0.36	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0782	0.45	103.09	8.2189	0.37	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0587	0.41	101.35	8.1879	0.40	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0395	0.42	99.52	8.1555	0.42	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0037	0.39	97.89	8.1475	0.41	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9940	0.45	96.19	8.1398	0.43	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0013	0.43	94.64	8.1392	0.45	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.9586	N/A	93.10	8.0970	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8325	N/A	91.51	8.0074	N/A	268.76
26	8.4231	0.34	173.51	8.4336	0.32	186.40	72	7.7701	N/A	90.04	7.9530	N/A	270.25
28	8.4058	0.32	154.05	8.4277	0.34	205.96	74	7.7092	N/A	88.72	7.9027	N/A	271.65
30	8.3873	0.30	144.99	8.4185	0.33	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3648	0.33	138.28	8.4058	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3451	0.34	133.04	8.4160	0.35	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3310	0.32	128.51	8.3770	0.33	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2912	0.35	125.51	8.3795	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2848	0.32	121.67	8.3783	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2713	0.33	118.64	8.3565	0.33	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2412	0.35	116.24	8.3347	0.37	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

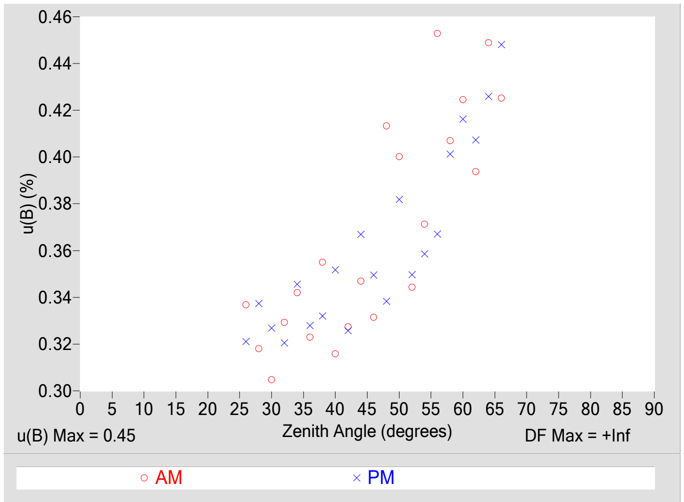


Figure 4. Residuals from Spline Interpolation

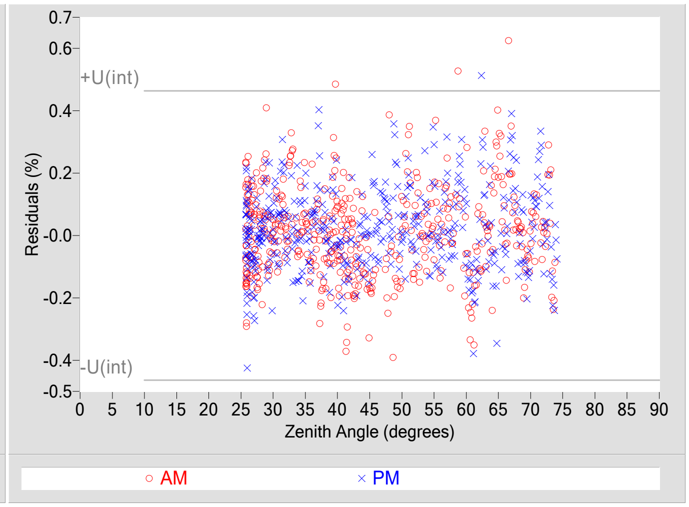


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	19077
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

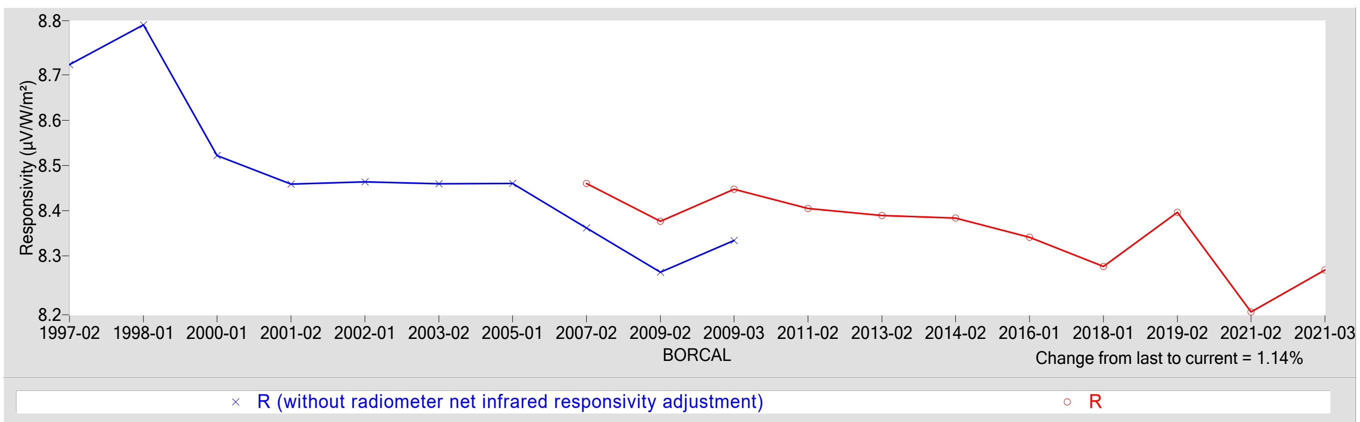
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.2691	0.67080

† Rnet determination date: 05/08/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31096F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ____________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31096F3 Eppley PSP

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

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

where,

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

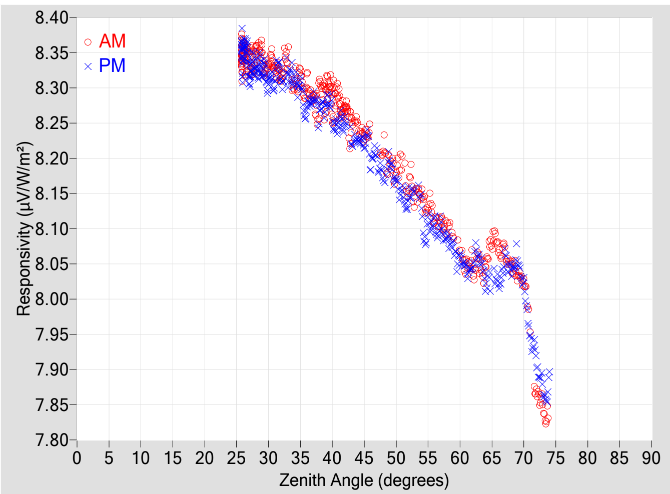


Figure 2. Responsivity vs Local Standard Time

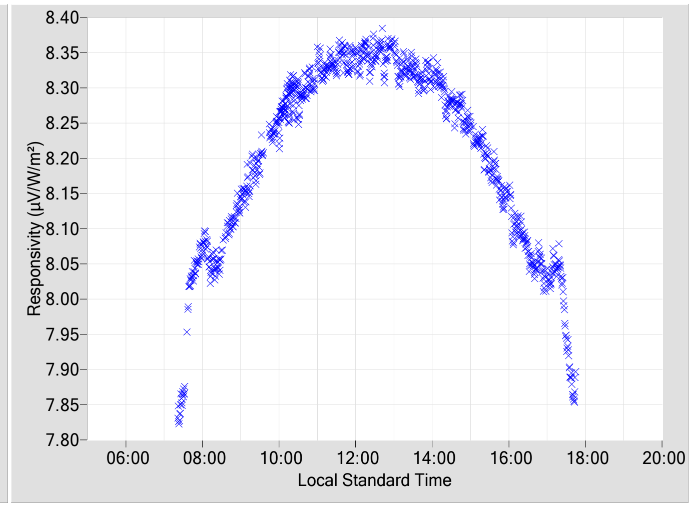


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2424	0.37	113.88	8.1947	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2121	0.37	111.27	8.1721	0.36	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1818	0.40	108.97	8.1699	0.34	251.39
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1596	0.34	106.95	8.1428	0.35	253.46
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1467	0.37	104.90	8.1274	0.40	255.42
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1119	0.38	103.11	8.1051	0.36	257.35
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0992	0.36	101.23	8.0853	0.40	259.11
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0692	0.39	99.43	8.0588	0.39	260.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0455	0.39	97.85	8.0469	0.40	262.44
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0455	0.46	96.25	8.0238	0.42	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0721	0.42	94.60	8.0240	0.44	265.65
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.0487	N/A	93.07	8.0434	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0222	N/A	91.57	8.0162	N/A	268.72
26	8.3491	0.34	173.13	8.3499	0.31	186.81	72	7.8666	N/A	90.05	7.9085	N/A	270.22
28	8.3440	0.32	153.91	8.3276	0.31	205.99	74	7.8397	N/A	88.74	7.8846	N/A	271.62
30	8.3341	0.34	144.87	8.3068	0.33	214.94	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3158	0.34	138.31	8.3126	0.31	221.59	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3075	0.31	132.96	8.3132	0.34	226.97	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3044	0.32	128.62	8.2719	0.32	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2905	0.34	125.32	8.2638	0.33	235.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2847	0.35	121.71	8.2615	0.34	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2726	0.35	118.55	8.2489	0.36	241.52	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2470	0.36	116.20	8.2255	0.34	244.34	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

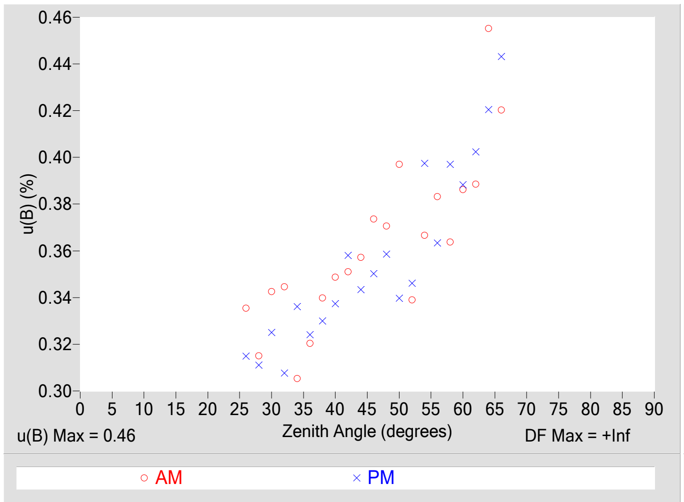


Figure 4. Residuals from Spline Interpolation

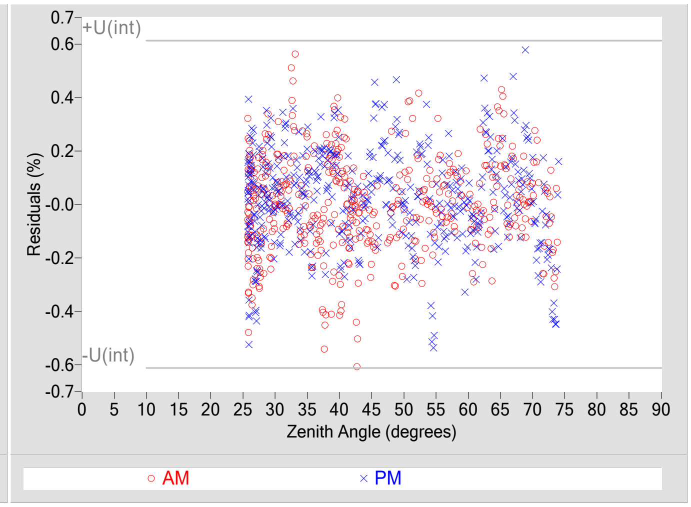


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.55
Effective degrees of freedom, DF(c)	8526
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

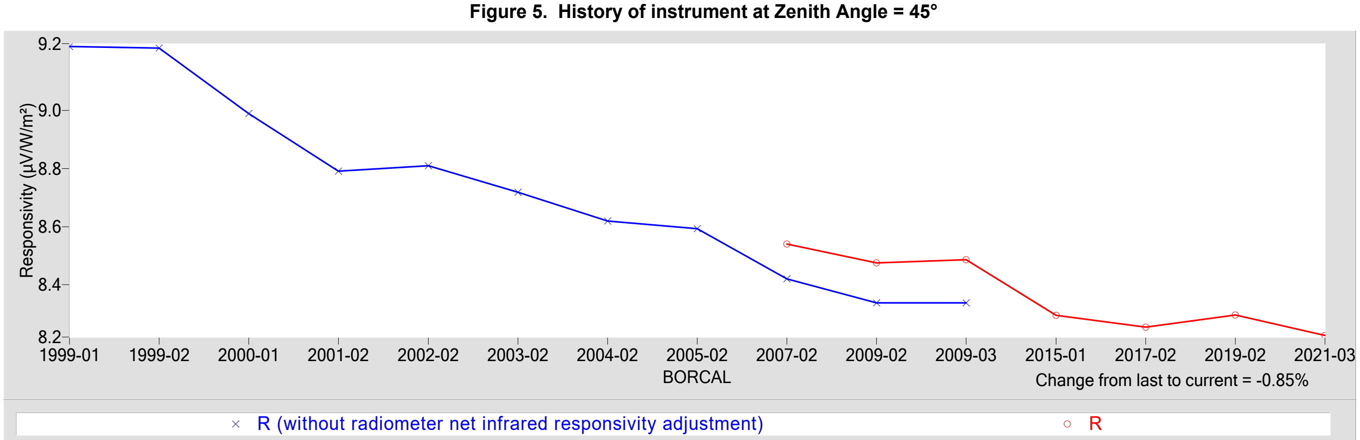
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.2257	0.71483

† Rnet determination date: 05/08/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.3 / -2.0
Expanded Uncertainty, U (%)	+2.1 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31099F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________   _______________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31099F3 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 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

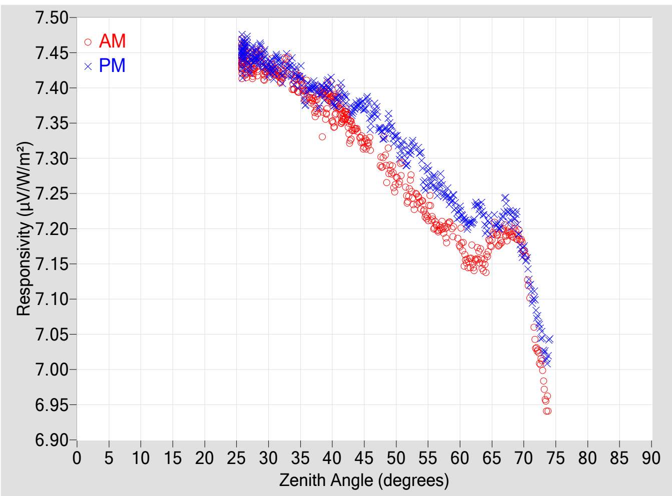


Figure 2. Responsivity vs Local Standard Time

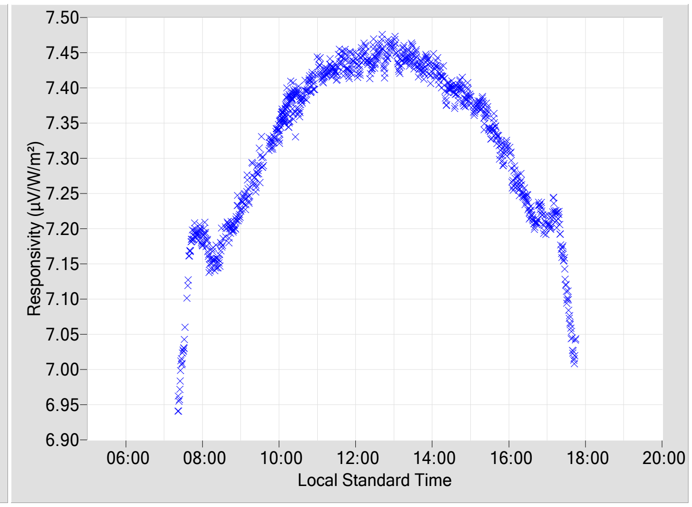


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.3210	0.39	113.83	7.3529	0.36	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3023	0.33	111.26	7.3326	0.37	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2651	0.41	109.06	7.3307	0.33	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2493	0.36	106.96	7.3068	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2339	0.36	104.91	7.2930	0.37	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2060	0.45	103.06	7.2673	0.38	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1971	0.38	101.22	7.2459	0.37	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1828	0.38	99.44	7.2238	0.38	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1540	0.41	97.86	7.2099	0.39	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.1534	0.44	96.16	7.2041	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.1824	0.42	94.61	7.2026	0.43	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.1926	N/A	93.08	7.2166	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.1697	N/A	91.57	7.1651	N/A	268.73
26	7.4417	0.33	173.64	7.4505	0.33	186.51	72	7.0315	N/A	90.06	7.0796	N/A	270.23
28	7.4364	0.32	153.68	7.4435	0.32	206.03	74	6.9407	N/A	88.70	7.0351	N/A	271.63
30	7.4253	0.34	144.83	7.4288	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.4119	0.33	138.29	7.4229	0.32	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.4064	0.34	132.98	7.4185	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3967	0.32	128.70	7.3927	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3867	0.36	125.37	7.3872	0.33	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3759	0.35	121.72	7.3904	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3623	0.35	118.60	7.3839	0.35	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3379	0.34	116.27	7.3772	0.34	244.35	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

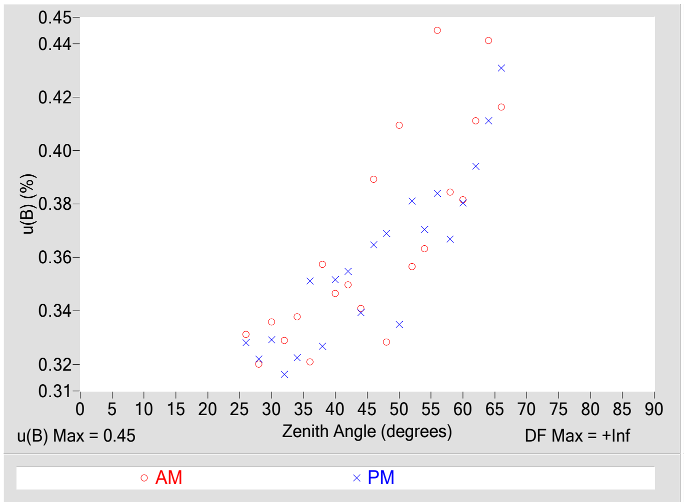


Figure 4. Residuals from Spline Interpolation

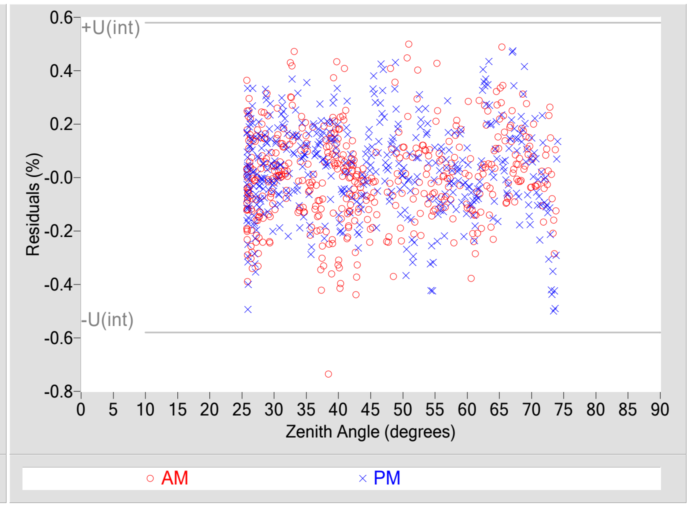


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	9434
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

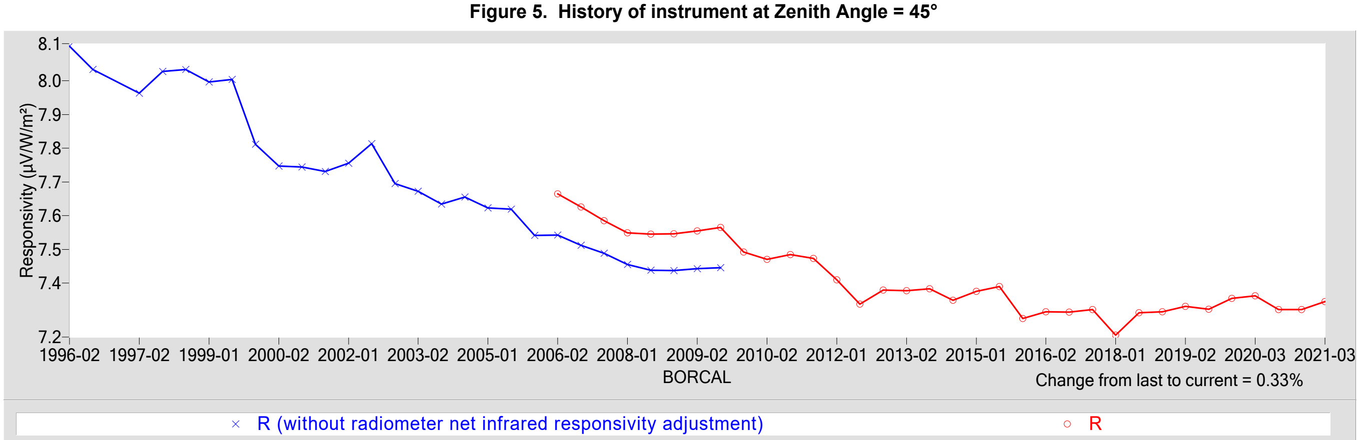
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.3457	0.57866

† Rnet determination date: 05/08/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.1 / -2.2
Expanded Uncertainty, U (%)	+2.0 / -3.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31100F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31100F3 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 - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of radiometer (K).

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

Figure 1. Responsivity vs Zenith Angle

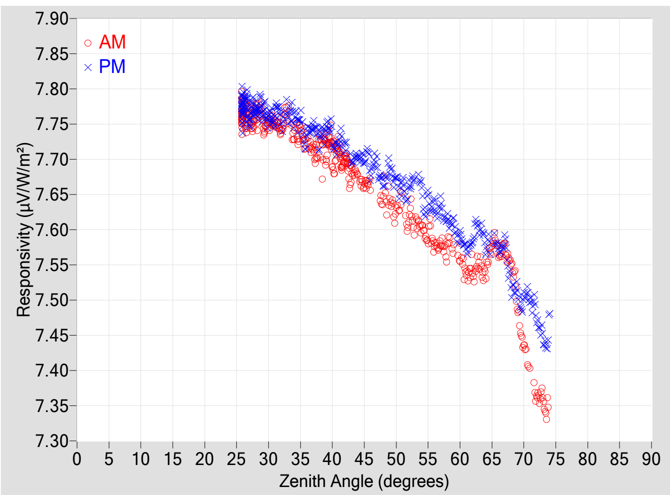


Figure 2. Responsivity vs Local Standard Time

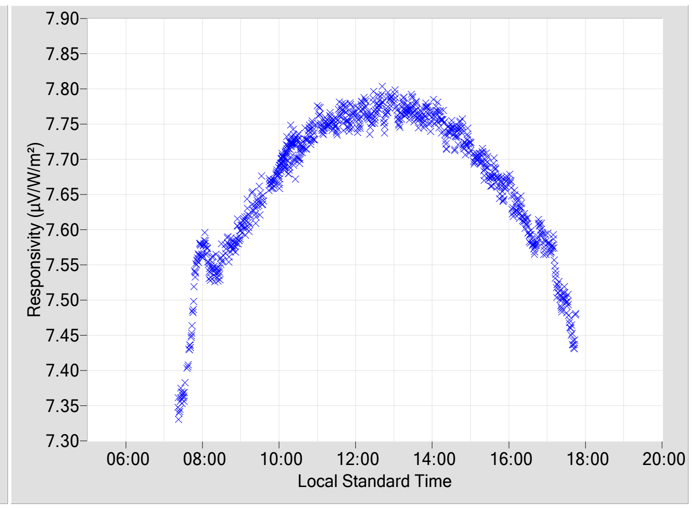


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6659	0.39	113.83	7.6813	0.37	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6496	0.33	111.26	7.6671	0.37	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6244	0.41	109.06	7.6736	0.34	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6126	0.36	106.96	7.6587	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6026	0.36	104.91	7.6544	0.37	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5775	0.45	103.06	7.6345	0.39	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5733	0.39	101.22	7.6127	0.37	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5628	0.38	99.44	7.5905	0.38	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5414	0.41	97.86	7.5839	0.40	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5441	0.44	96.16	7.5775	0.42	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5682	0.42	94.61	7.5733	0.44	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.5506	N/A	93.08	7.5243	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.4363	N/A	91.57	7.5003	N/A	268.73
26	7.7662	0.33	173.64	7.7757	0.33	186.51	72	7.3636	N/A	90.06	7.4744	N/A	270.23
28	7.7627	0.32	153.68	7.7693	0.32	206.03	74	7.3476	N/A	88.70	7.4678	N/A	271.63
30	7.7516	0.34	144.83	7.7587	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.7396	0.33	138.29	7.7557	0.32	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7375	0.34	132.98	7.7585	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7292	0.32	128.70	7.7325	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7216	0.36	125.37	7.7288	0.33	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7122	0.35	121.72	7.7314	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7009	0.35	118.60	7.7186	0.36	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6771	0.34	116.27	7.7033	0.34	244.35	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

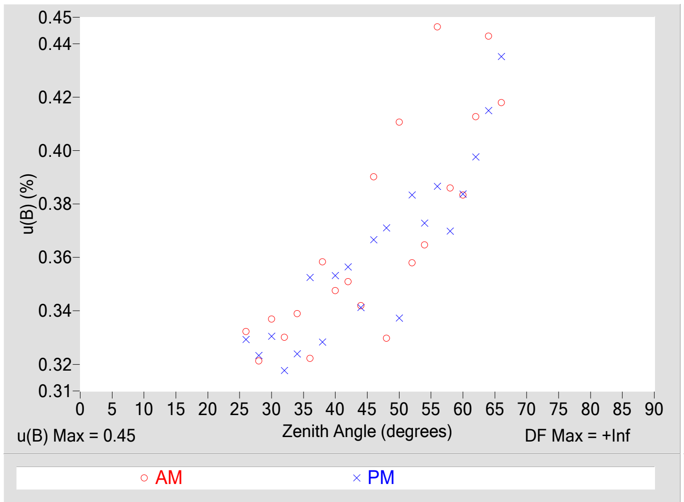


Figure 4. Residuals from Spline Interpolation

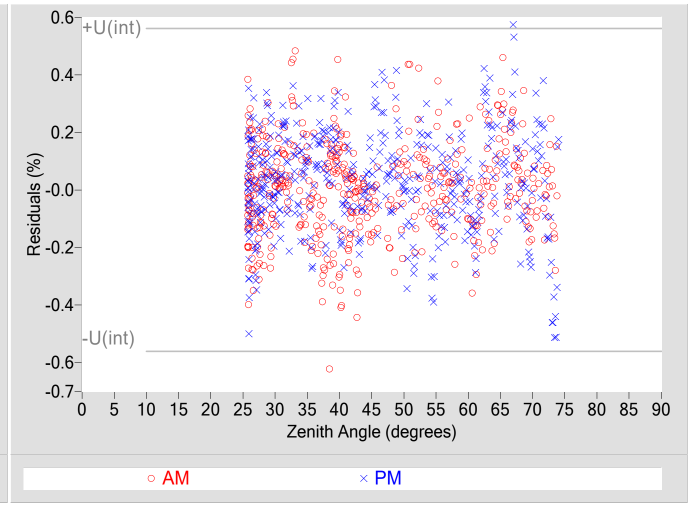


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	10471
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

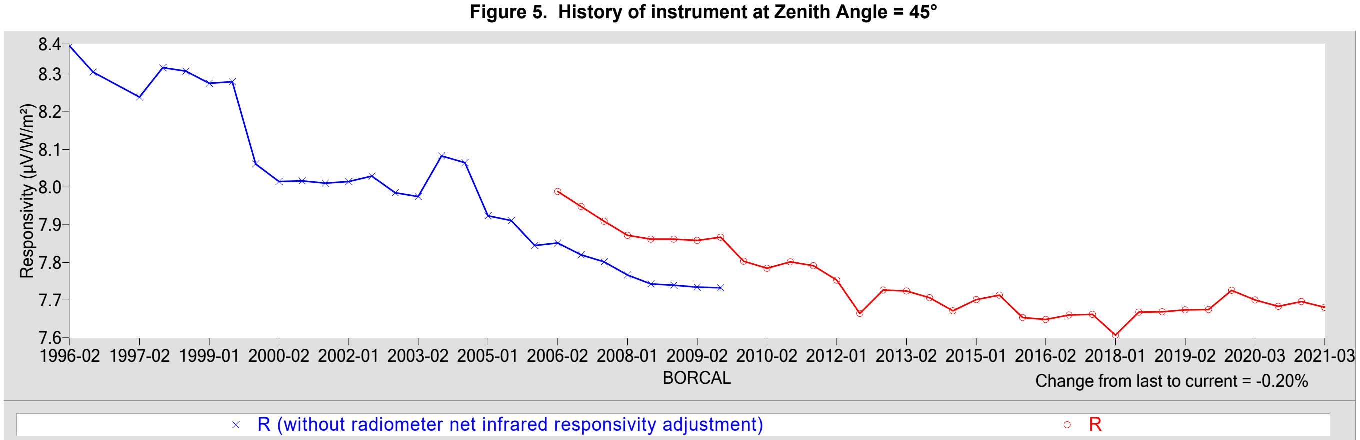
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6807	0.64729

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.0 / -1.5
Expanded Uncertainty, U (%)	+1.9 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31101F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31101F3 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 radiometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

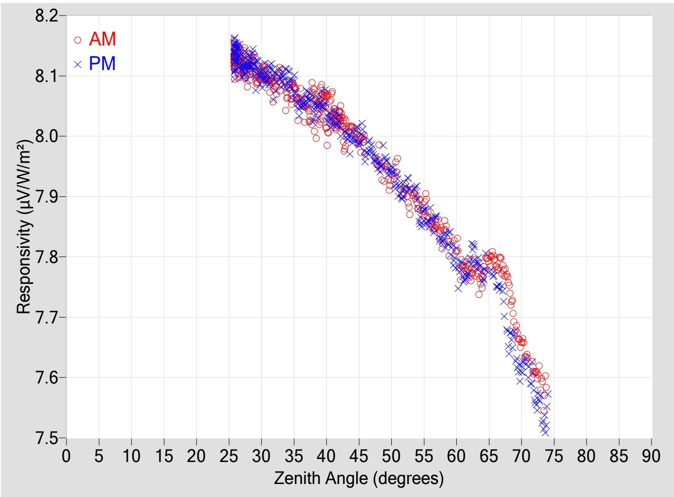


Figure 2. Responsivity vs Local Standard Time

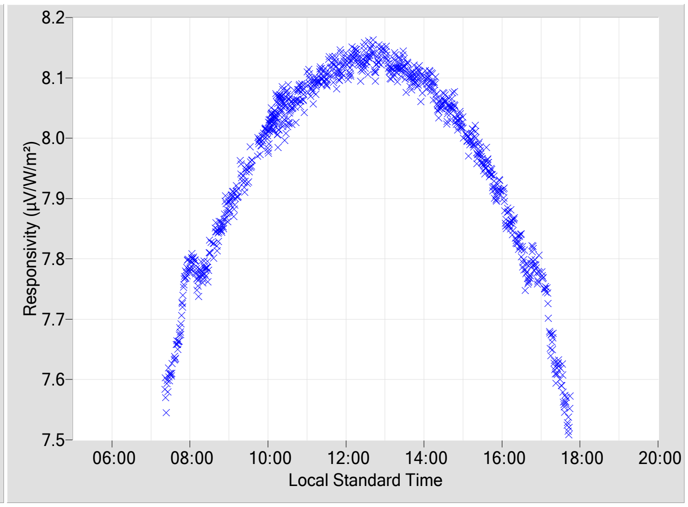


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9887	0.39	113.83	7.9690	0.37	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9594	0.33	111.26	7.9506	0.37	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9275	0.40	109.12	7.9440	0.34	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9102	0.36	106.96	7.9125	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8891	0.36	104.91	7.8904	0.37	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8566	0.45	103.06	7.8645	0.39	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8369	0.39	101.22	7.8267	0.37	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8150	0.38	99.44	7.7856	0.38	260.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7765	0.41	97.86	7.7837	0.40	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7684	0.44	96.16	7.7651	0.41	264.12
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7877	0.42	94.61	7.7566	0.43	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.7575	N/A	93.08	7.6644	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.6587	N/A	91.57	7.6112	N/A	268.73
26	8.1324	0.33	173.61	8.1337	0.33	186.40	72	7.6089	N/A	90.06	7.5725	N/A	270.23
28	8.1134	0.32	153.68	8.1183	0.32	206.03	74	7.5840	N/A	88.70	7.5483	N/A	271.63
30	8.1015	0.34	144.83	8.0985	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.0781	0.33	138.29	8.0880	0.32	221.57	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0703	0.34	132.98	8.0942	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0635	0.32	128.70	8.0509	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0575	0.36	125.37	8.0420	0.33	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0434	0.35	121.72	8.0447	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0339	0.35	118.60	8.0192	0.36	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0141	0.34	116.27	7.9967	0.34	244.43	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

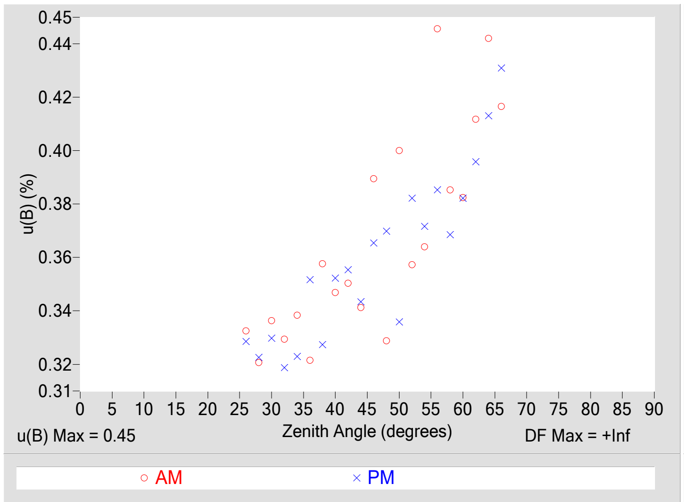


Figure 4. Residuals from Spline Interpolation

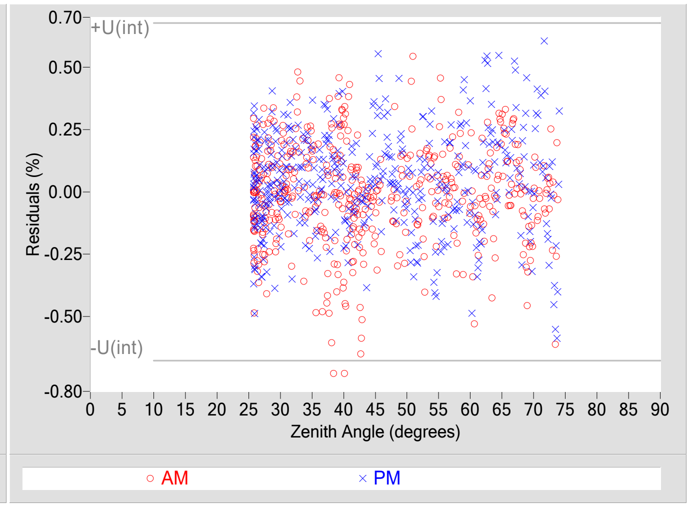


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.56
Effective degrees of freedom, DF(c)	6144
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

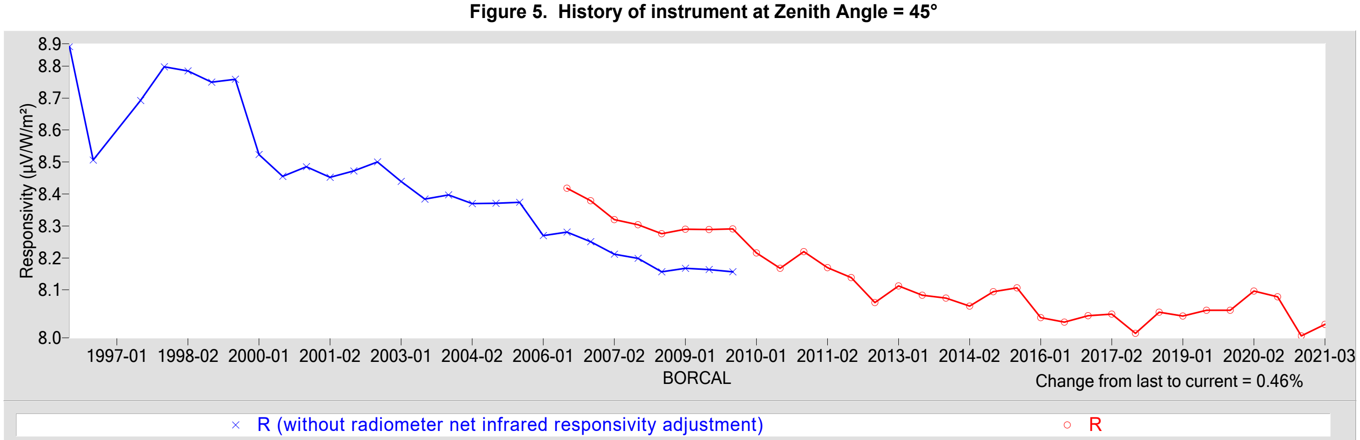
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9922	0.64834

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.4 / -2.6
Expanded Uncertainty, U (%)	+2.2 / -3.5
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31120E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31120E6 Eppley NIP

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

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

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

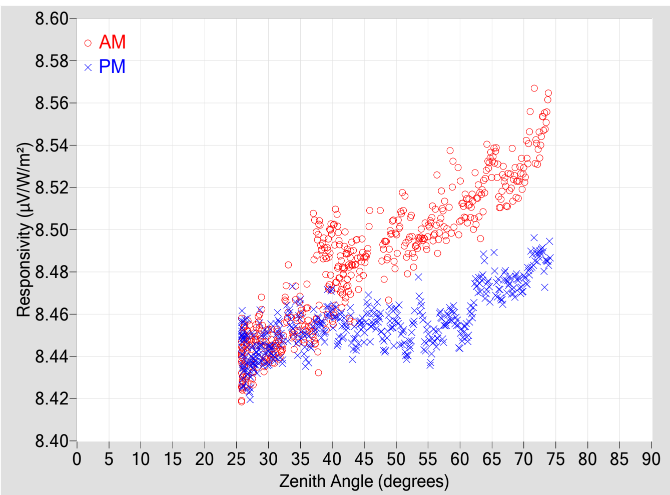


Figure 2. Responsivity vs Local Standard Time

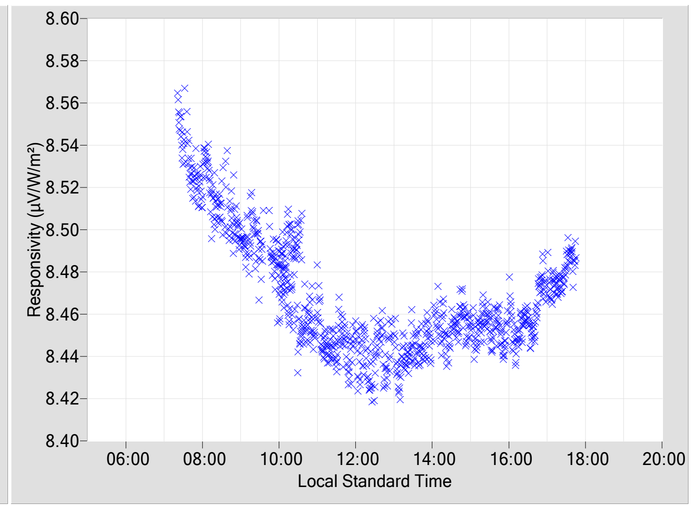


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5053	0.33	113.85	8.4544	0.32	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4880	0.32	111.24	8.4465	0.29	249.18
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4915	0.33	109.01	8.4590	0.29	251.43
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4930	0.29	106.92	8.4441	0.32	253.50
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4969	0.31	104.94	8.4615	0.29	255.40
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5004	0.33	103.03	8.4486	0.29	257.33
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4975	0.30	101.40	8.4575	0.30	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5116	0.34	99.56	8.4493	0.31	260.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5093	0.32	97.82	8.4644	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5267	0.36	96.23	8.4738	0.30	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5185	0.30	94.58	8.4726	0.30	265.63
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5233	N/A	93.04	8.4740	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5244	N/A	91.55	8.4749	N/A	268.70
26	8.4377	0.30	173.43	8.4436	0.31	187.00	72	8.5368	N/A	90.03	8.4875	N/A	270.20
28	8.4472	0.31	153.85	8.4384	0.30	206.02	74	8.5632	N/A	88.71	8.4874	N/A	271.65
30	8.4461	0.30	144.62	8.4433	0.31	214.98	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.4437	0.30	138.25	8.4450	0.29	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4552	0.30	132.92	8.4593	0.30	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4594	0.29	128.49	8.4403	0.29	231.29	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4809	0.32	125.32	8.4547	0.29	235.27	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4790	0.30	121.60	8.4636	0.31	238.60	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4812	0.31	118.63	8.4541	0.32	241.57	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4851	0.32	116.23	8.4506	0.29	244.38	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

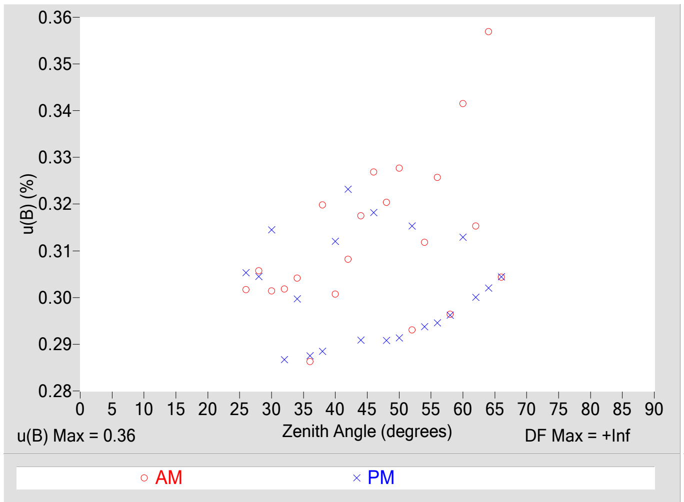


Figure 4. Residuals from Spline Interpolation

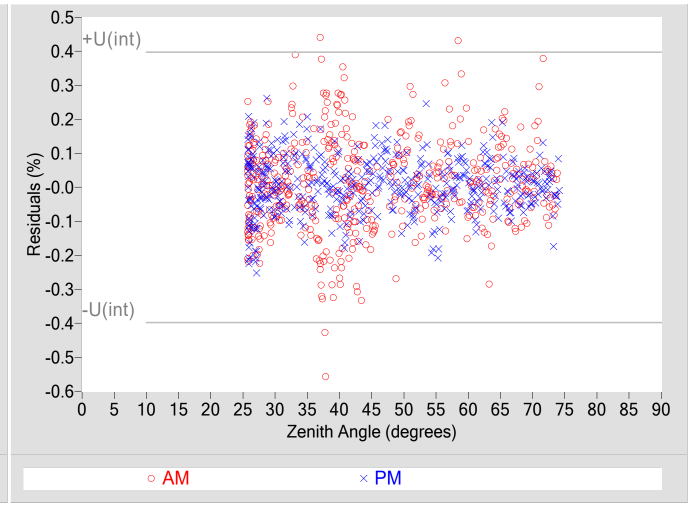


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.36
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	15072
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.80
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

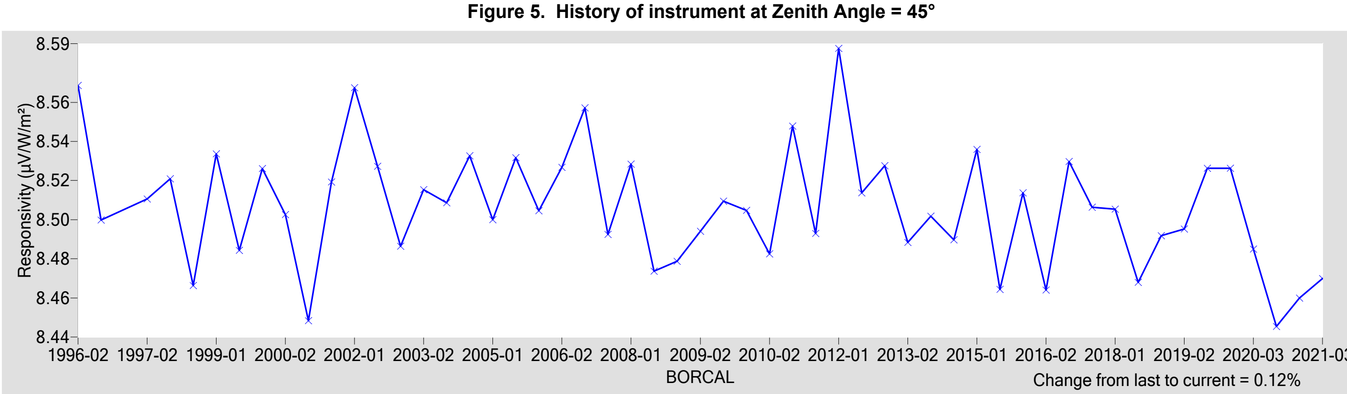
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4699	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.49 / -0.35
Expanded Uncertainty, U (%)	+1.2 / -1.0
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.

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31122E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ____________

Peter Gotseff, Technical Manager — Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31122E6 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

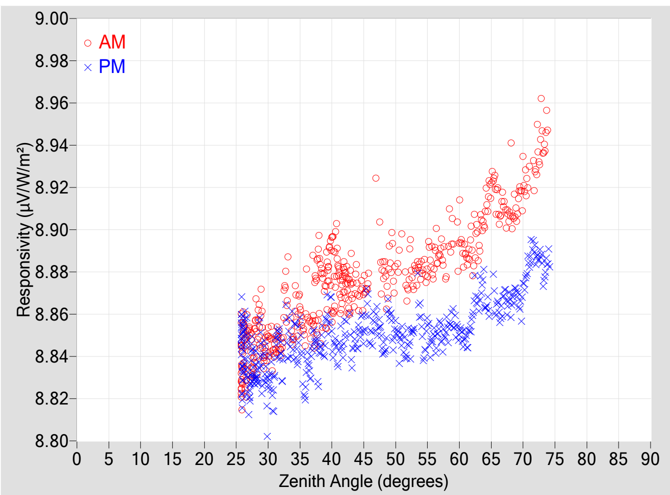


Figure 2. Responsivity vs Local Standard Time

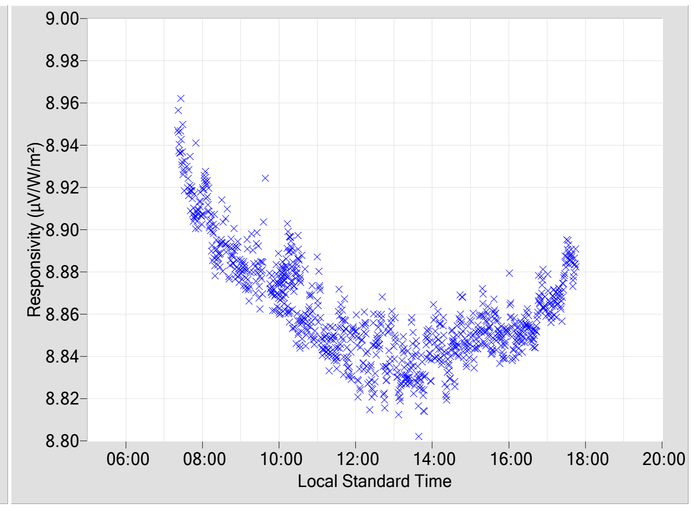


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.8795	0.29	113.93	8.8511	0.30	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8785	0.31	111.25	8.8445	0.30	249.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8763	0.29	109.16	8.8526	0.31	251.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8754	0.29	106.93	8.8460	0.31	253.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8804	0.31	104.89	8.8572	0.31	255.41
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8837	0.31	103.04	8.8484	0.31	257.34
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8822	0.30	101.23	8.8519	0.30	259.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8954	0.34	99.47	8.8514	0.30	260.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8896	0.30	97.83	8.8592	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9070	0.30	96.24	8.8676	0.30	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9112	0.30	94.59	8.8633	0.33	265.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.9048	N/A	93.08	8.8651	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.9202	N/A	91.55	8.8691	N/A	268.70
26	8.8400	0.30	173.47	8.8433	0.30	186.51	72	8.9301	N/A	90.04	8.8881	N/A	270.21
28	8.8483	0.30	153.88	8.8311	0.30	205.96	74	8.9518	N/A	88.71	8.8852	N/A	271.65
30	8.8472	0.31	144.87	8.8256	0.30	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.8455	0.30	138.19	8.8398	0.31	221.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8543	0.30	132.97	8.8510	0.31	226.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8546	0.29	128.57	8.8308	0.31	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8737	0.32	125.21	8.8377	0.31	235.23	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8797	0.31	121.68	8.8540	0.29	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8768	0.31	118.64	8.8499	0.31	241.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8727	0.31	116.17	8.8482	0.29	244.36	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

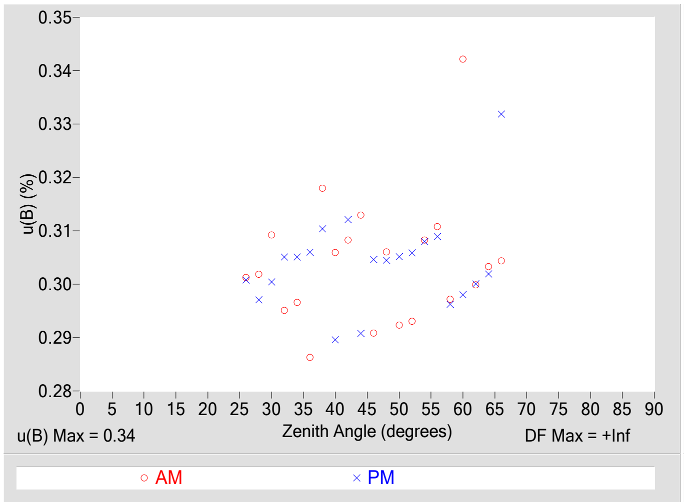


Figure 4. Residuals from Spline Interpolation

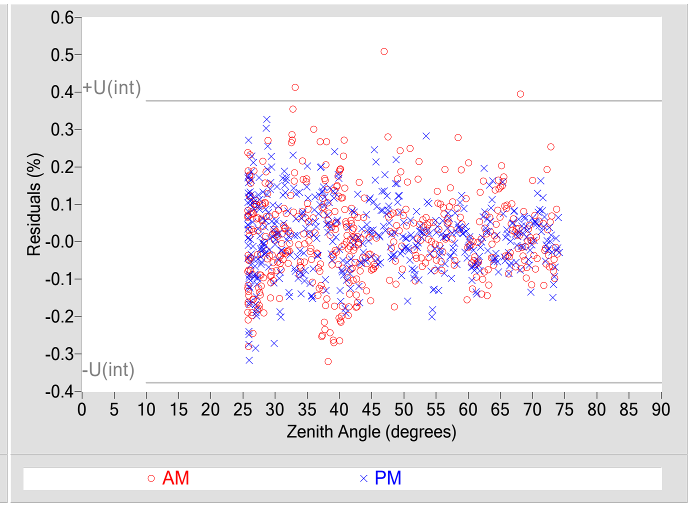


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	15385
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.77
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

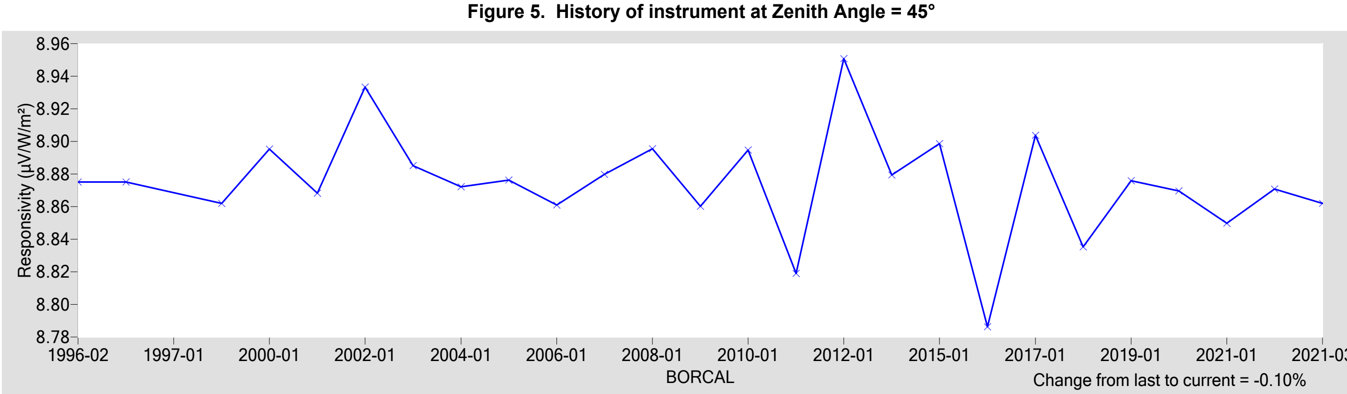
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8620	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.38 / -0.41
Expanded Uncertainty, U (%)	+1.0 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31149F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31149F3 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 radiometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  where, $G = B * COS(Z) + D$,
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

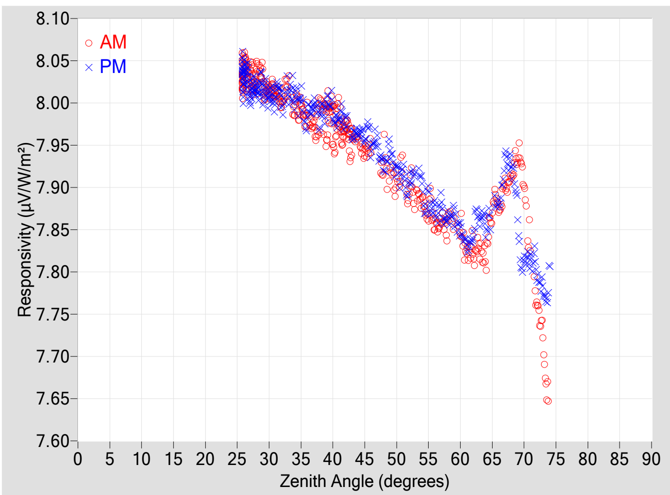


Figure 2. Responsivity vs Local Standard Time

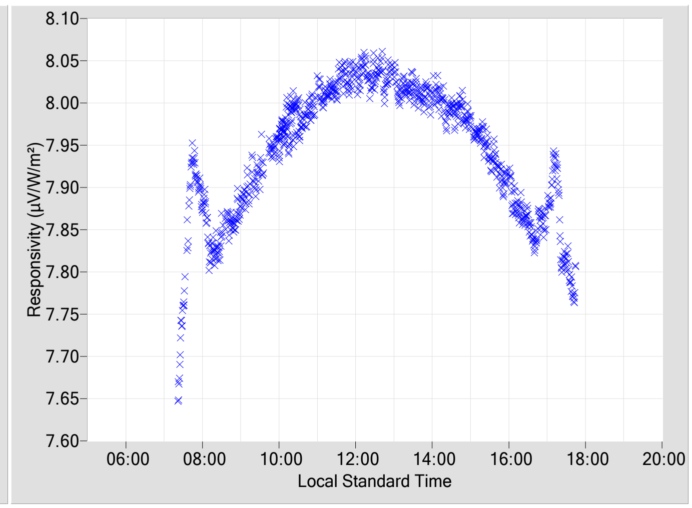


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9499	0.39	113.83	7.9458	0.36	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9317	0.33	111.26	7.9252	0.36	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9016	0.41	109.06	7.9253	0.33	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8948	0.35	106.96	7.9052	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8832	0.36	104.91	7.9007	0.36	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8564	0.44	103.06	7.8752	0.38	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8559	0.38	101.22	7.8626	0.36	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8498	0.38	99.44	7.8514	0.37	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8246	0.41	97.86	7.8419	0.39	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8226	0.44	96.16	7.8535	0.40	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8763	0.41	94.61	7.8813	0.42	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.9122	N/A	93.08	7.9272	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.9027	N/A	91.57	7.8107	N/A	268.73
26	8.0348	0.33	173.64	8.0333	0.33	186.54	72	7.7647	N/A	90.06	7.7978	N/A	270.23
28	8.0314	0.32	153.68	8.0155	0.32	206.03	74	7.6469	N/A	88.70	7.7965	N/A	271.63
30	8.0154	0.33	144.83	8.0081	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.9990	0.33	138.29	8.0016	0.31	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9947	0.34	132.98	8.0070	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9857	0.32	128.70	7.9843	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9895	0.36	125.37	7.9838	0.32	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9788	0.34	121.72	7.9909	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9703	0.35	118.60	7.9786	0.35	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9564	0.34	116.27	7.9654	0.34	244.35	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

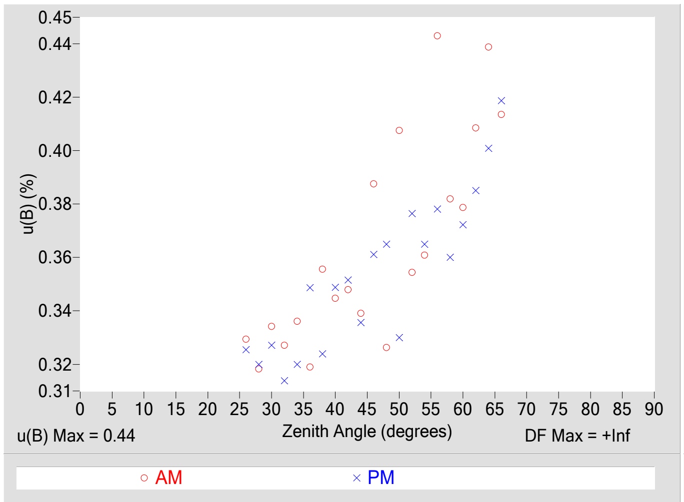


Figure 4. Residuals from Spline Interpolation

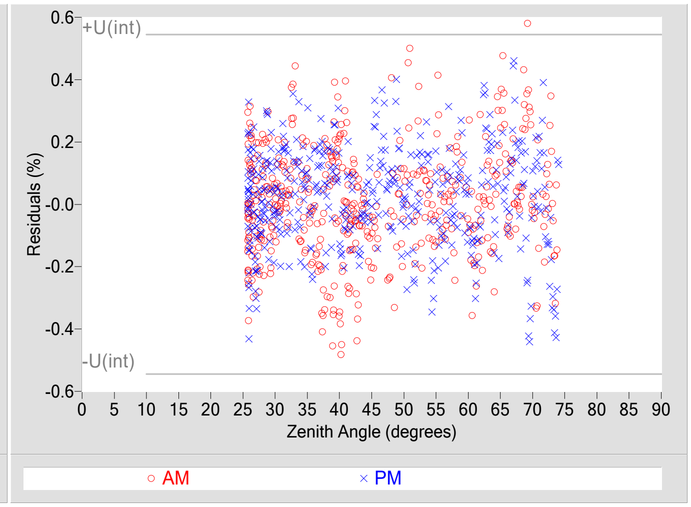


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	11102
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

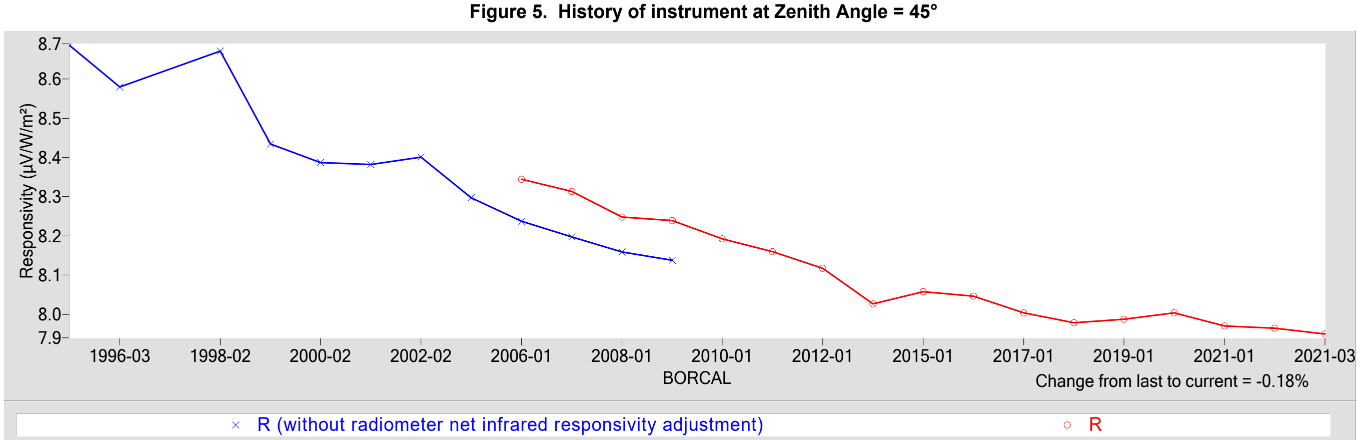
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9499	0.54900

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+0.82 / -1.3
Expanded Uncertainty, U (%)	+1.7 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31150F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31150F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

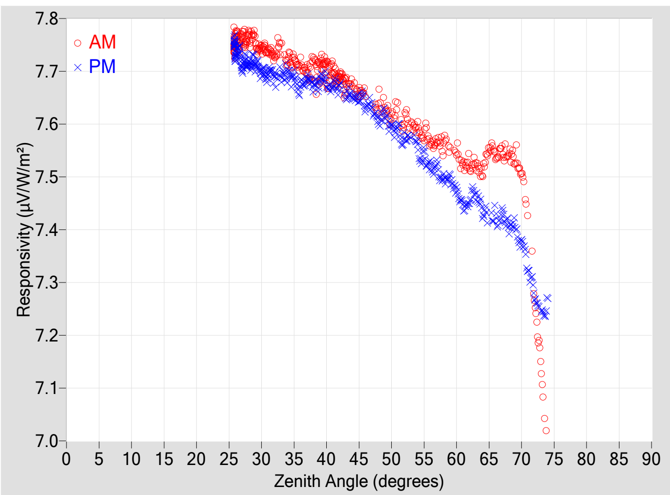


Figure 2. Responsivity vs Local Standard Time

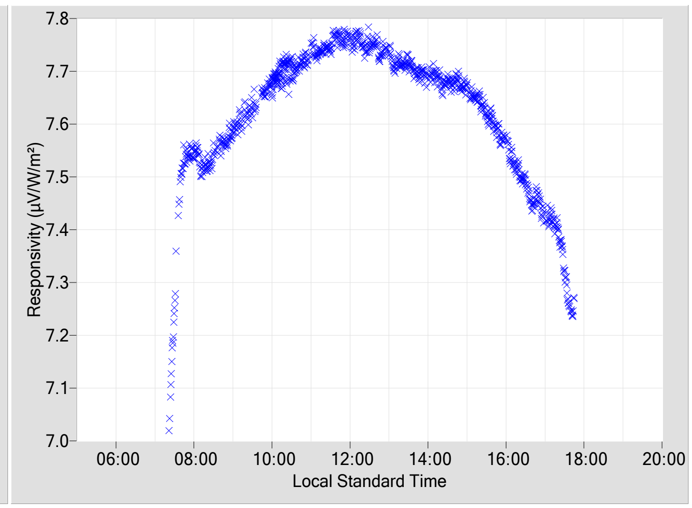


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6602	0.39	113.83	7.6310	0.36	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6394	0.33	111.26	7.6054	0.37	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6126	0.41	109.06	7.5983	0.33	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6042	0.36	106.96	7.5715	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5919	0.36	104.91	7.5561	0.37	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5640	0.44	103.06	7.5206	0.38	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5601	0.38	101.22	7.4956	0.36	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5488	0.38	99.44	7.4748	0.38	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5218	0.41	97.86	7.4512	0.39	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5128	0.44	96.16	7.4346	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5398	0.42	94.61	7.4245	0.42	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.5432	N/A	93.08	7.4094	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.5069	N/A	91.57	7.3744	N/A	268.73
26	7.7538	0.33	173.64	7.7429	0.33	186.54	72	7.2595	N/A	90.01	7.2744	N/A	270.23
28	7.7637	0.32	153.68	7.7129	0.32	206.03	74	7.0196	N/A	88.70	7.2625	N/A	271.63
30	7.7438	0.33	144.83	7.6989	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.7275	0.33	138.29	7.6875	0.31	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.7217	0.34	132.98	7.6928	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7123	0.32	128.70	7.6707	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7102	0.36	125.37	7.6738	0.33	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7024	0.35	121.72	7.6792	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6904	0.35	118.60	7.6690	0.35	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6781	0.34	116.27	7.6514	0.34	244.35	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

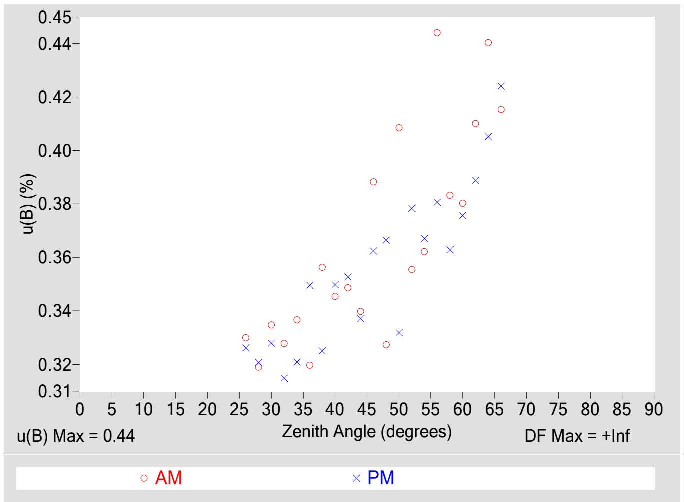


Figure 4. Residuals from Spline Interpolation

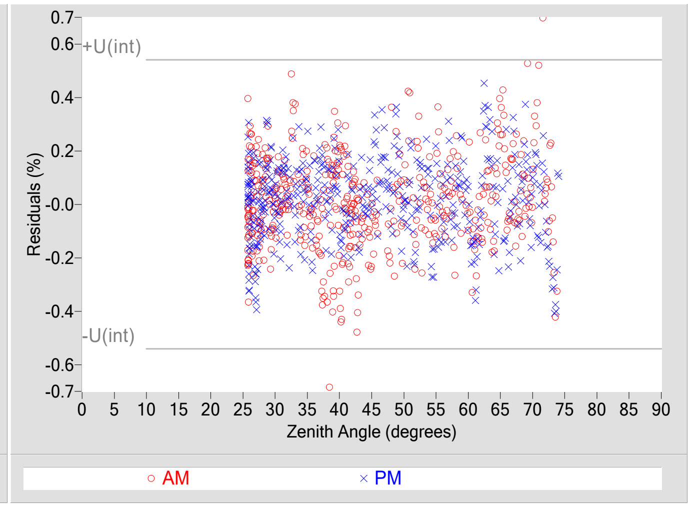


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	11428
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

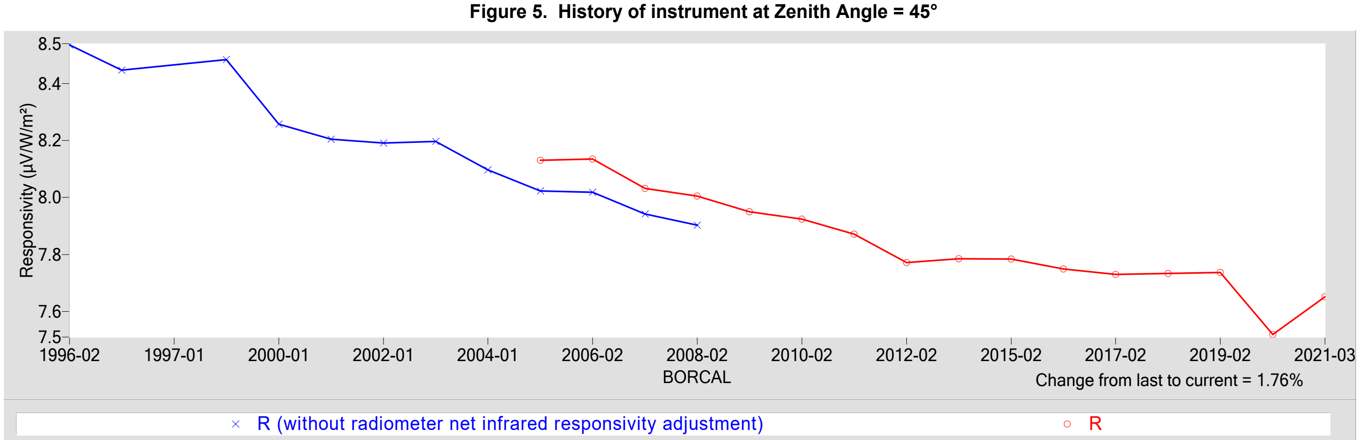
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6519	0.55100

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.2 / -2.3
Expanded Uncertainty, U (%)	+2.1 / -3.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31151F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31151F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

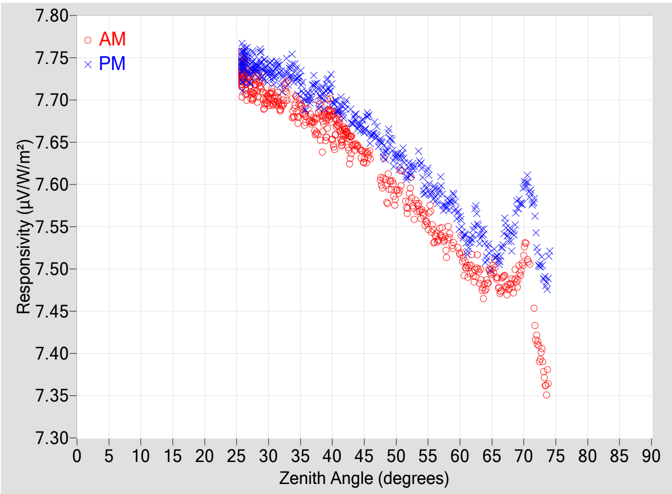


Figure 2. Responsivity vs Local Standard Time

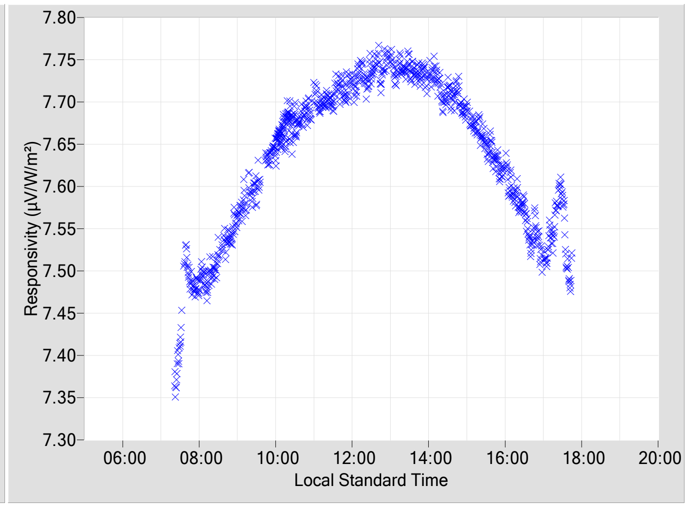


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.6349	0.39	113.83	7.6567	0.36	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6079	0.33	111.26	7.6391	0.36	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5860	0.41	109.06	7.6345	0.33	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5803	0.35	106.96	7.6165	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5657	0.36	104.91	7.6137	0.36	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5376	0.44	103.06	7.5902	0.38	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5316	0.38	101.22	7.5754	0.36	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5237	0.38	99.44	7.5571	0.37	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4986	0.41	97.86	7.5408	0.39	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4804	0.44	96.16	7.5222	0.40	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4808	0.41	94.61	7.5109	0.42	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.4817	N/A	93.08	7.5376	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.5168	N/A	91.57	7.5947	N/A	268.73
26	7.7318	0.33	173.64	7.7423	0.33	186.54	72	7.4190	N/A	90.06	7.5310	N/A	270.23
28	7.7159	0.32	153.68	7.7380	0.32	206.03	74	7.3640	N/A	88.70	7.5084	N/A	271.63
30	7.7022	0.33	144.83	7.7338	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.6907	0.33	138.29	7.7241	0.31	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6878	0.34	132.98	7.7333	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6846	0.32	128.70	7.6992	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6796	0.36	125.37	7.7029	0.32	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6733	0.34	121.72	7.7078	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6630	0.35	118.60	7.6915	0.35	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6454	0.34	116.27	7.6719	0.34	244.35	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

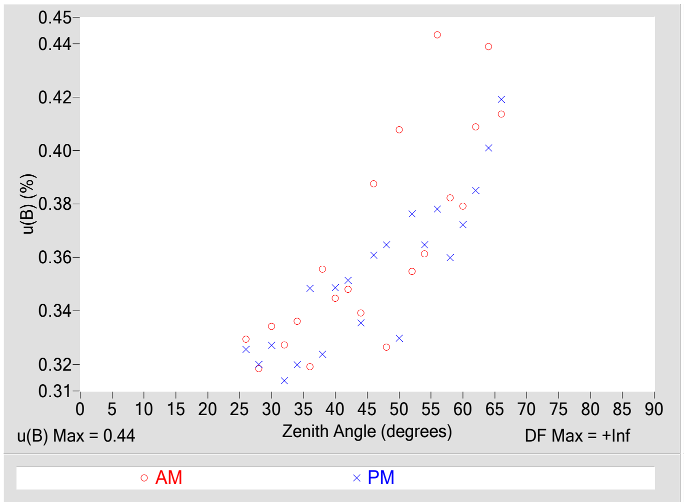


Figure 4. Residuals from Spline Interpolation

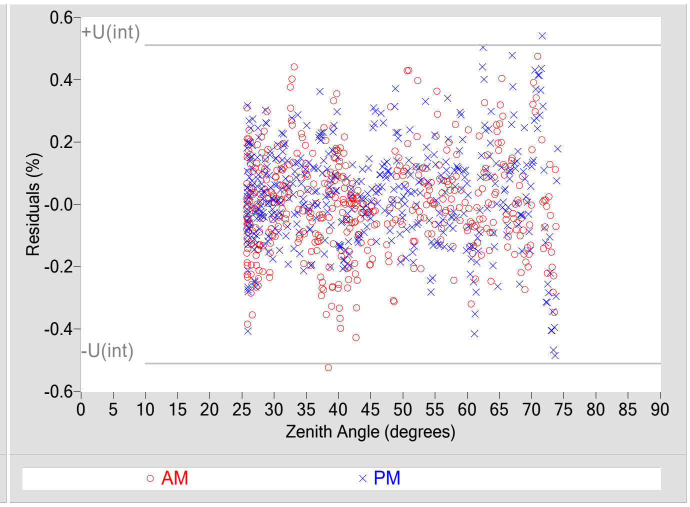


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	13578
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

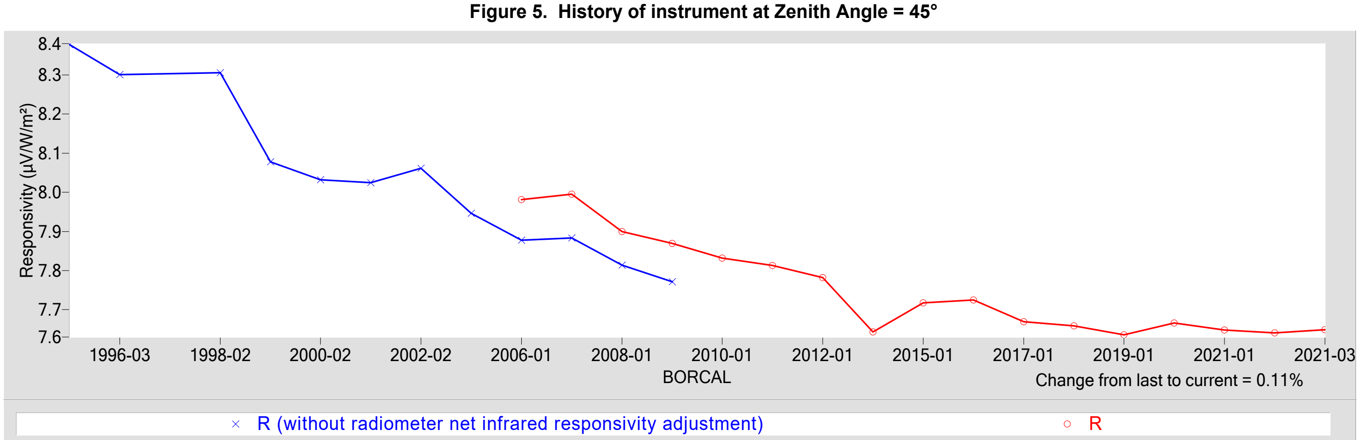
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6488	0.53300

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.1 / -1.6
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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31152F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31152F3 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 radiometer (K).
- I = reference irradiance (W/m²), beam (B) or global (G)
  - where, $G = B * COS(Z) + D$,
  - Z = zenith angle (degrees),
  - D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

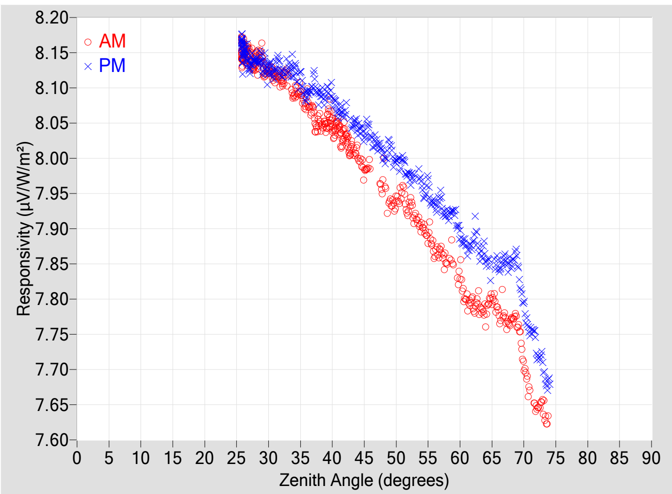


Figure 2. Responsivity vs Local Standard Time

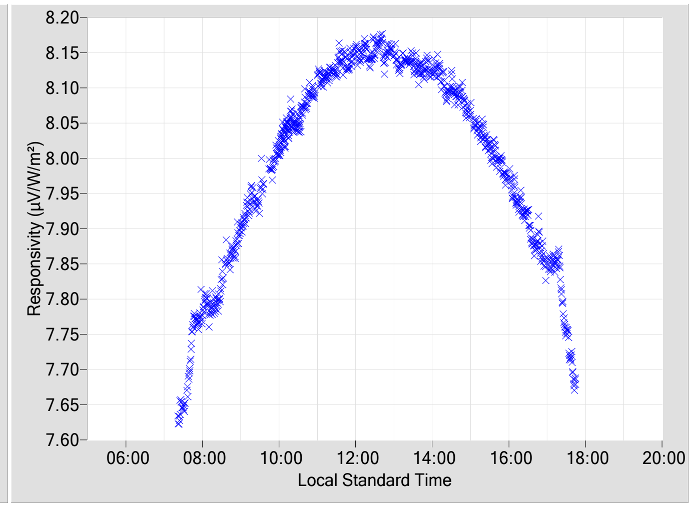


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9916	0.33	113.79	8.0306	0.35	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9669	0.41	111.29	8.0019	0.34	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9370	0.40	109.03	7.9974	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9315	0.34	106.87	7.9739	0.35	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9023	0.37	104.95	7.9599	0.36	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8678	0.45	103.09	7.9356	0.36	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8509	0.40	101.35	7.9197	0.40	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8344	0.42	99.52	7.8909	0.41	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7937	0.39	97.89	7.8805	0.40	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7800	0.45	96.19	7.8603	0.42	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7807	0.42	94.64	7.8482	0.44	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.7688	N/A	93.10	7.8525	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7043	N/A	91.51	7.7864	N/A	268.76
26	8.1508	0.34	173.51	8.1562	0.32	186.40	72	7.6462	N/A	90.04	7.7237	N/A	270.25
28	8.1368	0.32	154.05	8.1380	0.34	205.96	74	7.6343	N/A	88.72	7.6839	N/A	271.65
30	8.1240	0.30	144.99	8.1241	0.33	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1081	0.33	138.28	8.1206	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0907	0.34	133.04	8.1295	0.34	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0801	0.32	128.51	8.0891	0.33	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0522	0.35	125.51	8.0894	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0463	0.31	121.67	8.0888	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0348	0.33	118.64	8.0666	0.32	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0074	0.35	116.24	8.0441	0.36	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

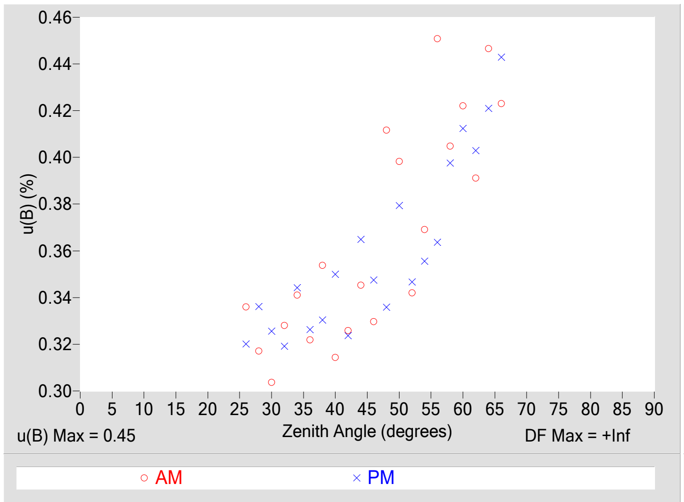


Figure 4. Residuals from Spline Interpolation

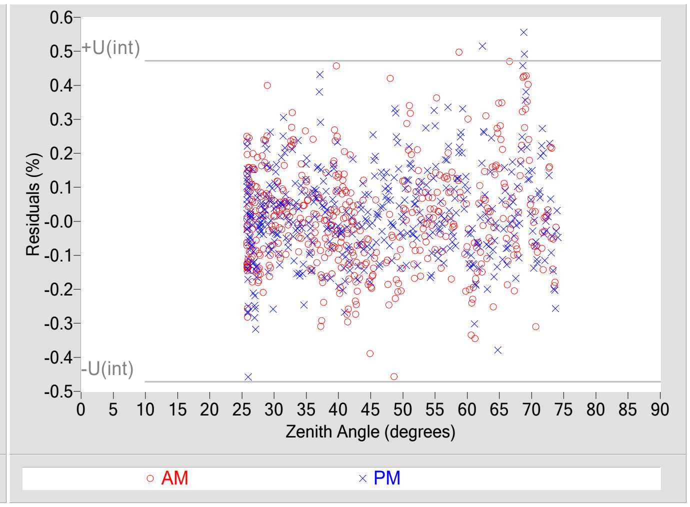


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	17804
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

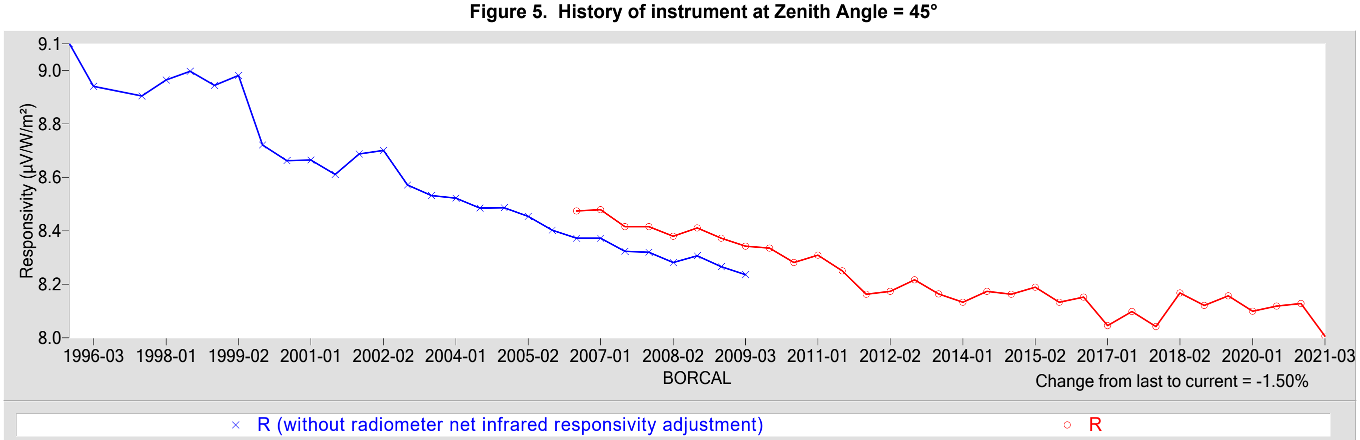
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0063	0.63390

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+1.5 / -2.1
Expanded Uncertainty, U (%)	+2.4 / -3.0
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31153F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

_______________________________ ____________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31153F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

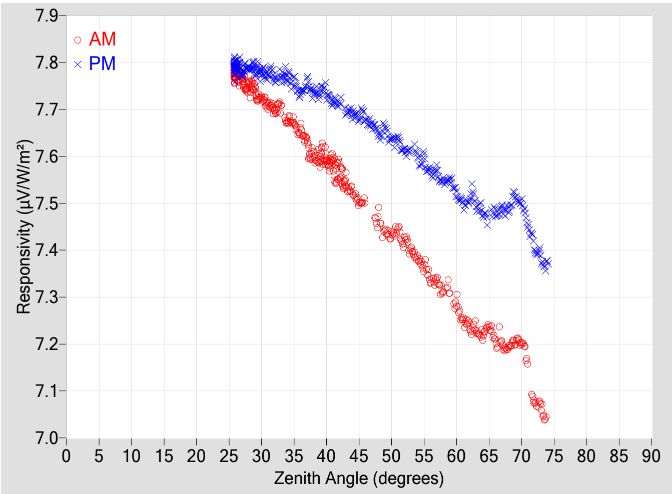


Figure 2. Responsivity vs Local Standard Time

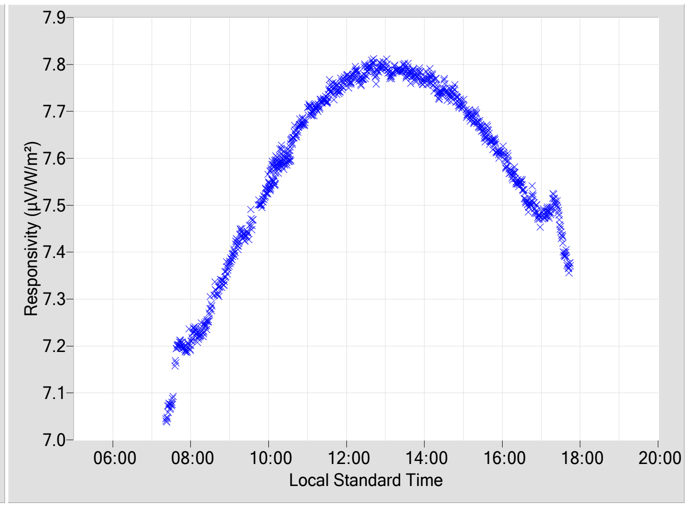


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5061	0.33	113.79	7.6789	0.35	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4648	0.41	111.29	7.6452	0.34	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4314	0.40	109.03	7.6374	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4194	0.34	106.87	7.6110	0.35	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3812	0.37	104.95	7.5979	0.36	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3392	0.45	103.09	7.5684	0.37	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3101	0.41	101.35	7.5461	0.40	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2862	0.43	99.52	7.5188	0.42	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2391	0.39	97.89	7.5075	0.41	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2195	0.45	96.19	7.4811	0.43	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.2064	0.43	94.64	7.4799	0.45	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.1926	N/A	93.10	7.4891	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.2005	N/A	91.51	7.4973	N/A	268.76
26	7.7776	0.34	173.51	7.7930	0.32	186.40	72	7.0767	N/A	90.04	7.4006	N/A	270.25
28	7.7479	0.32	154.05	7.7873	0.34	205.96	74	7.0451	N/A	88.72	7.3747	N/A	271.65
30	7.7233	0.31	144.99	7.7777	0.33	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.6960	0.33	138.28	7.7639	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6750	0.34	133.04	7.7737	0.35	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6546	0.32	128.51	7.7345	0.33	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6025	0.36	125.51	7.7355	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5929	0.32	121.67	7.7368	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5685	0.33	118.64	7.7141	0.33	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5268	0.35	116.24	7.6915	0.37	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

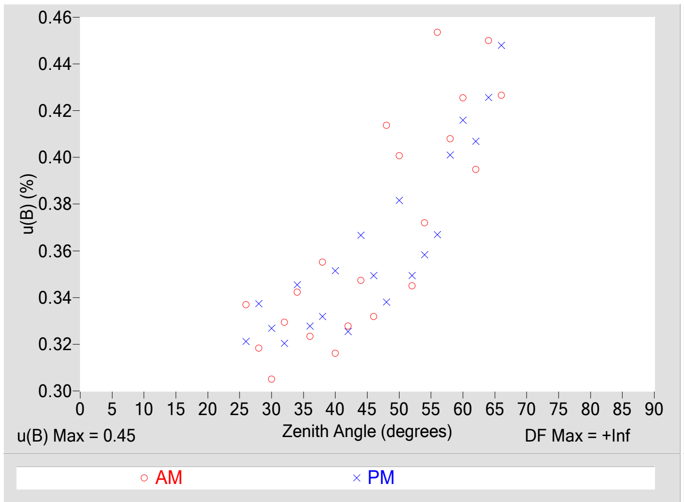


Figure 4. Residuals from Spline Interpolation

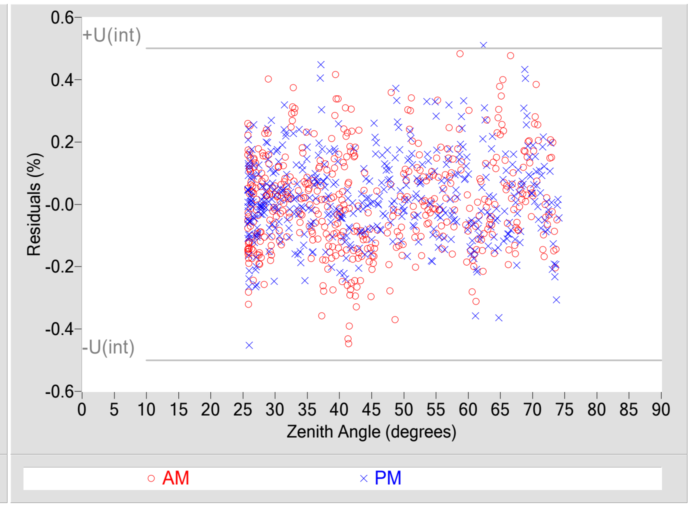


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	15089
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

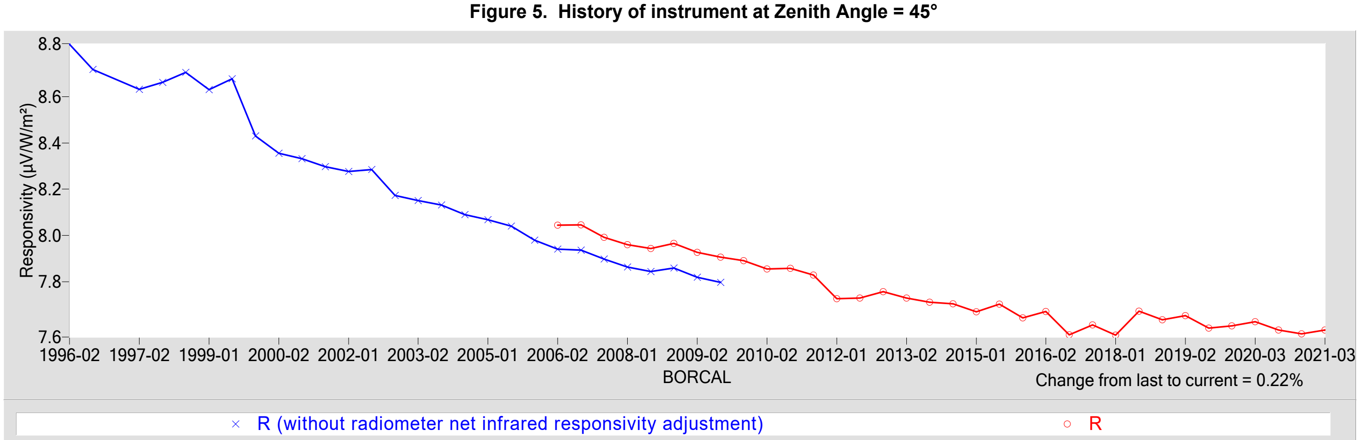
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5905	0.64286

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+2.5 / -4.0
Expanded Uncertainty, U (%)	+3.4 / -4.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31154F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31154F3 Eppley PSP

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

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

where,

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

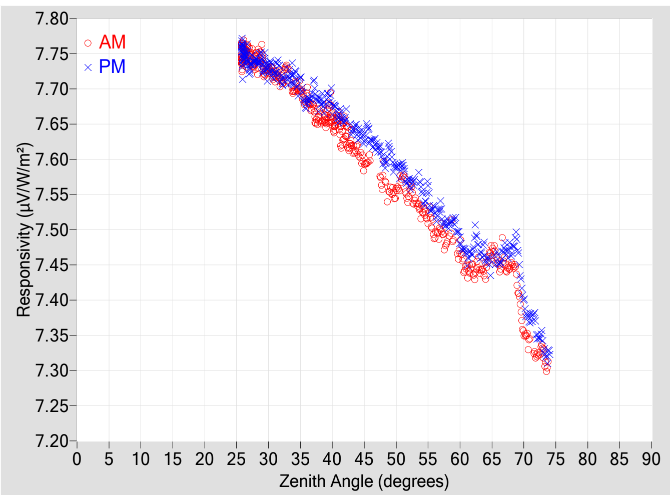


Figure 2. Responsivity vs Local Standard Time

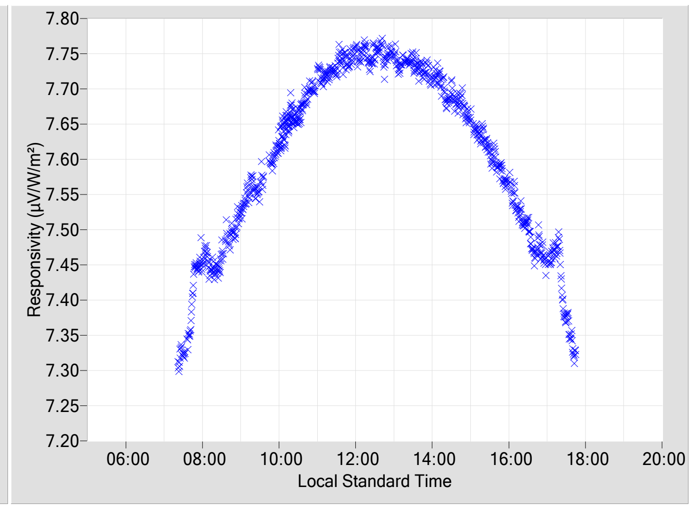


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6021	0.33	113.79	7.6279	0.34	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5727	0.41	111.29	7.5966	0.33	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5528	0.40	109.03	7.5903	0.38	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5542	0.34	106.87	7.5664	0.34	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5258	0.37	104.95	7.5543	0.35	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4961	0.45	103.09	7.5271	0.36	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4802	0.40	101.35	7.5079	0.39	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4689	0.42	99.52	7.4839	0.41	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4438	0.39	97.89	7.4732	0.40	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4435	0.44	96.19	7.4624	0.41	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4521	0.42	94.64	7.4577	0.43	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.4481	N/A	93.10	7.4726	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.3529	N/A	91.51	7.3945	N/A	268.76
26	7.7483	0.33	173.51	7.7518	0.32	186.40	72	7.3223	N/A	90.04	7.3526	N/A	270.25
28	7.7399	0.32	154.05	7.7390	0.33	205.96	74	7.3129	N/A	88.72	7.3266	N/A	271.65
30	7.7264	0.30	144.99	7.7279	0.32	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.7100	0.33	138.28	7.7132	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6984	0.34	133.04	7.7203	0.34	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6883	0.32	128.51	7.6799	0.32	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6624	0.35	125.51	7.6806	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6550	0.31	121.67	7.6812	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6418	0.32	118.64	7.6597	0.32	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6128	0.34	116.24	7.6390	0.36	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

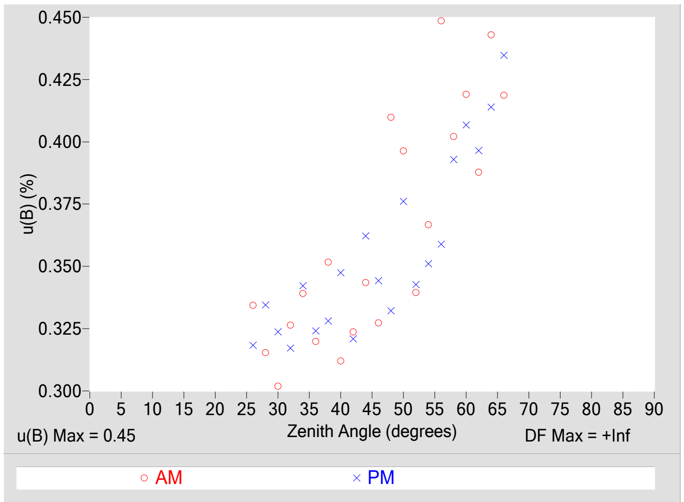


Figure 4. Residuals from Spline Interpolation

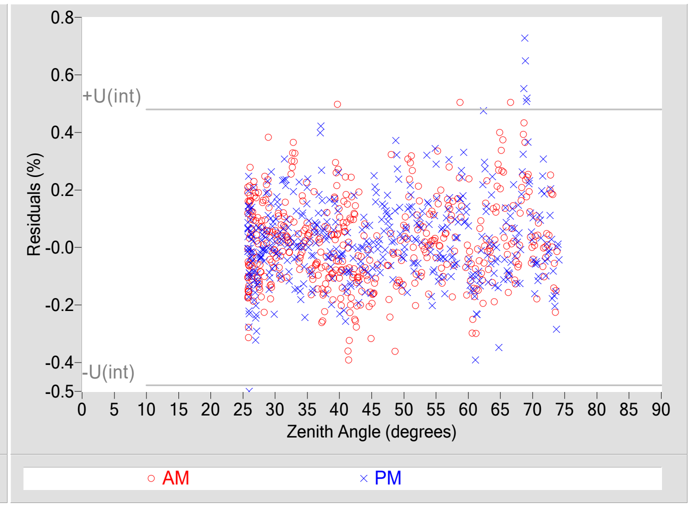


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	16717
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

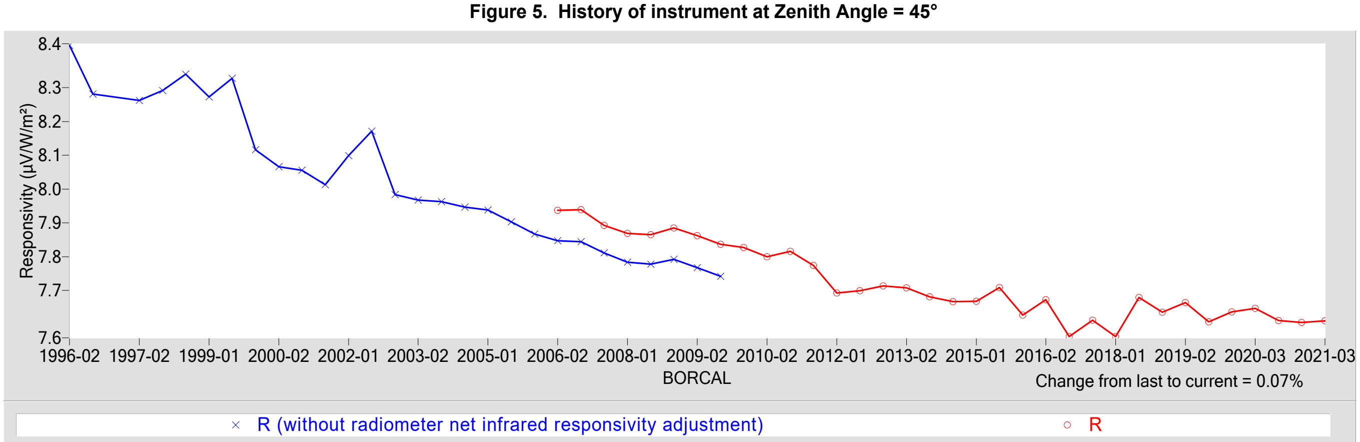
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6103	0.56158

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+1.5 / -1.9
Expanded Uncertainty, U (%)	+2.4 / -2.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer

Manufacturer: Eppley

Model: PSP

Serial Number: 31158F3

Calibration Date: 8/25/2021

Due Date: 8/25/2022

Customer: Calibration System

Environmental Conditions: see page 4

Test Dates: 8/24-25

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

† Through the World Radiometric Reference (WRR)

‡ Through the World Infrared Standard Group (WISG)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31158F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

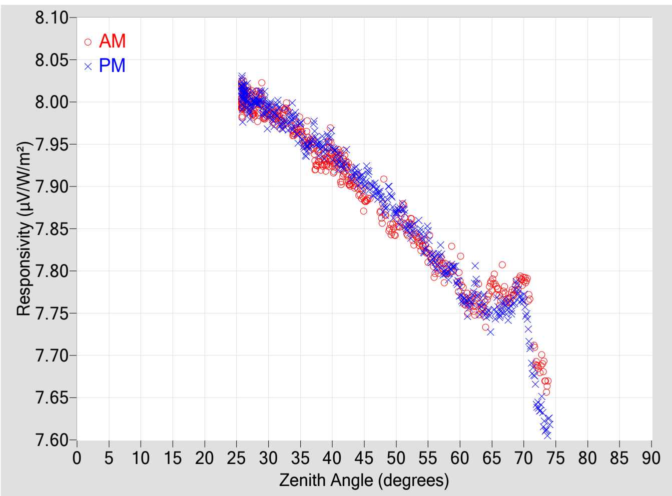


Figure 2. Responsivity vs Local Standard Time

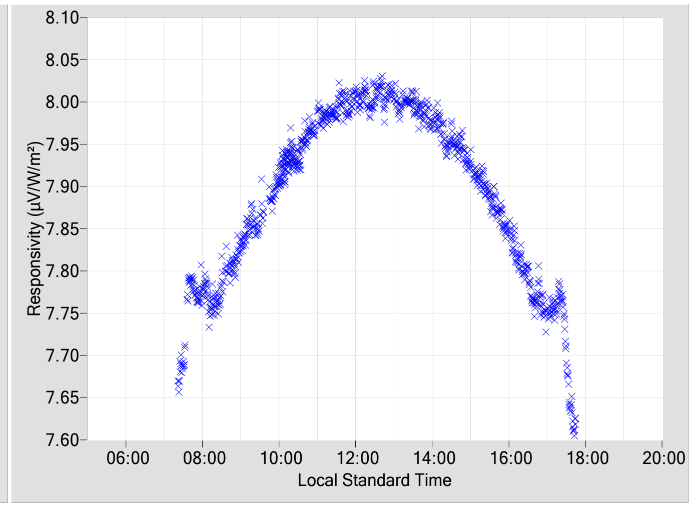


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8927	0.33	113.79	7.9019	0.34	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8748	0.41	111.29	7.8752	0.33	249.26
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8517	0.39	109.03	7.8701	0.37	251.44
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8526	0.34	106.87	7.8496	0.34	253.51
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8302	0.36	104.95	7.8380	0.35	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8044	0.45	103.09	7.8127	0.35	257.28
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7970	0.40	101.35	7.7979	0.39	259.15
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7923	0.42	99.52	7.7747	0.40	260.83
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7634	0.38	97.89	7.7715	0.39	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7520	0.44	96.19	7.7556	0.41	264.09
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7739	0.42	94.64	7.7536	0.43	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.7693	N/A	93.10	7.7574	N/A	267.22
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7882	N/A	91.51	7.7610	N/A	268.76
26	8.0040	0.33	173.51	8.0111	0.32	186.40	72	7.6920	N/A	90.04	7.6459	N/A	270.25
28	7.9961	0.31	154.05	8.0003	0.33	205.96	74	7.6695	N/A	88.72	7.6230	N/A	271.65
30	7.9867	0.30	144.99	7.9876	0.32	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.9762	0.32	138.28	7.9733	0.32	221.68	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9646	0.34	133.04	7.9817	0.34	226.84	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9586	0.32	128.51	7.9428	0.32	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9342	0.35	125.51	7.9470	0.33	235.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9320	0.31	121.67	7.9483	0.35	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9262	0.32	118.64	7.9296	0.32	241.62	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9029	0.34	116.24	7.9119	0.36	244.32	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

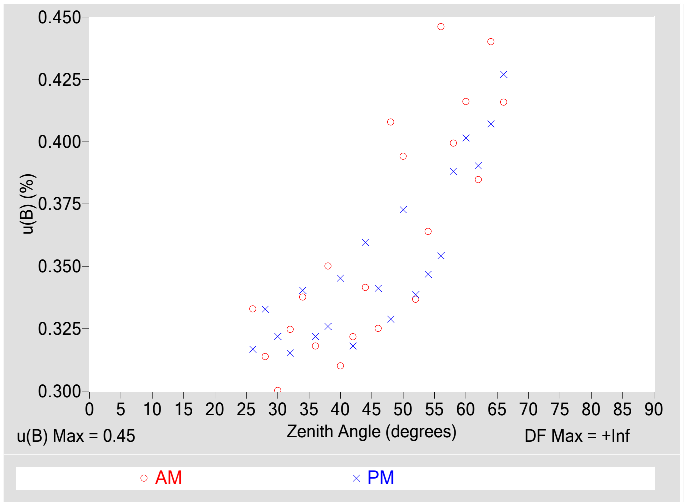


Figure 4. Residuals from Spline Interpolation

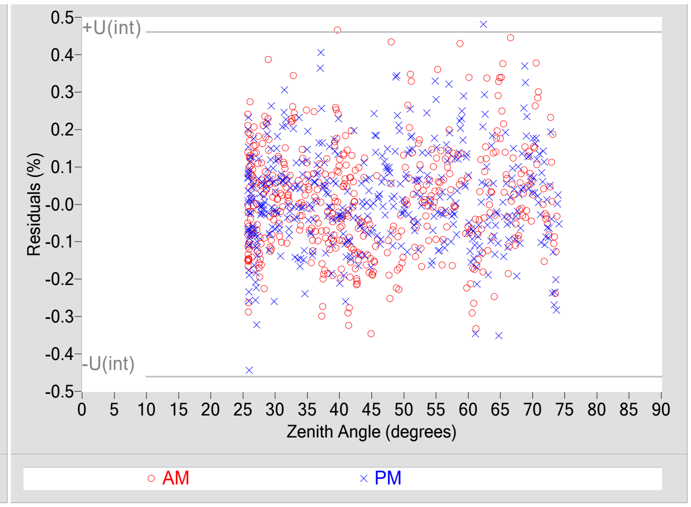


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	18596
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

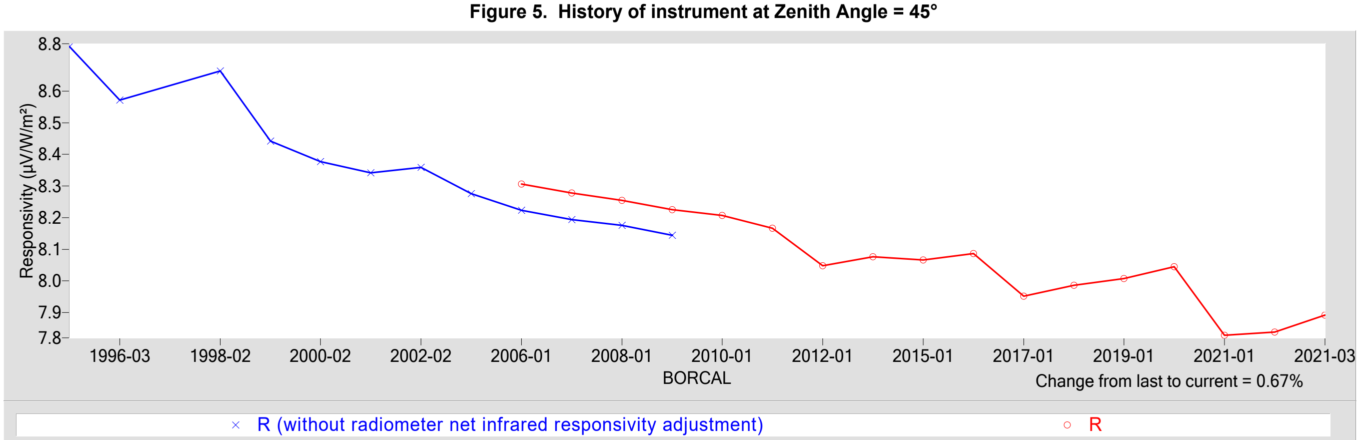
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8915	0.52400

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31159F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ____________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31159F3 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 - σ * Tc^4*
  where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
  Tc = case temperature of radiometer (K).
- *I* = reference irradiance (W/m²), beam (B) or global (G)
  where, *G = B * COS(Z) + D,*
  Z = zenith angle (degrees),
  D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

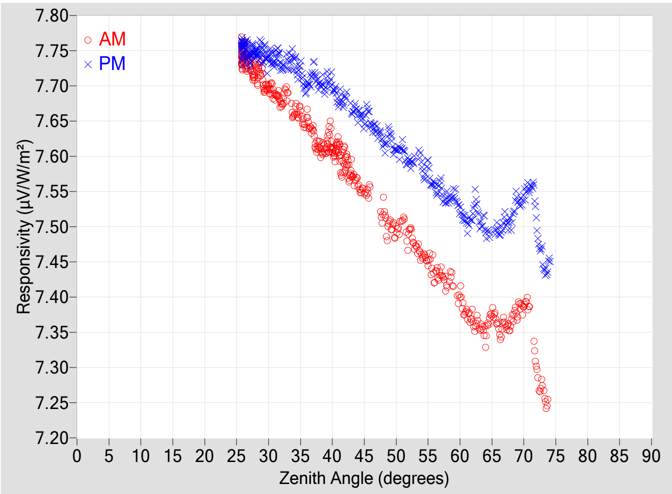


Figure 2. Responsivity vs Local Standard Time

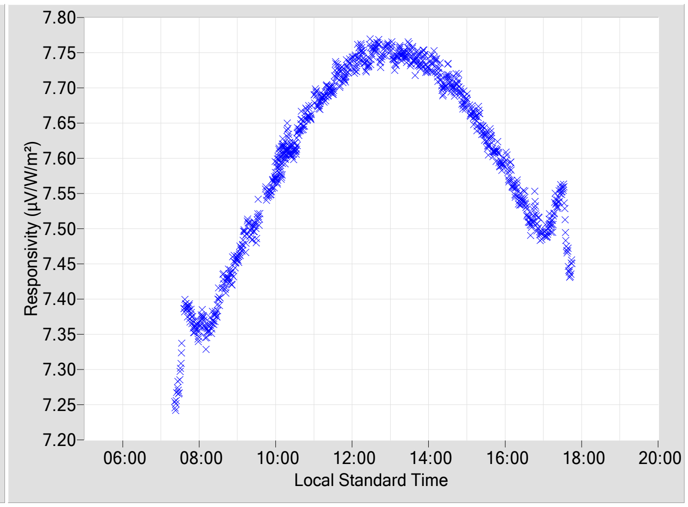


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5579	0.37	113.81	7.6461	0.34	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5204	0.35	111.20	7.6157	0.37	249.27
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4915	0.39	109.04	7.6090	0.35	251.45
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4894	0.34	106.88	7.5915	0.34	253.52
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4577	0.36	104.96	7.5860	0.39	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4349	0.39	103.05	7.5582	0.35	257.29
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4131	0.44	101.36	7.5385	0.36	259.05
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4019	0.42	99.53	7.5229	0.38	260.85
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3652	0.41	97.79	7.5187	0.39	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.3475	0.48	96.20	7.4959	0.44	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3579	0.45	94.65	7.4938	0.43	265.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.3636	N/A	93.06	7.5087	N/A	267.23
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.3859	N/A	91.52	7.5437	N/A	268.72
26	7.7440	0.33	173.32	7.7534	0.33	186.25	72	7.2982	N/A	90.05	7.5048	N/A	270.21
28	7.7168	0.34	154.08	7.7461	0.33	205.99	74	7.2546	N/A	88.73	7.4482	N/A	271.62
30	7.6957	0.33	144.94	7.7374	0.33	215.03	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.6745	0.31	138.30	7.7296	0.32	221.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.6599	0.33	132.96	7.7391	0.35	226.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6534	0.30	128.43	7.6982	0.34	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6118	0.34	125.36	7.7007	0.33	235.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6116	0.35	121.70	7.7018	0.35	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5956	0.33	118.65	7.6832	0.32	241.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5618	0.38	116.18	7.6604	0.34	244.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

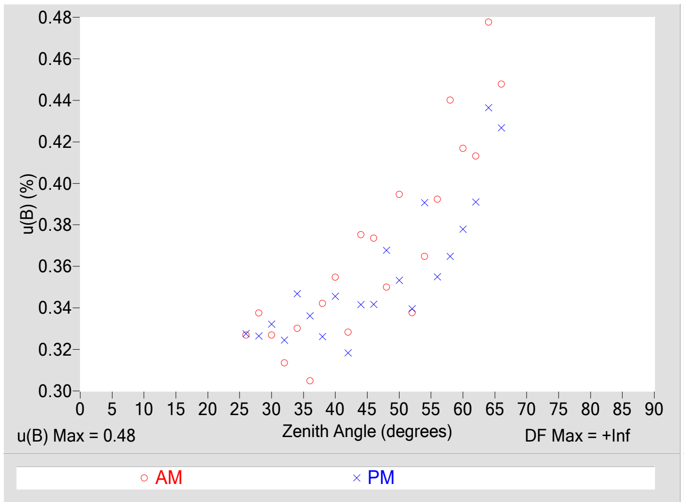


Figure 4. Residuals from Spline Interpolation

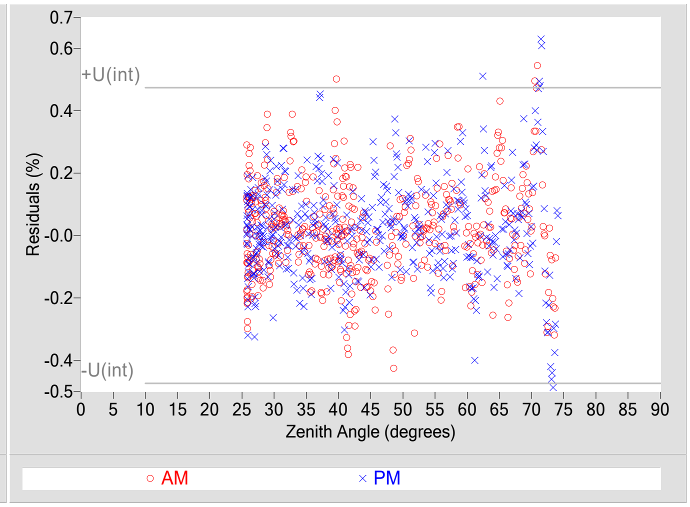


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.48
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	21598
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

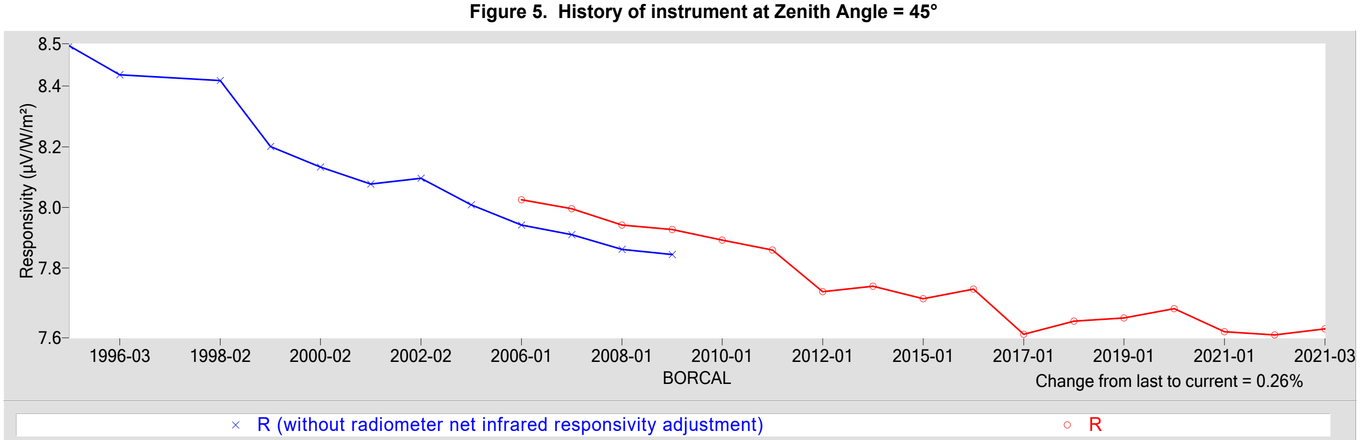
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5992	0.53200

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.86
Offset Uncertainty, U(off) (%)	+1.8 / -2.6
Expanded Uncertainty, U (%)	+2.7 / -3.5
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

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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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31160F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31160F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

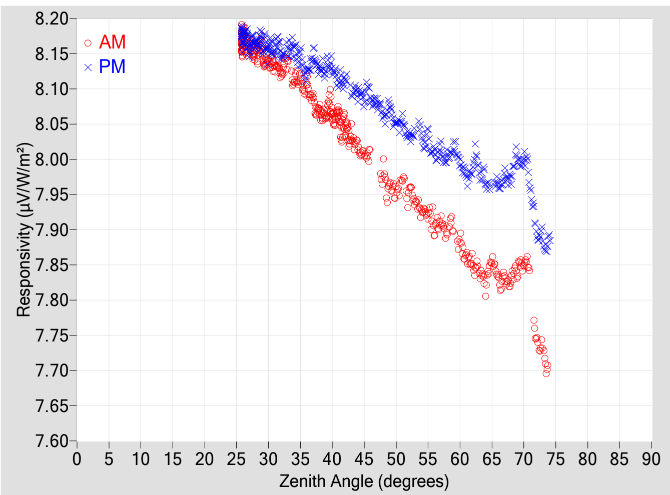


Figure 2. Responsivity vs Local Standard Time

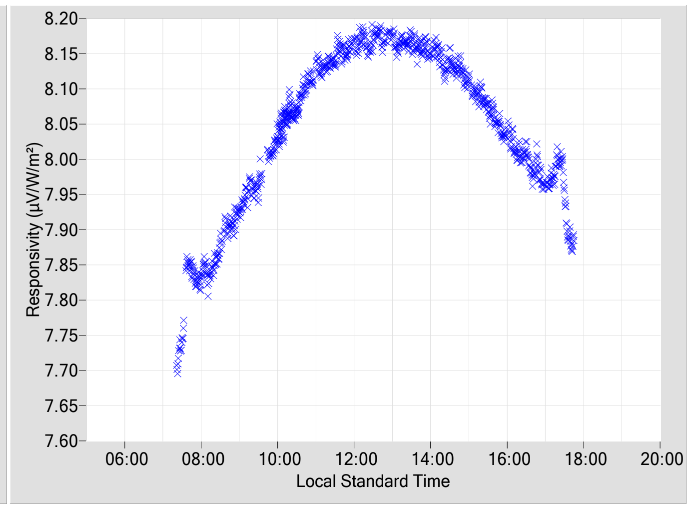


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.0138	0.37	113.81	8.0857	0.34	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9790	0.35	111.20	8.0599	0.36	249.27
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9522	0.39	109.04	8.0515	0.35	251.45
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9527	0.33	106.88	8.0332	0.33	253.52
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9247	0.36	104.96	8.0319	0.39	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9067	0.39	103.05	8.0096	0.35	257.29
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8919	0.44	101.36	8.0026	0.36	259.05
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8834	0.41	99.53	7.9945	0.37	260.85
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8489	0.41	97.79	7.9885	0.38	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8242	0.47	96.20	7.9675	0.43	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8323	0.44	94.65	7.9636	0.42	265.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.8298	N/A	93.06	7.9771	N/A	267.23
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8497	N/A	91.52	7.9994	N/A	268.72
26	8.1673	0.33	173.32	8.1749	0.33	186.25	72	7.7443	N/A	90.05	7.8953	N/A	270.21
28	8.1505	0.34	154.08	8.1640	0.32	205.99	74	7.7074	N/A	88.73	7.8860	N/A	271.62
30	8.1370	0.32	144.94	8.1555	0.33	215.03	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1221	0.31	138.30	8.1508	0.32	221.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1105	0.33	132.96	8.1603	0.34	226.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1042	0.30	128.43	8.1226	0.33	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0684	0.34	125.36	8.1274	0.32	235.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0640	0.35	121.70	8.1305	0.34	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0483	0.33	118.65	8.1134	0.32	241.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0185	0.37	116.18	8.0939	0.34	244.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

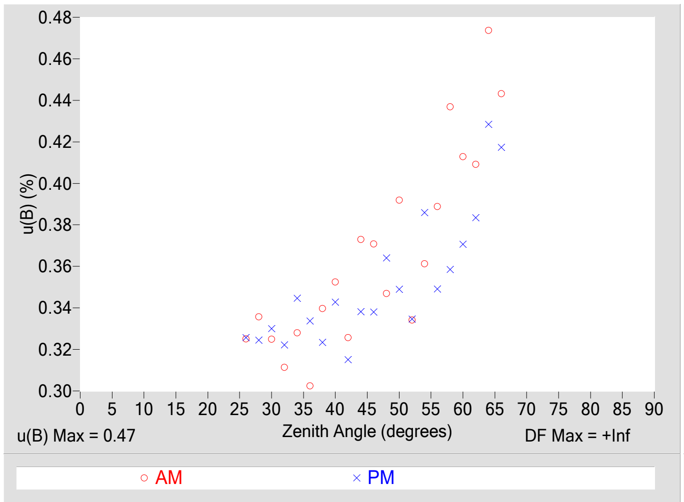


Figure 4. Residuals from Spline Interpolation

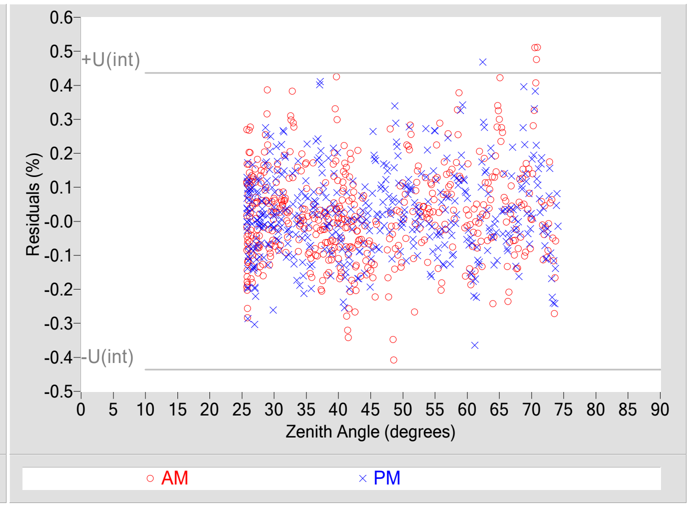


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.47
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	27492
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

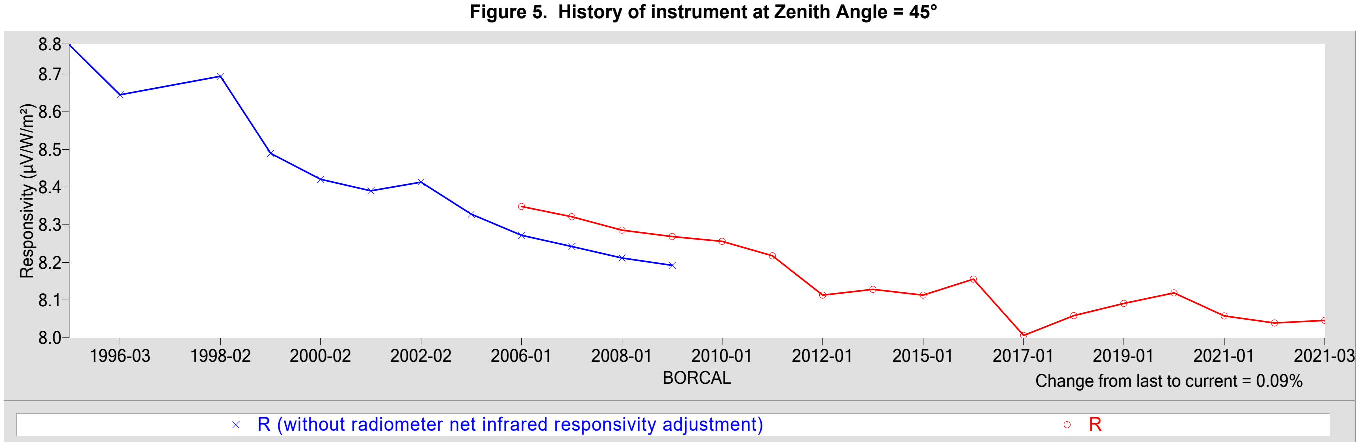
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0459	0.49000

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.86
Offset Uncertainty, U(off) (%)	+1.4 / -2.0
Expanded Uncertainty, U (%)	+2.3 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31277F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31277F3 Eppley PSP

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

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

where,

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

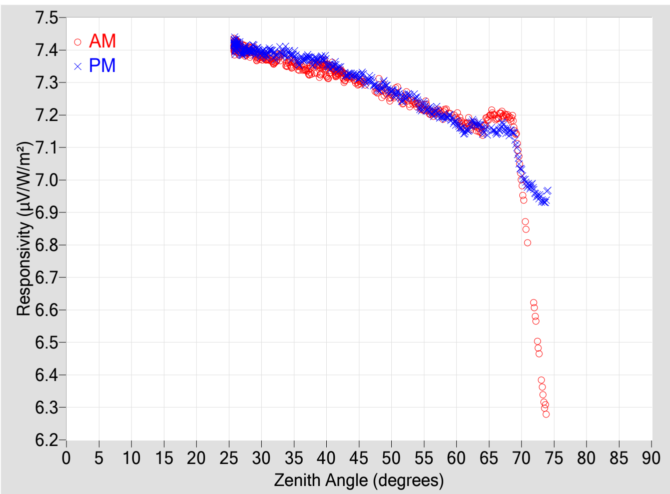


Figure 2. Responsivity vs Local Standard Time

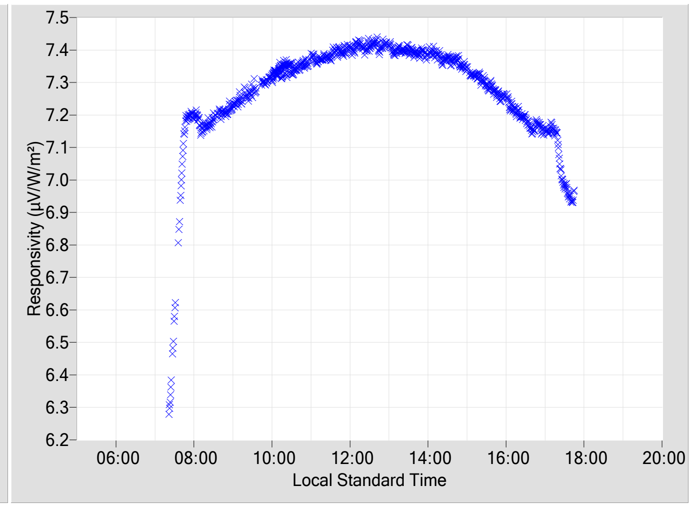


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.3016	0.39	113.83	7.3014	0.36	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2831	0.33	111.26	7.2810	0.37	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2545	0.41	109.06	7.2752	0.33	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2459	0.35	106.96	7.2537	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2317	0.36	104.91	7.2429	0.37	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2064	0.44	103.06	7.2151	0.38	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2045	0.38	101.22	7.1943	0.36	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1925	0.38	99.44	7.1758	0.37	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1704	0.41	97.86	7.1594	0.39	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.1552	0.44	96.16	7.1530	0.40	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.1918	0.41	94.61	7.1471	0.42	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.1937	N/A	93.08	7.1497	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.0009	N/A	91.57	7.0231	N/A	268.73
26	7.4118	0.33	173.64	7.4151	0.33	186.54	72	6.5937	N/A	90.01	6.9620	N/A	270.23
28	7.3964	0.32	153.68	7.3976	0.32	206.03	74	6.2788	N/A	88.70	6.9570	N/A	271.63
30	7.3772	0.33	144.83	7.3904	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.3605	0.33	138.29	7.3834	0.31	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.3581	0.34	132.98	7.3888	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3505	0.32	128.70	7.3676	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3480	0.36	125.37	7.3643	0.32	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3423	0.34	121.72	7.3621	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3335	0.35	118.60	7.3430	0.35	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3139	0.34	116.27	7.3227	0.34	244.35	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

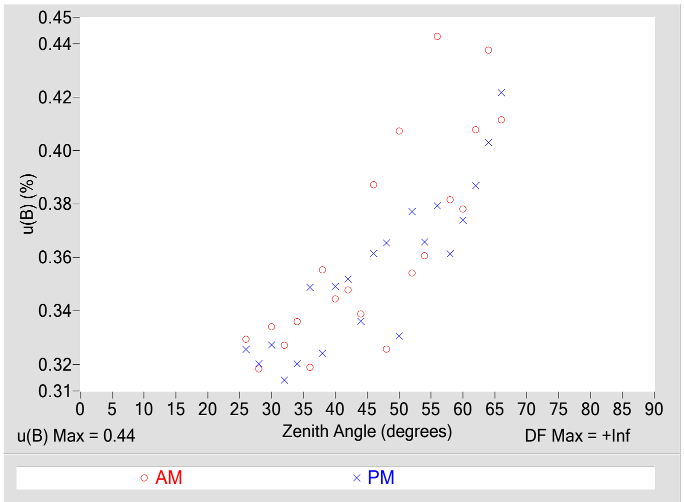


Figure 4. Residuals from Spline Interpolation

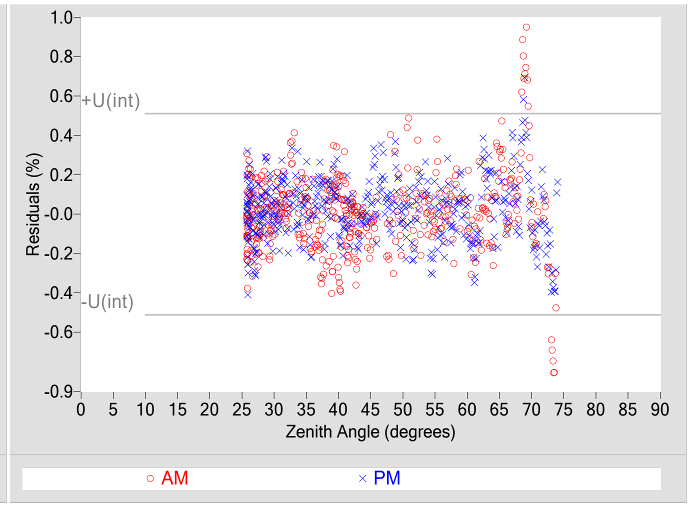


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	13384
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

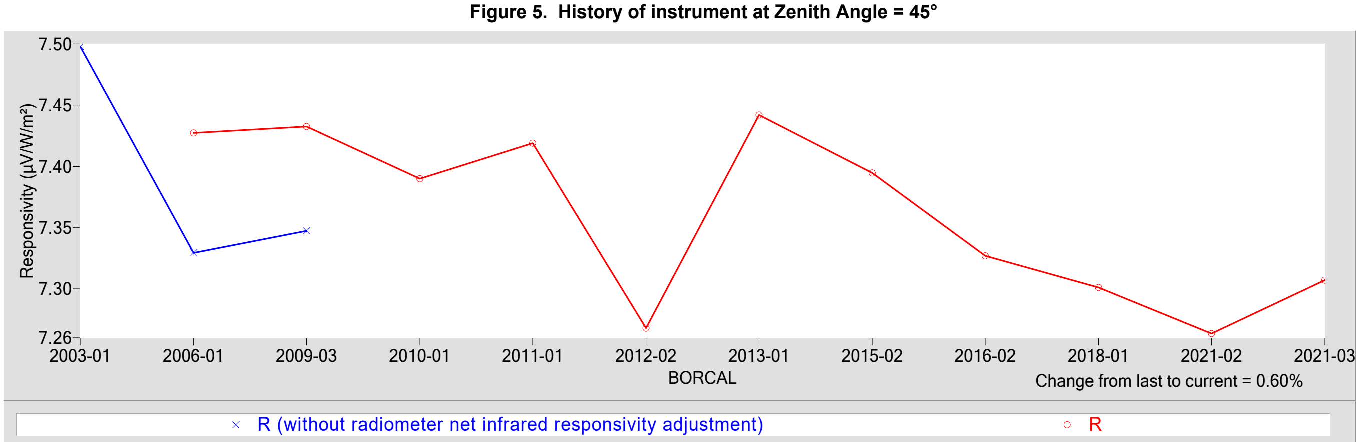
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.3071	0.50400

† Rnet determination date: 04/03/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.1 / -1.8
Expanded Uncertainty, U (%)	+2.0 / -2.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31283F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31283F3 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

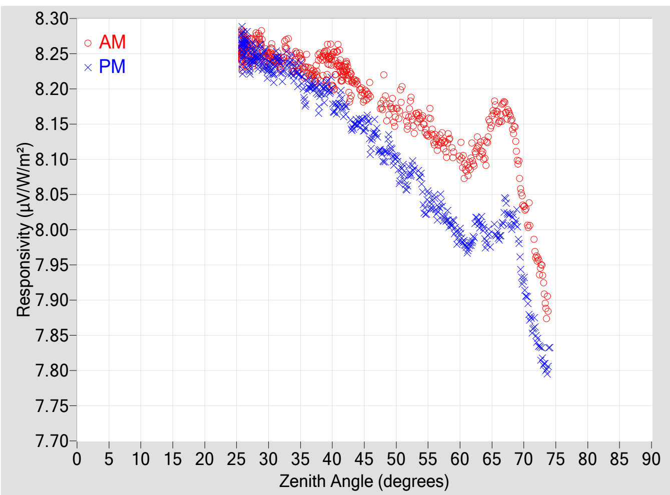


Figure 2. Responsivity vs Local Standard Time

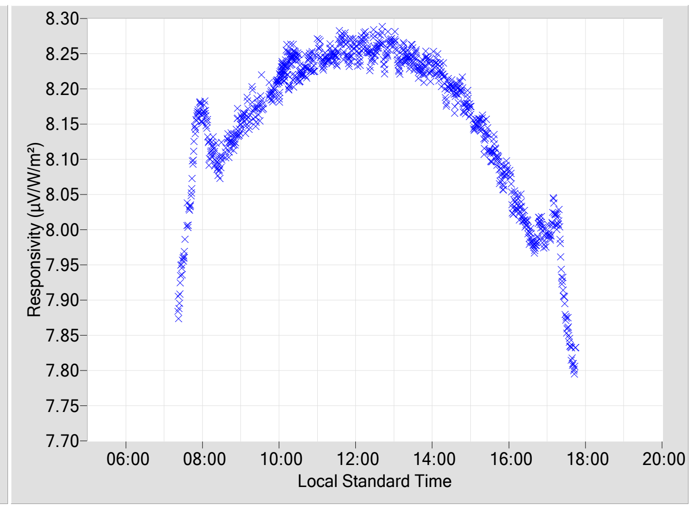


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1969	0.39	113.83	8.1216	0.36	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1875	0.33	111.26	8.1018	0.37	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1630	0.41	109.06	8.1022	0.33	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1609	0.36	106.96	8.0774	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1548	0.36	104.91	8.0617	0.37	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1277	0.44	103.06	8.0379	0.38	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1202	0.38	101.22	8.0141	0.36	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1074	0.38	99.44	7.9927	0.38	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1013	0.41	97.86	7.9846	0.39	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1137	0.44	96.16	7.9855	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1582	0.41	94.61	7.9907	0.43	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.1560	N/A	93.08	8.0136	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.0355	N/A	91.57	7.9203	N/A	268.73
26	8.2577	0.33	173.64	8.2588	0.33	186.54	72	7.9615	N/A	90.06	7.8461	N/A	270.23
28	8.2598	0.32	153.68	8.2450	0.32	206.03	74	7.8839	N/A	88.70	7.8236	N/A	271.63
30	8.2468	0.33	144.83	8.2283	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.2339	0.33	138.29	8.2278	0.32	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.2345	0.34	132.98	8.2249	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2320	0.32	128.70	8.1966	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2352	0.36	125.37	8.1872	0.33	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2331	0.35	121.72	8.1862	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2292	0.35	118.60	8.1704	0.35	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2069	0.34	116.27	8.1527	0.34	244.35	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

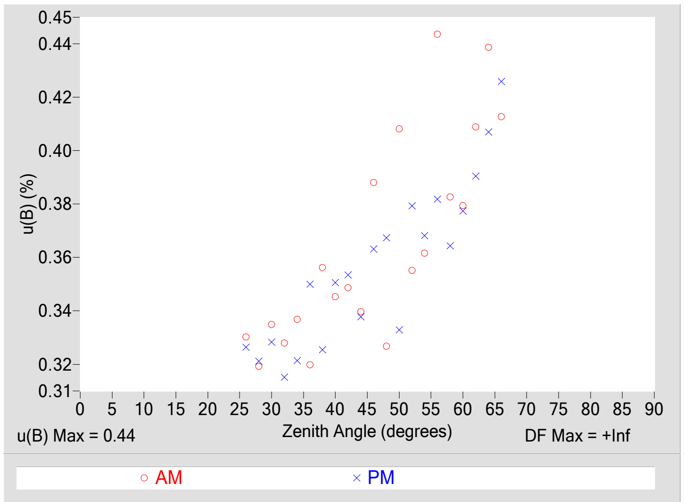


Figure 4. Residuals from Spline Interpolation

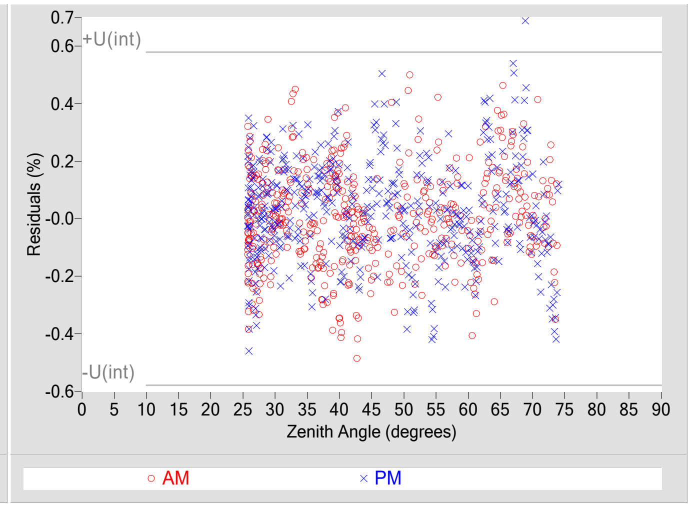


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	9390
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

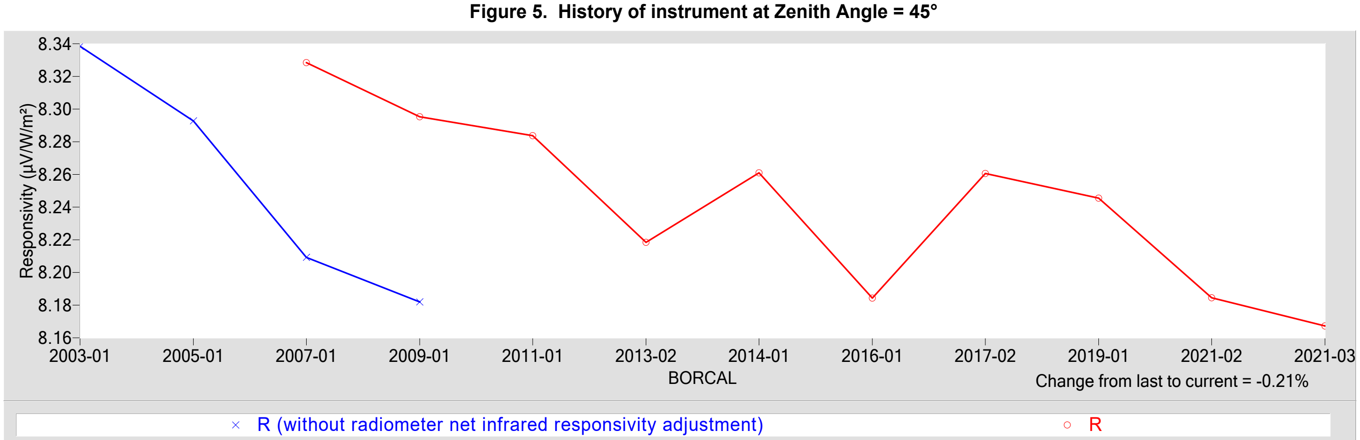
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1673	0.60171

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+0.97 / -2.1
Expanded Uncertainty, U (%)	+1.8 / -3.0
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31284F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31284F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

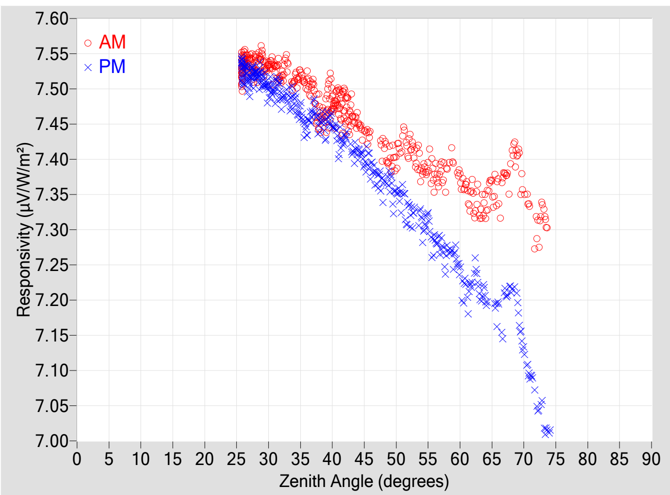


Figure 2. Responsivity vs Local Standard Time

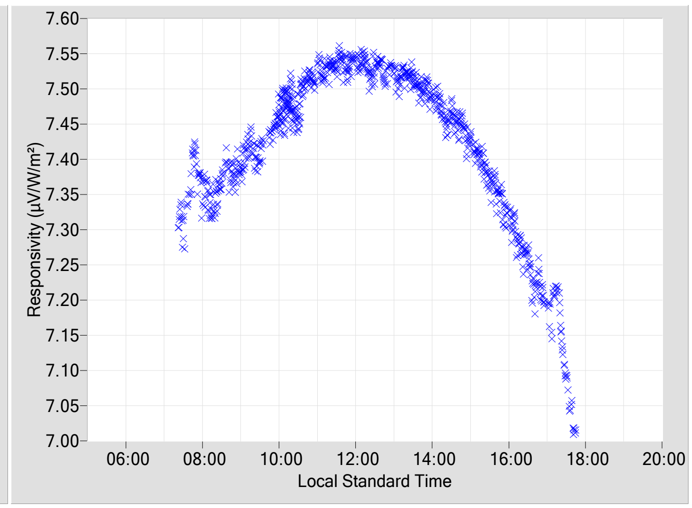


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4354	0.37	113.81	7.3903	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4170	0.33	111.20	7.3616	0.38	249.21
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3999	0.40	109.04	7.3529	0.36	251.45
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4166	0.34	106.88	7.3265	0.34	253.52
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3804	0.37	104.96	7.3086	0.40	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3762	0.39	103.05	7.2818	0.36	257.29
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3754	0.44	101.36	7.2621	0.37	258.99
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3729	0.42	99.53	7.2334	0.38	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3437	0.41	97.79	7.2272	0.40	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.3374	0.48	96.20	7.2021	0.44	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3528	0.46	94.69	7.1848	0.44	265.60
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.4032	N/A	93.01	7.2164	N/A	267.18
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.3532	N/A	91.57	7.1284	N/A	268.67
26	7.5301	0.33	173.32	7.5286	0.33	186.25	72	7.3064	N/A	90.00	7.0458	N/A	270.31
28	7.5300	0.34	154.08	7.5203	0.33	205.99	74	N/A	N/A	N/A	7.0134	N/A	271.71
30	7.5318	0.33	144.94	7.4962	0.33	215.03	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.5166	0.31	138.30	7.4894	0.33	221.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.5112	0.33	132.96	7.4899	0.35	226.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5107	0.31	128.43	7.4449	0.34	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.4597	0.34	125.36	7.4472	0.33	235.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4820	0.36	121.70	7.4516	0.35	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4775	0.33	118.65	7.4318	0.32	241.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4521	0.38	116.18	7.4095	0.34	244.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

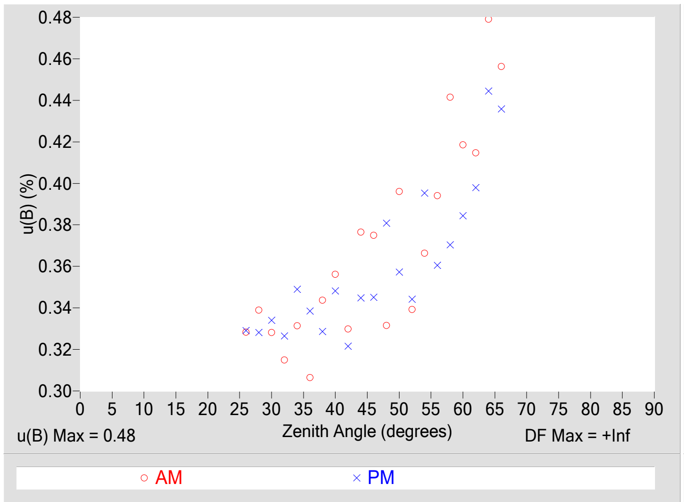


Figure 4. Residuals from Spline Interpolation

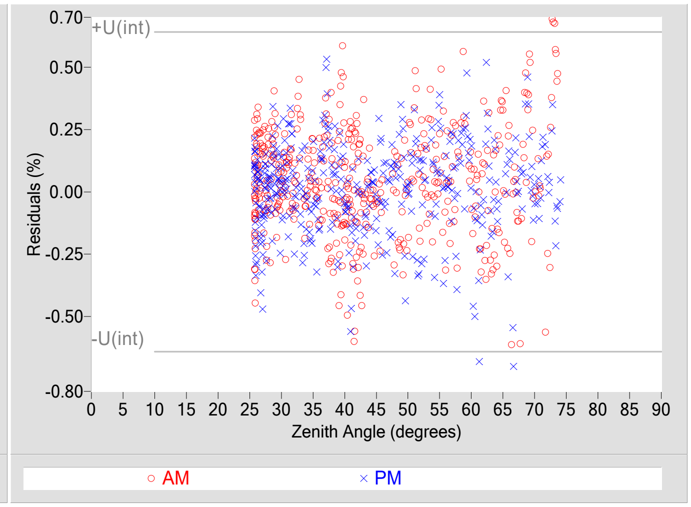


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.48
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	8613
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

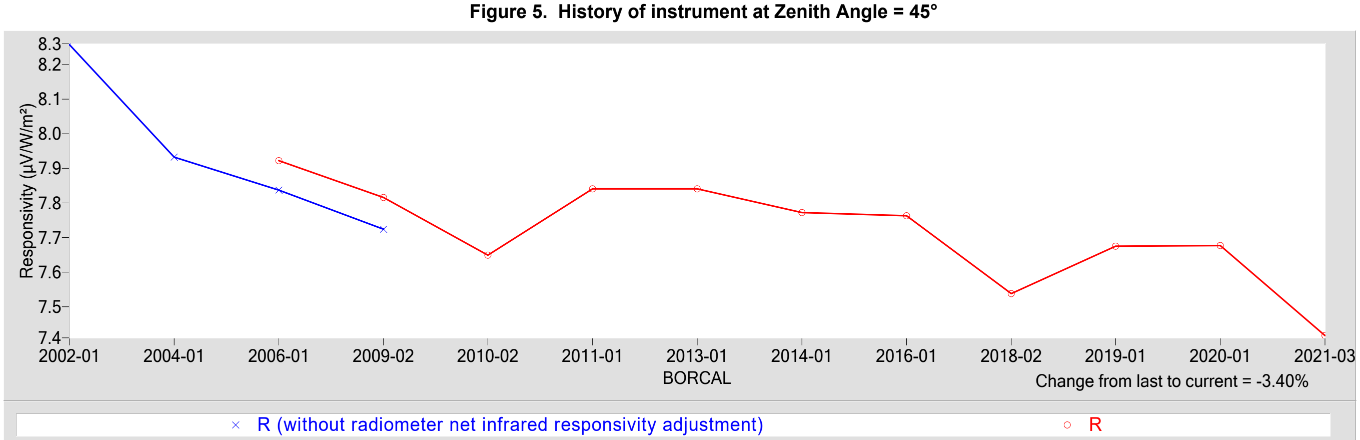
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.4162	0.54600

† Rnet determination date: 03/31/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.6 / -2.5
Expanded Uncertainty, U (%)	+2.4 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31289F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager Date

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

Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31289F3 Eppley PSP

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

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

where,

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

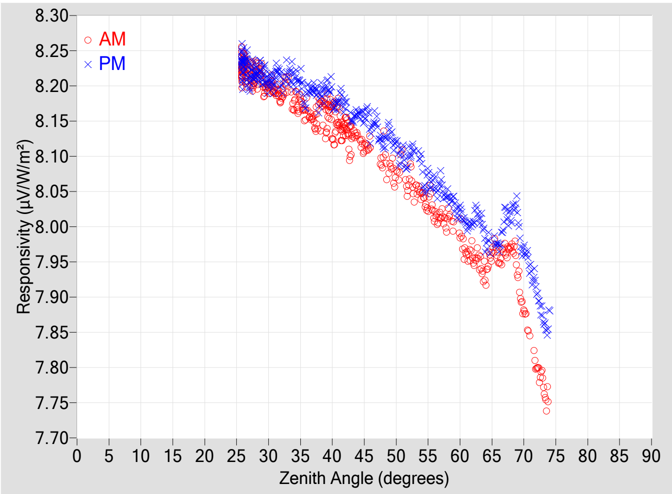


Figure 2. Responsivity vs Local Standard Time

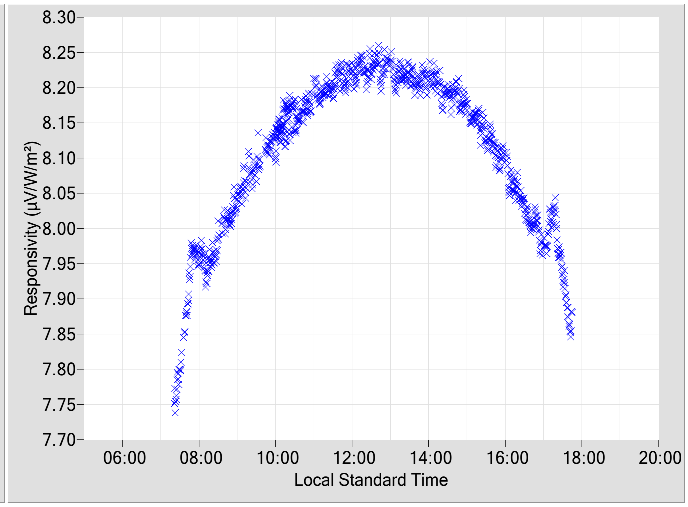


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1171	0.39	113.83	8.1343	0.37	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1016	0.33	111.26	8.1172	0.37	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0709	0.41	109.06	8.1195	0.34	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0621	0.36	106.96	8.1001	0.38	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0449	0.36	104.91	8.0848	0.37	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0159	0.45	103.06	8.0628	0.39	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0085	0.39	101.22	8.0422	0.37	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9930	0.38	99.44	8.0227	0.38	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9590	0.41	97.86	8.0039	0.40	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9342	0.44	96.16	7.9780	0.41	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9537	0.42	94.61	7.9733	0.43	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.9699	N/A	93.08	8.0175	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8815	N/A	91.57	7.9648	N/A	268.73
26	8.2278	0.33	173.64	8.2307	0.33	186.54	72	7.8013	N/A	90.06	7.9084	N/A	270.23
28	8.2163	0.32	153.68	8.2174	0.32	206.03	74	7.7514	N/A	88.70	7.8723	N/A	271.63
30	8.1983	0.34	144.83	8.2053	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1806	0.33	138.29	8.2059	0.32	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1750	0.34	132.98	8.2090	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1663	0.32	128.70	8.1868	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1646	0.36	125.37	8.1830	0.33	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1552	0.35	121.72	8.1845	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1436	0.35	118.60	8.1734	0.36	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1291	0.34	116.27	8.1612	0.34	244.35	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

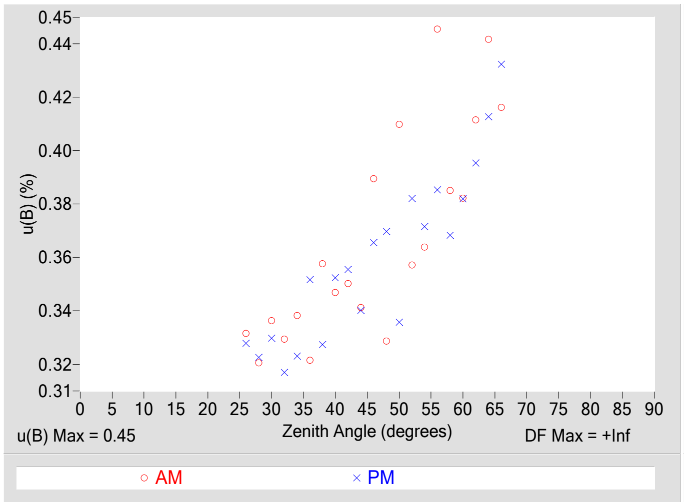


Figure 4. Residuals from Spline Interpolation

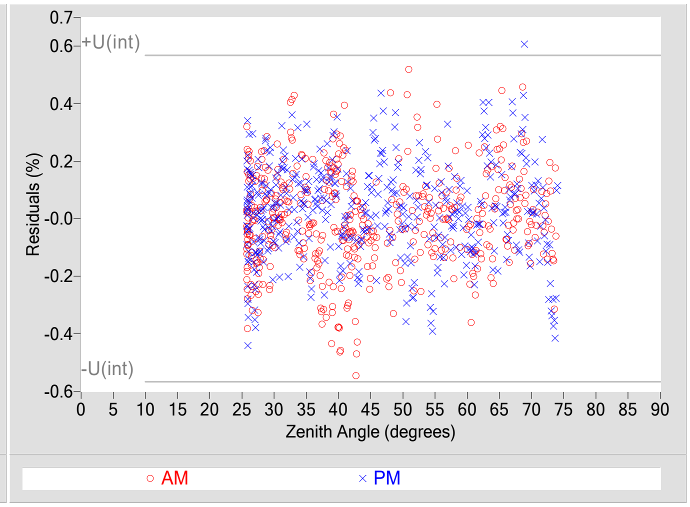


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	10047
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

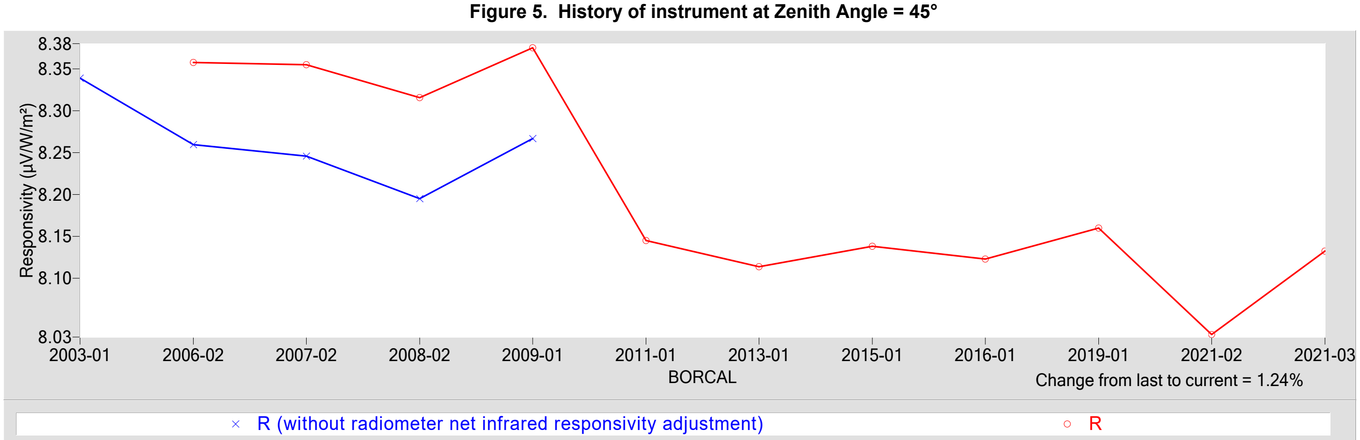
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1326	0.65232

† Rnet determination date: 05/08/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+0.94 / -1.7
Expanded Uncertainty, U (%)	+1.8 / -2.6
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31291F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30696F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ____________________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31291F3 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

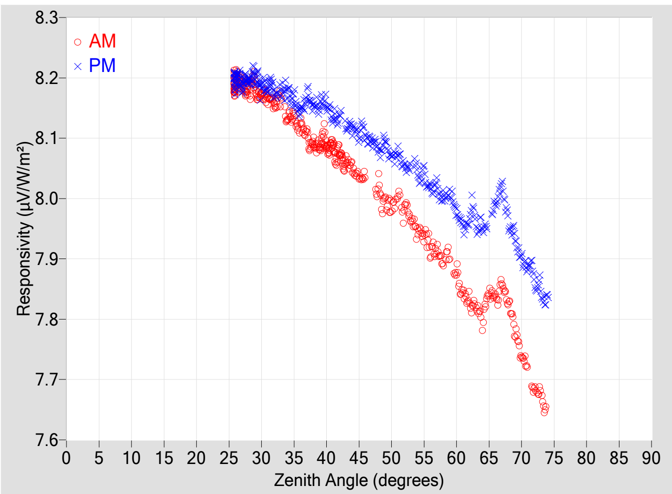


Figure 2. Responsivity vs Local Standard Time

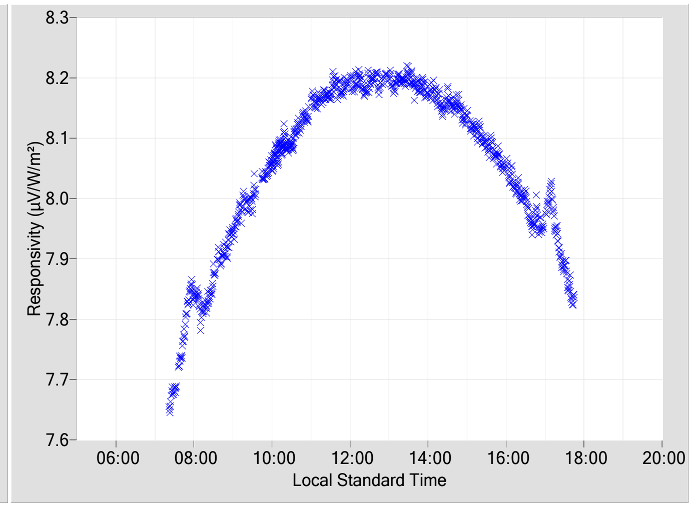


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0396	0.38	113.81	8.1028	0.35	246.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0182	0.35	111.20	8.0789	0.37	249.27
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9849	0.40	109.04	8.0714	0.36	251.45
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9824	0.34	106.88	8.0538	0.35	253.52
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9446	0.37	104.96	8.0411	0.40	255.47
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9178	0.40	103.05	8.0184	0.36	257.29
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8908	0.44	101.36	8.0013	0.37	259.05
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8787	0.42	99.53	7.9765	0.39	260.85
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8265	0.42	97.79	7.9669	0.40	262.48
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7990	0.48	96.17	7.9531	0.45	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8367	0.45	94.65	7.9923	0.44	265.70
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.8273	N/A	93.06	7.9602	N/A	267.23
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7368	N/A	91.52	7.9004	N/A	268.72
26	8.1903	0.33	173.32	8.1968	0.33	186.25	72	7.6834	N/A	90.05	7.8604	N/A	270.21
28	8.1820	0.34	154.08	8.1952	0.33	205.99	74	7.6550	N/A	88.73	7.8352	N/A	271.62
30	8.1699	0.33	144.94	8.1850	0.33	215.03	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1550	0.32	138.30	8.1755	0.33	221.58	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1316	0.33	132.96	8.1815	0.35	226.89	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1230	0.31	128.43	8.1464	0.34	231.33	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0900	0.34	125.36	8.1527	0.33	235.16	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0874	0.36	121.70	8.1554	0.35	238.54	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0757	0.33	118.65	8.1369	0.32	241.59	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0509	0.38	116.18	8.1165	0.35	244.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

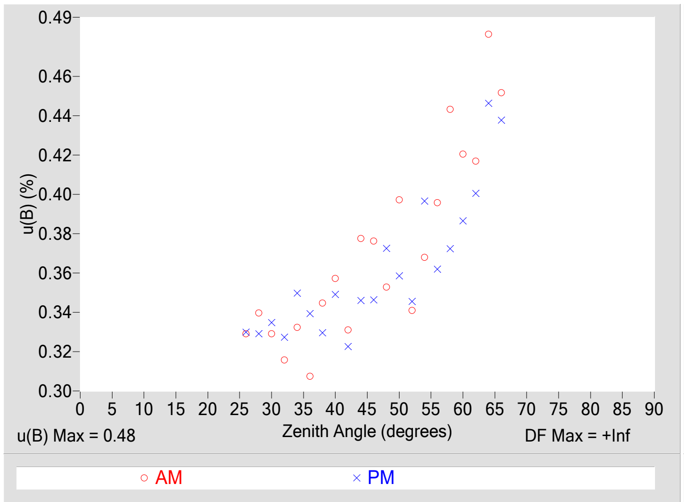


Figure 4. Residuals from Spline Interpolation

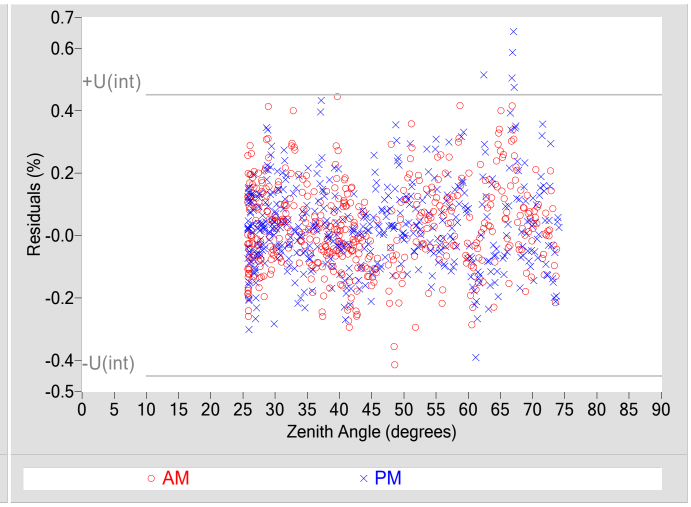


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.48
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	26005
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

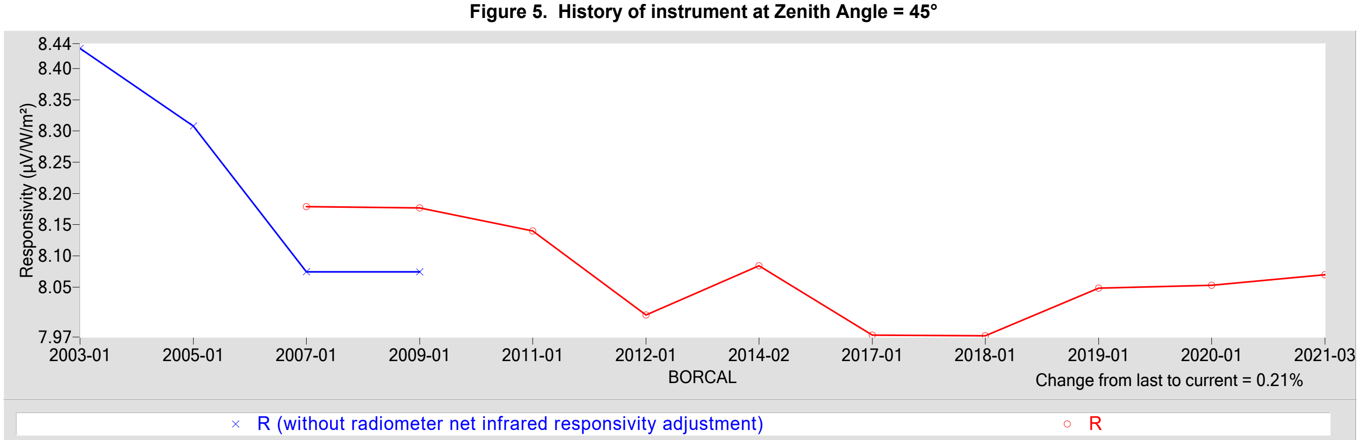
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0697	0.61842

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.87
Offset Uncertainty, U(off) (%)	+1.4 / -2.4
Expanded Uncertainty, U (%)	+2.3 / -3.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31294F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ______________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31294F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

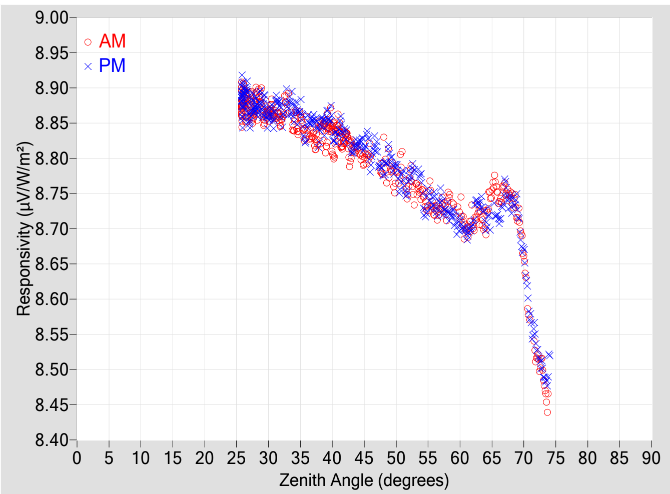


Figure 2. Responsivity vs Local Standard Time

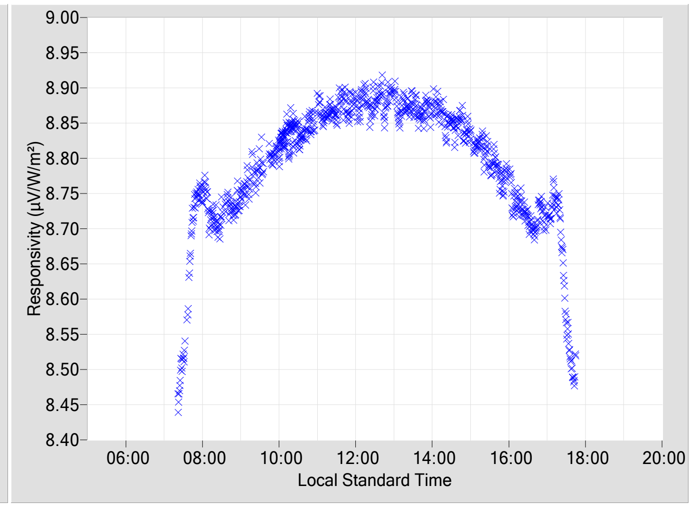


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8100	0.39	113.83	8.7959	0.36	246.91
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7956	0.32	111.26	8.7816	0.36	249.22
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7691	0.41	109.06	8.7887	0.33	251.40
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7613	0.35	106.96	8.7692	0.37	253.47
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7500	0.36	104.91	8.7598	0.36	255.43
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7258	0.44	103.06	8.7399	0.38	257.31
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7332	0.38	101.22	8.7232	0.36	259.12
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7250	0.38	99.44	8.7087	0.37	260.81
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7094	0.41	97.86	8.7061	0.38	262.45
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7133	0.43	96.16	8.7091	0.40	264.06
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7433	0.41	94.61	8.7146	0.41	265.66
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.7460	N/A	93.08	8.7371	N/A	267.19
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6614	N/A	91.57	8.6589	N/A	268.73
26	8.8801	0.33	173.64	8.8847	0.32	186.54	72	8.5184	N/A	90.06	8.5319	N/A	270.23
28	8.8775	0.32	153.68	8.8737	0.32	206.03	74	8.4656	N/A	88.70	8.5103	N/A	271.63
30	8.8647	0.33	144.83	8.8608	0.33	215.06	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.8519	0.33	138.29	8.8638	0.31	221.62	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8491	0.33	132.98	8.8678	0.32	226.86	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8418	0.32	128.70	8.8438	0.35	231.38	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8392	0.35	125.37	8.8374	0.32	235.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8342	0.34	121.72	8.8439	0.35	238.56	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8315	0.35	118.60	8.8339	0.35	241.54	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8133	0.34	116.27	8.8223	0.33	244.35	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

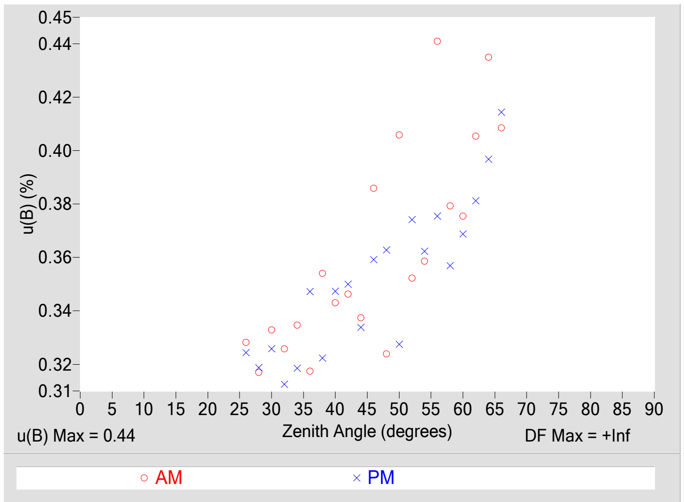


Figure 4. Residuals from Spline Interpolation

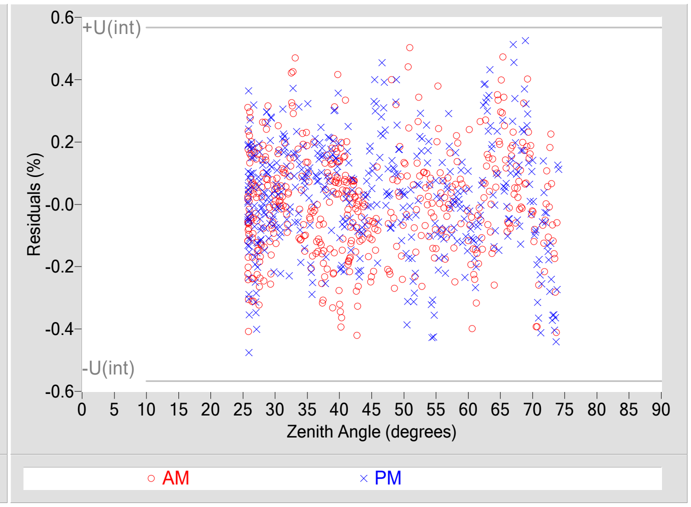


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	9795
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

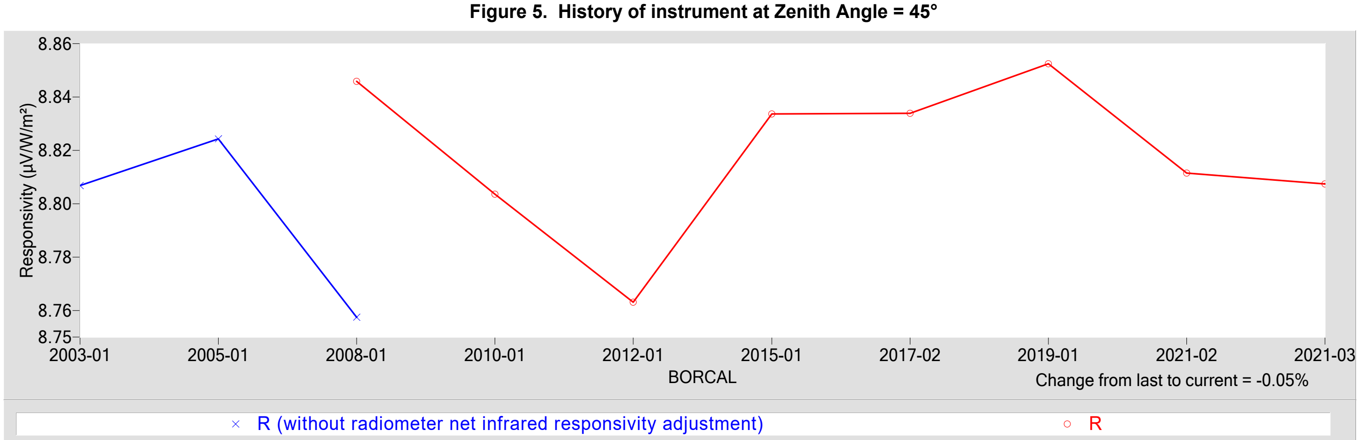
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8074	0.54700

† Rnet determination date: 04/03/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.86
Offset Uncertainty, U(off) (%)	+0.69 / -1.1
Expanded Uncertainty, U (%)	+1.6 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31636F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

__________________________________ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results
31636F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

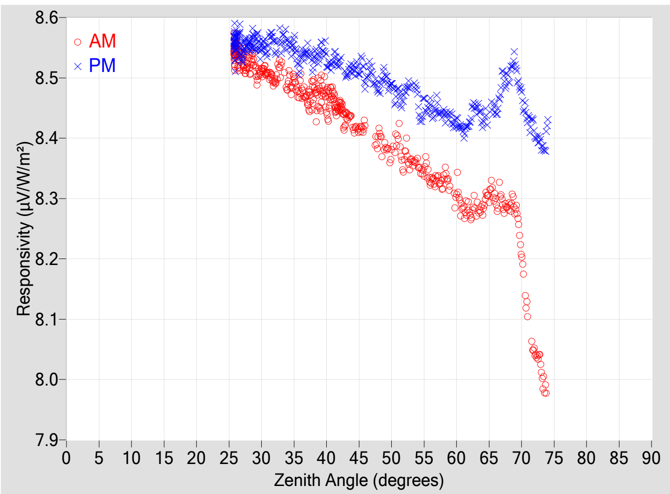


Figure 2. Responsivity vs Local Standard Time

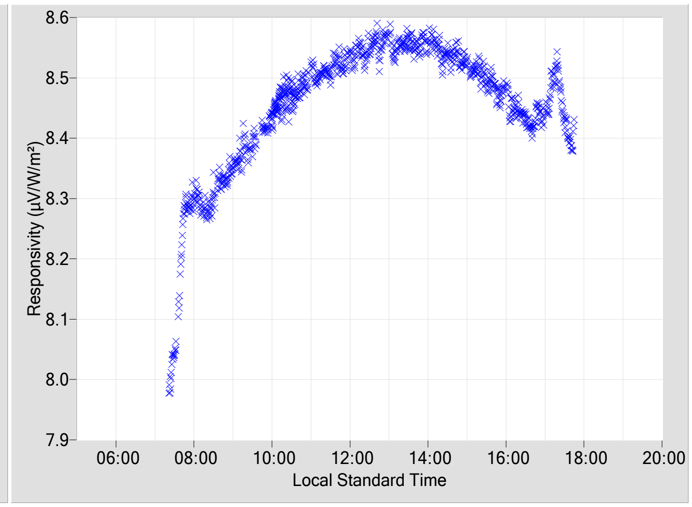


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4218	0.39	113.84	8.4933	0.36	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4004	0.38	111.23	8.4804	0.33	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3729	0.38	109.04	8.4885	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3687	0.35	106.91	8.4739	0.36	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3569	0.34	104.90	8.4662	0.37	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3291	0.37	103.07	8.4532	0.35	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3309	0.38	101.23	8.4376	0.36	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3096	0.42	99.50	8.4269	0.38	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2779	0.44	97.87	8.4252	0.39	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2841	0.48	96.17	8.4286	0.41	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2945	0.41	94.62	8.4463	0.43	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.2868	N/A	93.08	8.5021	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2128	N/A	91.58	8.4693	N/A	268.74
26	8.5439	0.32	173.50	8.5597	0.33	186.71	72	8.0463	N/A	90.07	8.4087	N/A	270.24
28	8.5243	0.31	153.71	8.5544	0.32	206.00	74	7.9776	N/A	88.71	8.4209	N/A	271.64
30	8.5106	0.31	144.83	8.5498	0.33	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.4924	0.30	138.24	8.5511	0.30	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4902	0.30	132.90	8.5580	0.35	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4816	0.33	128.57	8.5272	0.32	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4773	0.35	125.33	8.5267	0.33	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4646	0.35	121.67	8.5329	0.33	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4541	0.33	118.61	8.5258	0.35	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4228	0.39	116.20	8.5152	0.35	244.37	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

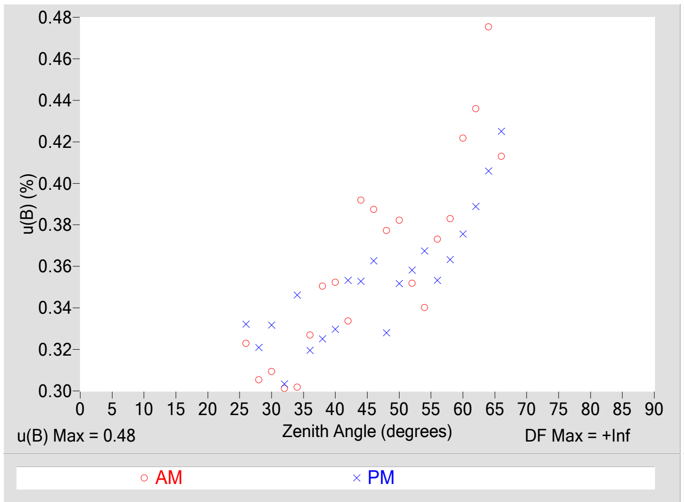


Figure 4. Residuals from Spline Interpolation

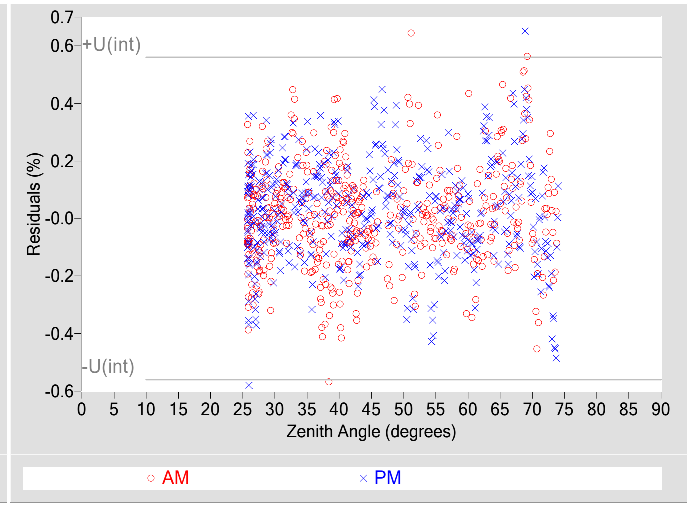


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.48
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.55
Effective degrees of freedom, DF(c)	12584
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

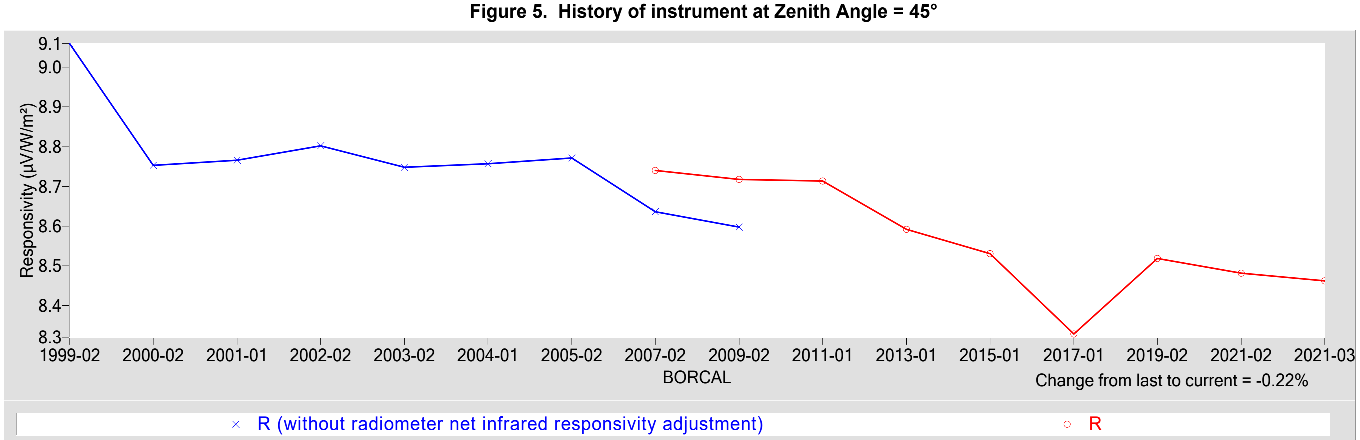
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4622	0.62111

† Rnet determination date: 06/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.83
Offset Uncertainty, U(off) (%)	+1.1 / -1.8
Expanded Uncertainty, U (%)	+2.0 / -2.6
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31763E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager — Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31763E6 Eppley NIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

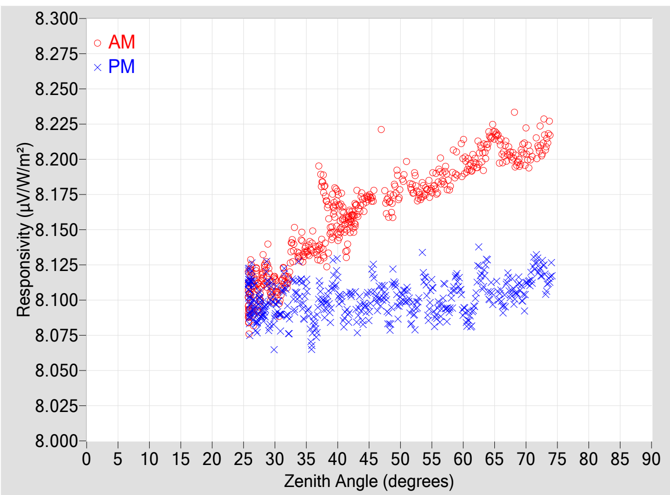


Figure 2. Responsivity vs Local Standard Time

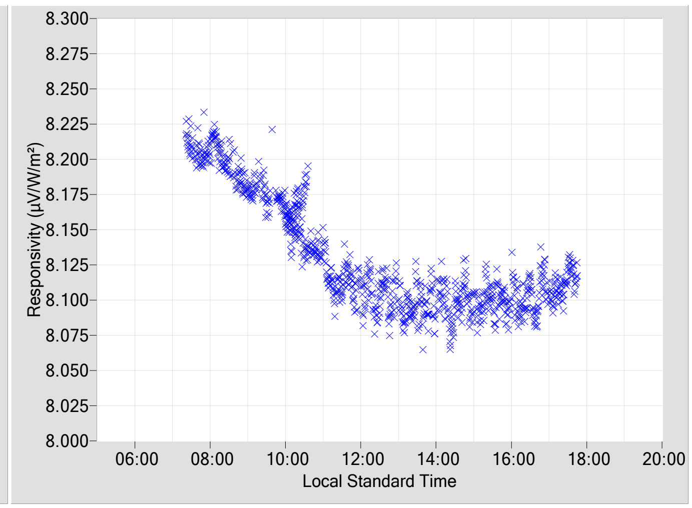


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	8.1780	0.29	113.93	8.1047	0.30	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1667	0.31	111.25	8.0898	0.30	249.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1755	0.29	109.16	8.0999	0.31	251.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1806	0.29	106.93	8.0908	0.31	253.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1774	0.31	104.89	8.1119	0.31	255.41
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1839	0.31	103.04	8.0922	0.31	257.34
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1833	0.30	101.23	8.0973	0.30	259.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1988	0.34	99.47	8.0951	0.30	260.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1968	0.30	97.83	8.1078	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2131	0.30	96.24	8.1089	0.30	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2046	0.30	94.59	8.1016	0.33	265.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.2000	N/A	93.08	8.1053	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2065	N/A	91.55	8.1065	N/A	268.70
26	8.1037	0.30	173.47	8.1038	0.30	186.51	72	8.2095	N/A	90.04	8.1240	N/A	270.21
28	8.1159	0.30	153.88	8.0907	0.30	205.96	74	8.2220	N/A	88.71	8.1184	N/A	271.65
30	8.1111	0.31	144.87	8.0907	0.30	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1137	0.30	138.19	8.0890	0.31	221.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1356	0.30	132.97	8.1119	0.31	226.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1397	0.29	128.56	8.0763	0.31	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1578	0.32	125.21	8.0952	0.31	235.23	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1608	0.31	121.68	8.1132	0.29	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1571	0.31	118.64	8.0988	0.31	241.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1708	0.31	116.17	8.0908	0.29	244.36	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

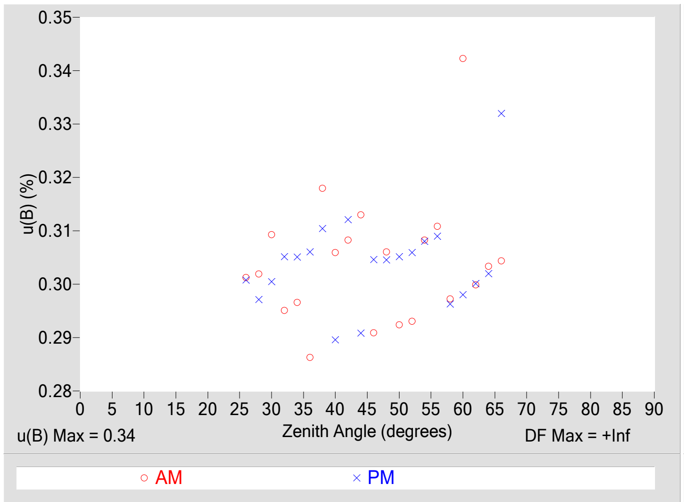


Figure 4. Residuals from Spline Interpolation

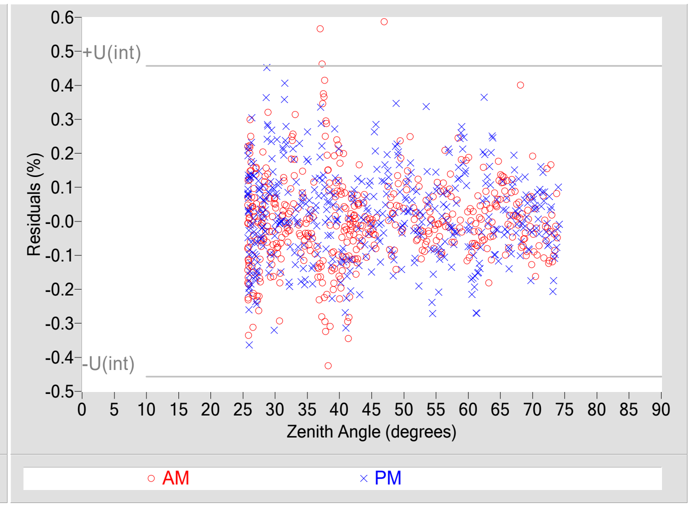


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	8782
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.81
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

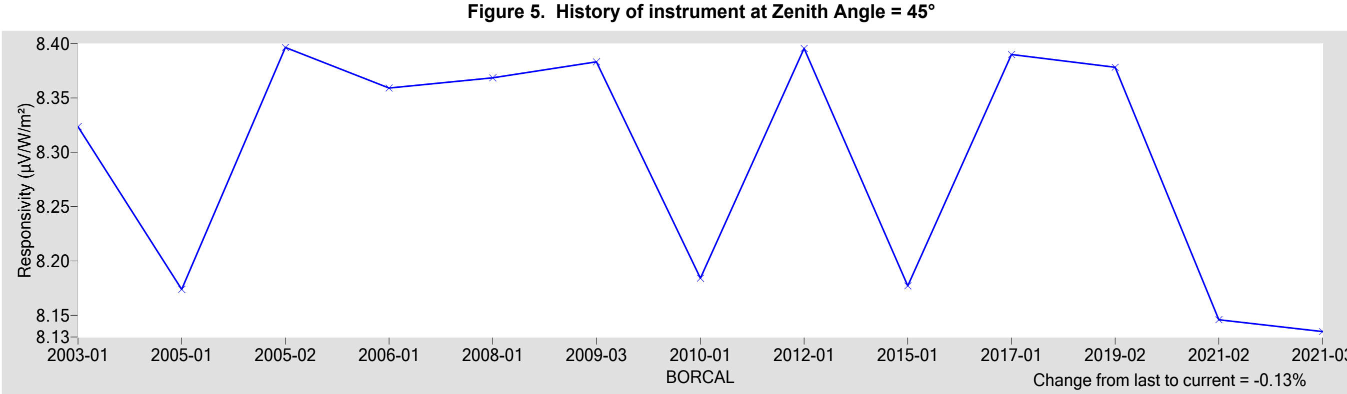
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1351	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.78 / -0.72
Expanded Uncertainty, U (%)	+1.5 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31875E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

31875E6 Eppley NIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

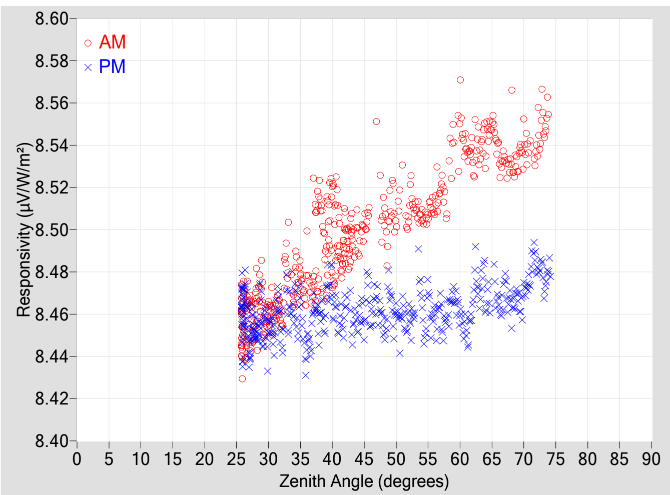


Figure 2. Responsivity vs Local Standard Time

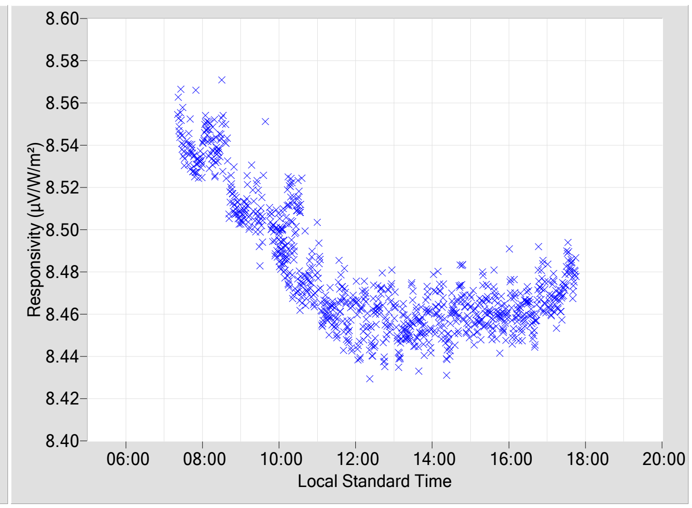


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5105	0.29	113.93	8.4594	0.30	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5056	0.31	111.25	8.4543	0.30	249.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5015	0.32	109.09	8.4613	0.31	251.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5086	0.29	106.93	8.4581	0.31	253.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5057	0.31	104.89	8.4669	0.31	255.41
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5105	0.31	103.04	8.4581	0.31	257.34
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5151	0.30	101.23	8.4589	0.30	259.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5490	0.34	99.47	8.4604	0.30	260.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5330	0.30	97.83	8.4682	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5425	0.30	96.24	8.4683	0.30	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5348	0.30	94.59	8.4660	0.33	265.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5297	N/A	93.08	8.4636	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5387	N/A	91.55	8.4684	N/A	268.70
26	8.4565	0.30	173.47	8.4599	0.30	186.51	72	8.5400	N/A	90.04	8.4836	N/A	270.21
28	8.4614	0.30	153.88	8.4510	0.30	205.96	74	8.5587	N/A	88.71	8.4809	N/A	271.65
30	8.4611	0.31	144.87	8.4548	0.30	215.07	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.4588	0.30	138.19	8.4513	0.31	221.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4725	0.30	132.97	8.4680	0.31	226.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4800	0.29	128.56	8.4429	0.31	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5003	0.32	125.27	8.4558	0.31	235.23	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5006	0.31	121.68	8.4702	0.29	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4969	0.31	118.64	8.4618	0.31	241.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4970	0.31	116.17	8.4568	0.29	244.36	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

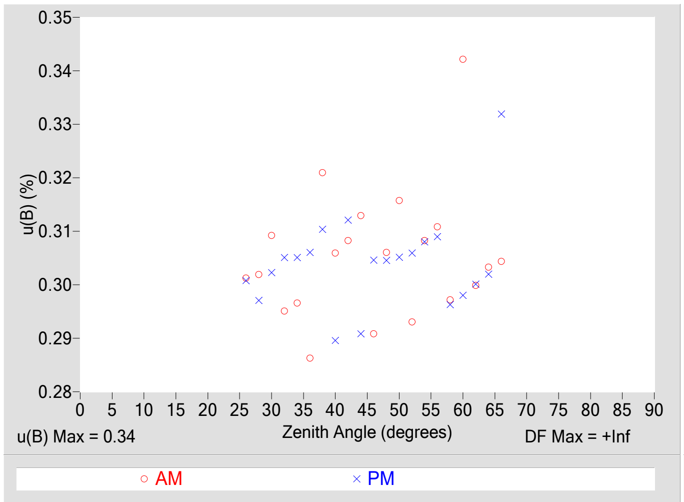


Figure 4. Residuals from Spline Interpolation

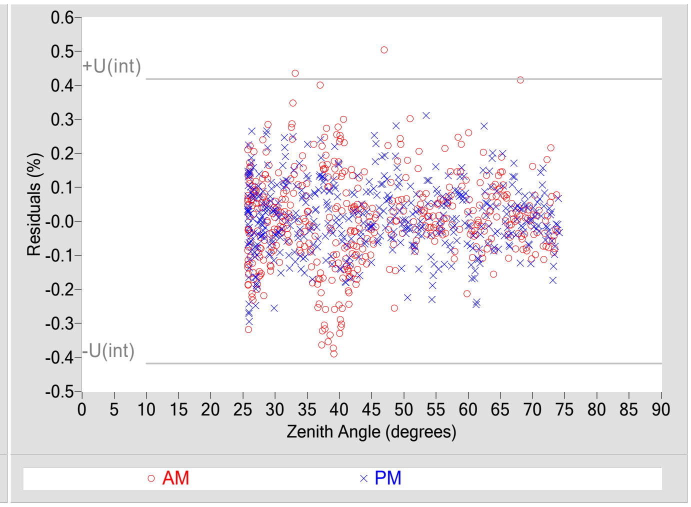


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	11262
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.79
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

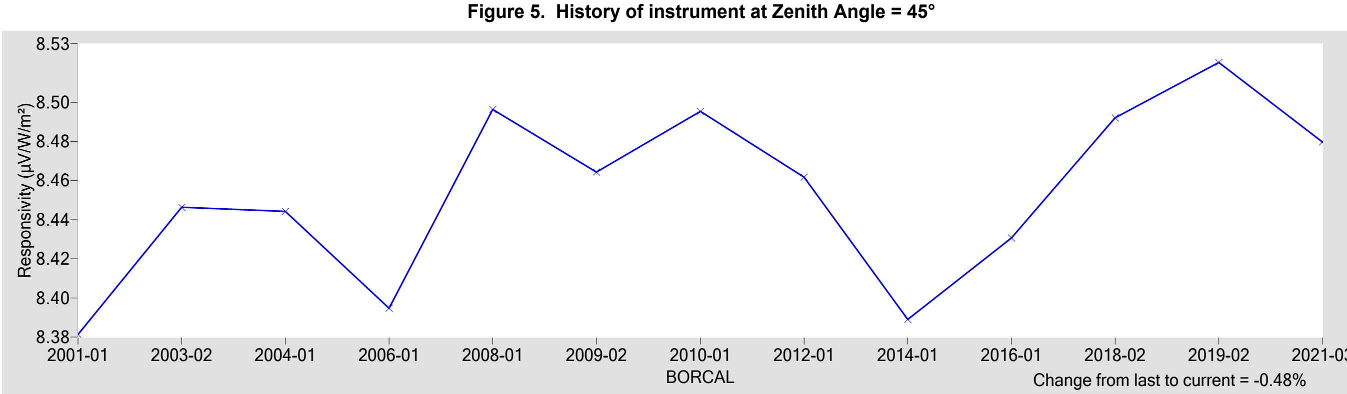
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4797	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.82 / -0.43
Expanded Uncertainty, U (%)	+1.5 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	32026F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____　____________________

Peter Gotseff, Technical Manager　　Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32026F3 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

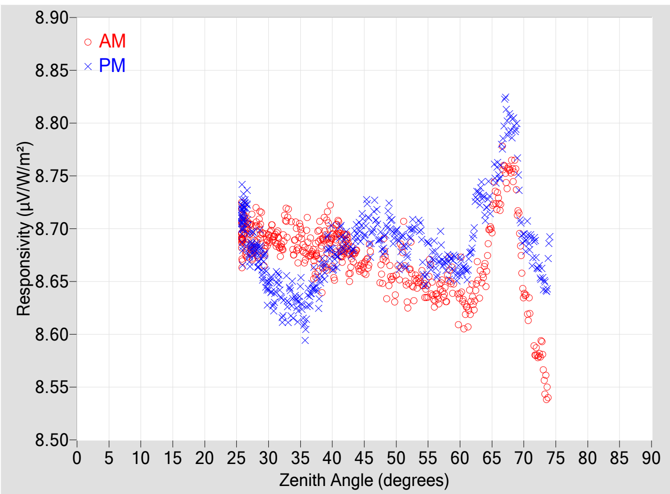


Figure 2. Responsivity vs Local Standard Time

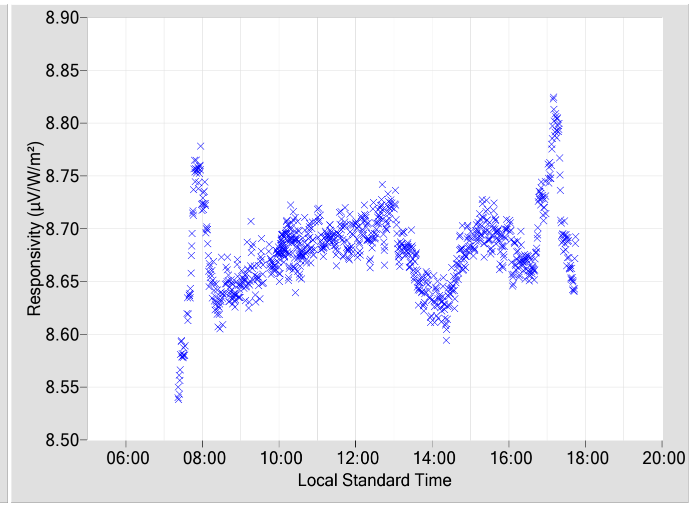


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6763	0.39	113.84	8.6876	0.36	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6698	0.38	111.23	8.6819	0.33	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6472	0.38	109.04	8.6960	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6523	0.35	106.91	8.6879	0.36	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6507	0.34	104.90	8.6837	0.37	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6330	0.37	103.07	8.6753	0.35	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6484	0.38	101.23	8.6655	0.36	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6390	0.42	99.50	8.6648	0.37	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6331	0.44	97.87	8.6892	0.39	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6621	0.47	96.17	8.7181	0.40	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7245	0.41	94.62	8.7535	0.42	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.7571	N/A	93.08	8.7996	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.6422	N/A	91.58	8.6887	N/A	268.74
26	8.6970	0.32	173.50	8.7118	0.33	186.71	72	8.5812	N/A	90.07	8.6697	N/A	270.24
28	8.6918	0.31	153.71	8.6788	0.32	206.00	74	8.5399	N/A	88.71	8.6834	N/A	271.64
30	8.6908	0.31	144.83	8.6447	0.33	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.6810	0.30	138.24	8.6260	0.30	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.6859	0.30	132.90	8.6301	0.35	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6857	0.33	128.57	8.6211	0.32	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6866	0.34	125.41	8.6445	0.32	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6846	0.35	121.67	8.6754	0.33	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6871	0.33	118.61	8.6879	0.35	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6691	0.39	116.20	8.6988	0.35	244.37	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

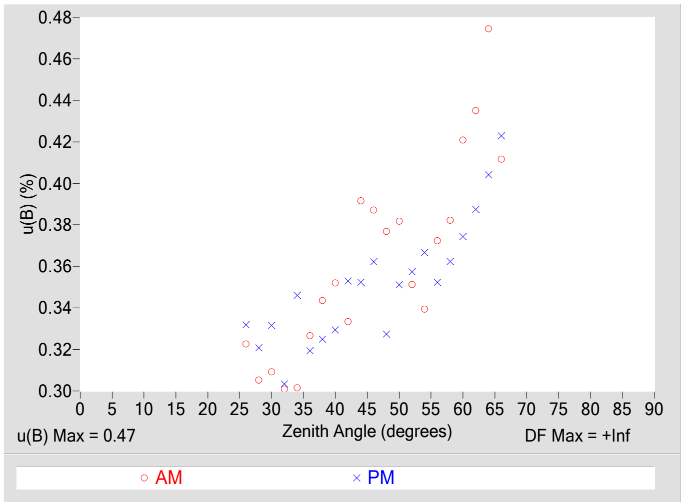


Figure 4. Residuals from Spline Interpolation

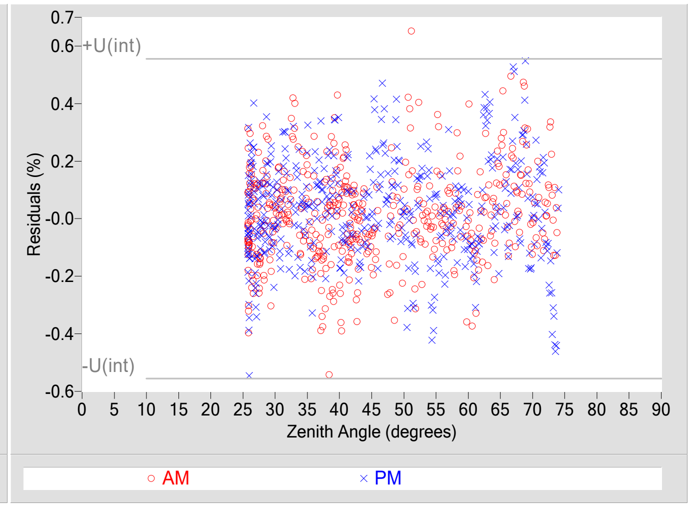


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.47
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.55
Effective degrees of freedom, DF(c)	12751
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

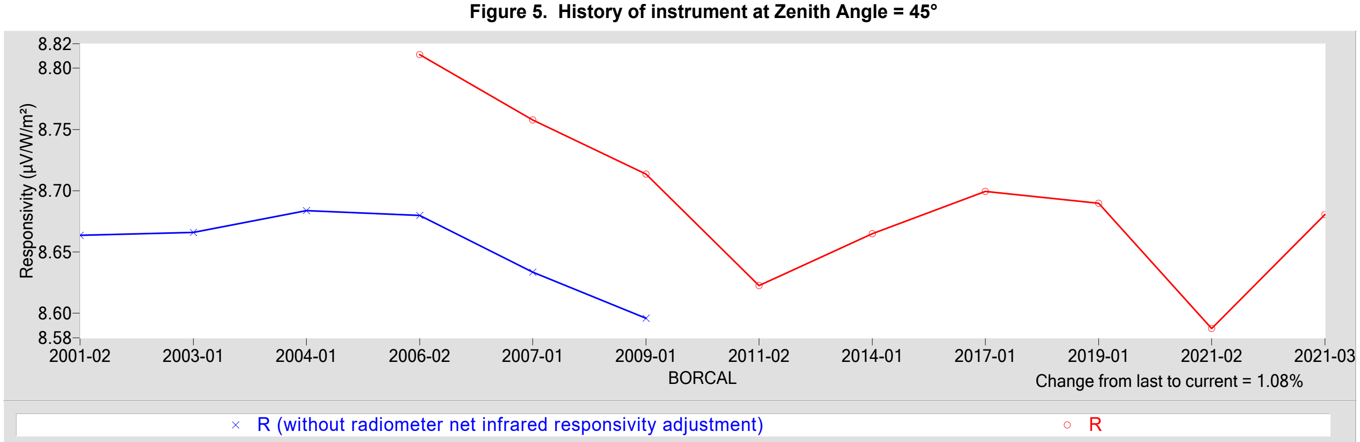
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6807	0.62415

† Rnet determination date: 06/13/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.82
Offset Uncertainty, U(off) (%)	+0.21 / -0.69
Expanded Uncertainty, U (%)	+1.0 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated)
Manufacturer: Eppley
Model: 8-48
Serial Number: 32882
Calibration Date: 8/25/2021
Due Date: 8/25/2022
Customer: TWP
Environmental Conditions: see page 4
Test Dates: 8/24-25

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ________________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

32882 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

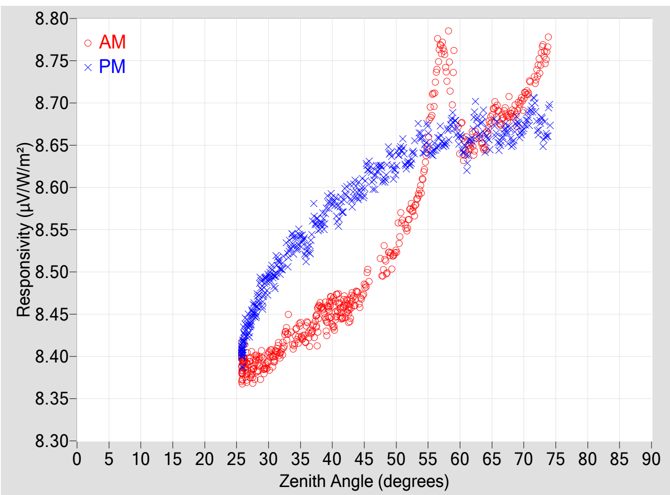


Figure 2. Responsivity vs Local Standard Time

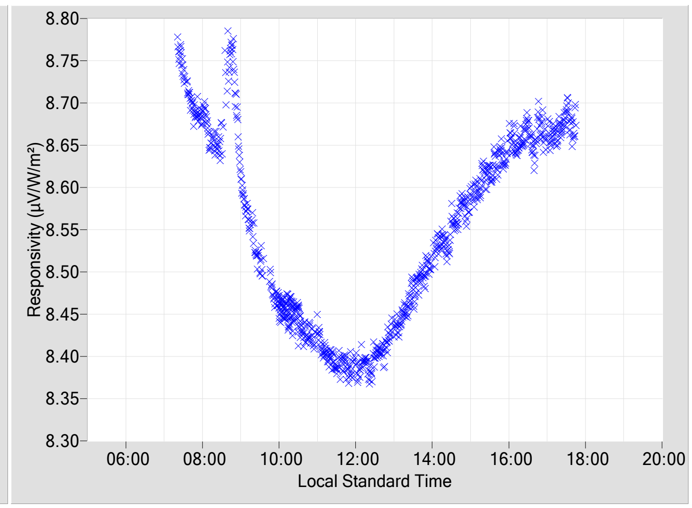


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4887	0.31	113.91	8.6200	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5078	0.36	111.23	8.6115	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5239	0.32	109.07	8.6273	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5649	0.35	106.91	8.6286	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6024	0.35	104.99	8.6561	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7159	0.36	103.02	8.6453	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7474	0.38	101.31	8.6592	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6626	0.44	99.55	8.6584	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6498	0.40	97.82	8.6711	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6534	0.39	96.23	8.6556	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6886	0.40	94.62	8.6569	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.6869	N/A	93.04	8.6574	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.7046	N/A	91.54	8.6704	N/A	268.69
26	8.3918	0.31	173.54	8.4113	0.31	186.47	72	8.7331	N/A	90.03	8.6796	N/A	270.19
28	8.3908	0.30	153.89	8.4569	0.30	206.03	74	8.7721	N/A	88.71	8.6816	N/A	271.64
30	8.3959	0.29	144.86	8.4899	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.4055	0.32	138.25	8.5057	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.4178	0.31	132.87	8.5367	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4296	0.34	128.57	8.5225	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4542	0.35	125.45	8.5539	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4533	0.34	121.62	8.5855	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4607	0.32	118.58	8.5899	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4730	0.31	116.26	8.5941	0.35	244.37	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

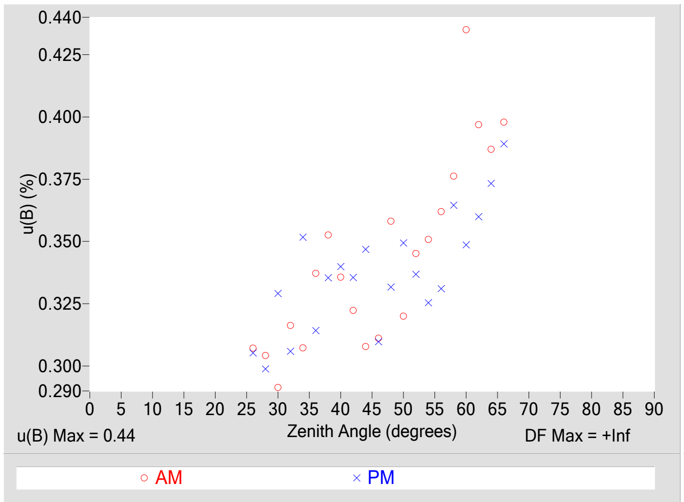


Figure 4. Residuals from Spline Interpolation

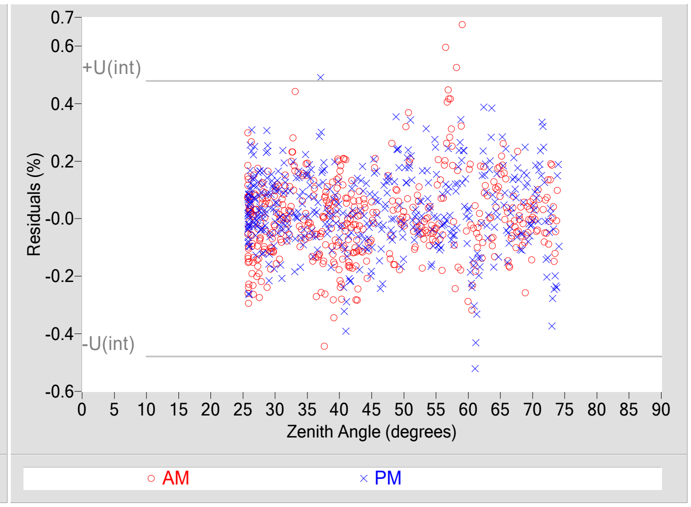


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	15280
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

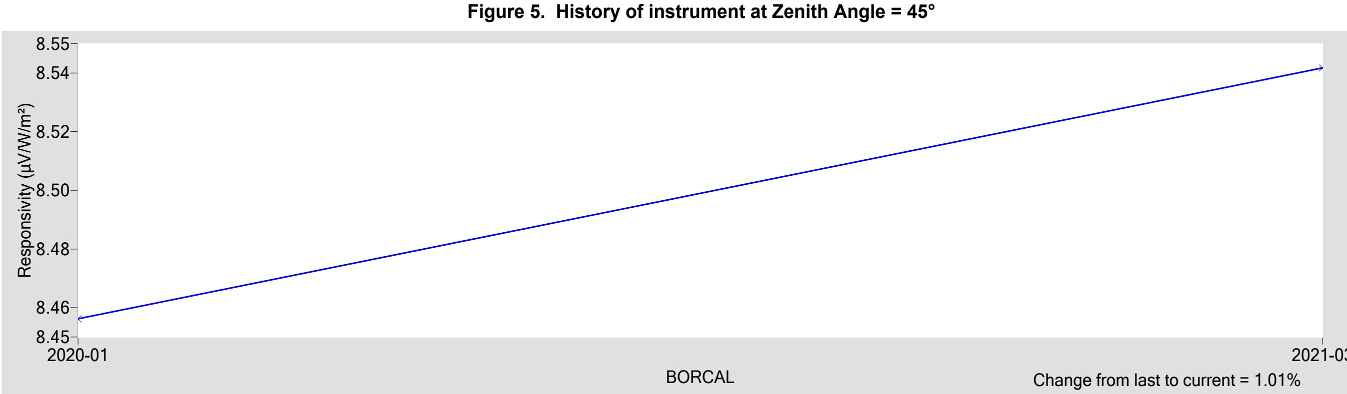
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5418	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+2.4 / -1.7
Expanded Uncertainty, U (%)	+3.3 / -2.6
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33247
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33247 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

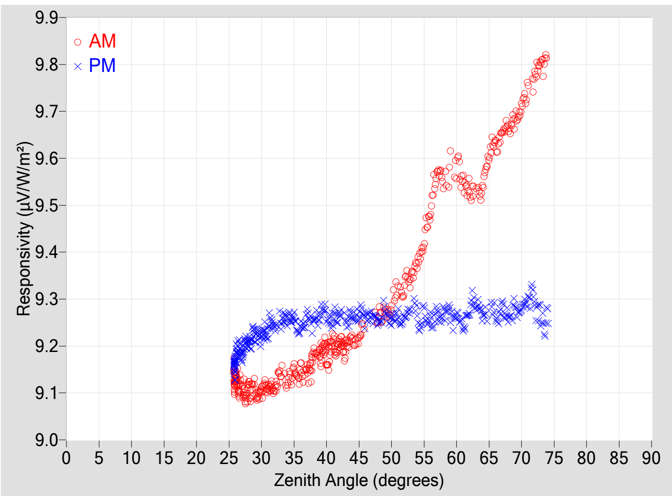


Figure 2. Responsivity vs Local Standard Time

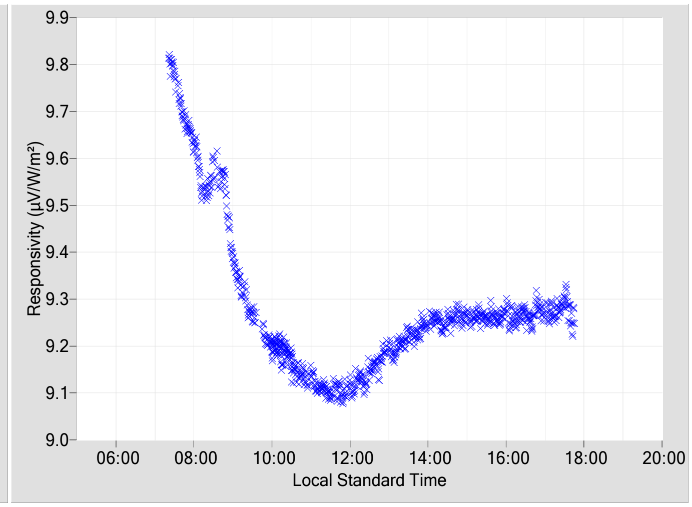


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	9.2356	0.31	113.91	9.2577	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2625	0.36	111.23	9.2515	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2748	0.32	109.07	9.2570	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3275	0.35	106.91	9.2609	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3774	0.35	104.99	9.2622	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4887	0.36	103.02	9.2553	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5482	0.38	101.39	9.2685	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5783	0.46	99.58	9.2649	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.5281	0.40	97.82	9.2773	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.5356	0.39	96.23	9.2654	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.6308	0.40	94.62	9.2685	0.39	265.69
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.6627	N/A	93.04	9.2643	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.7088	N/A	91.54	9.2795	N/A	268.69
26	9.1320	0.31	173.54	9.1672	0.31	186.47	72	9.7695	N/A	90.03	9.2921	N/A	270.19
28	9.1059	0.30	153.89	9.2070	0.30	206.03	74	9.8173	N/A	88.71	9.2647	N/A	271.64
30	9.1044	0.29	144.86	9.2208	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	9.1088	0.32	138.25	9.2414	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.1240	0.31	132.87	9.2603	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1449	0.34	128.57	9.2383	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1766	0.35	125.45	9.2499	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1852	0.34	121.62	9.2643	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2061	0.32	118.58	9.2658	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2153	0.31	116.26	9.2625	0.35	244.37	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

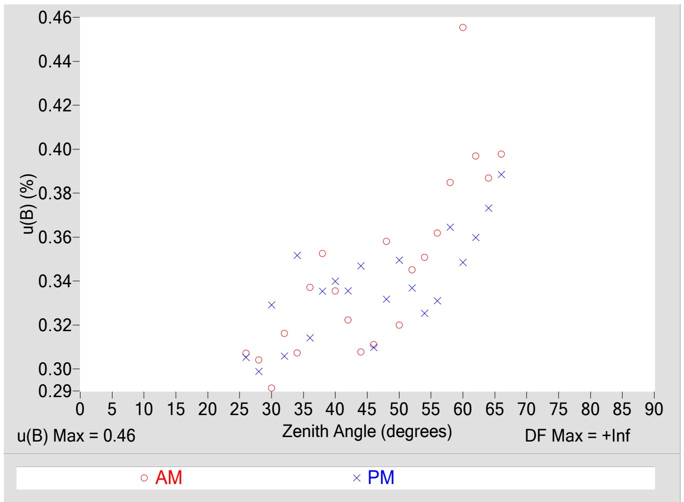


Figure 4. Residuals from Spline Interpolation

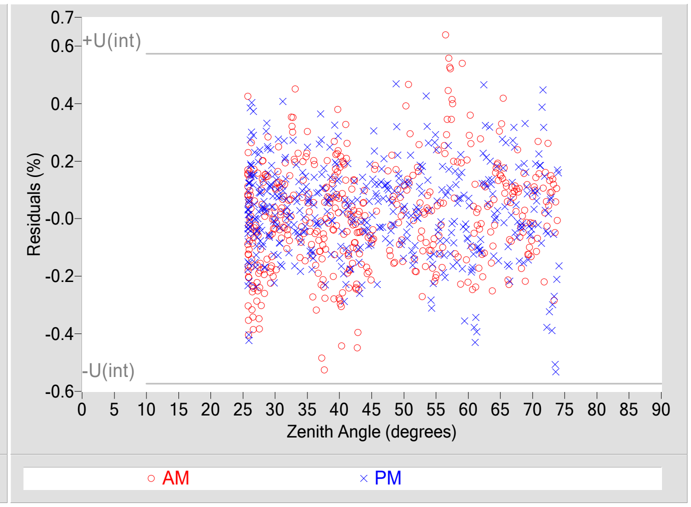


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	10248
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

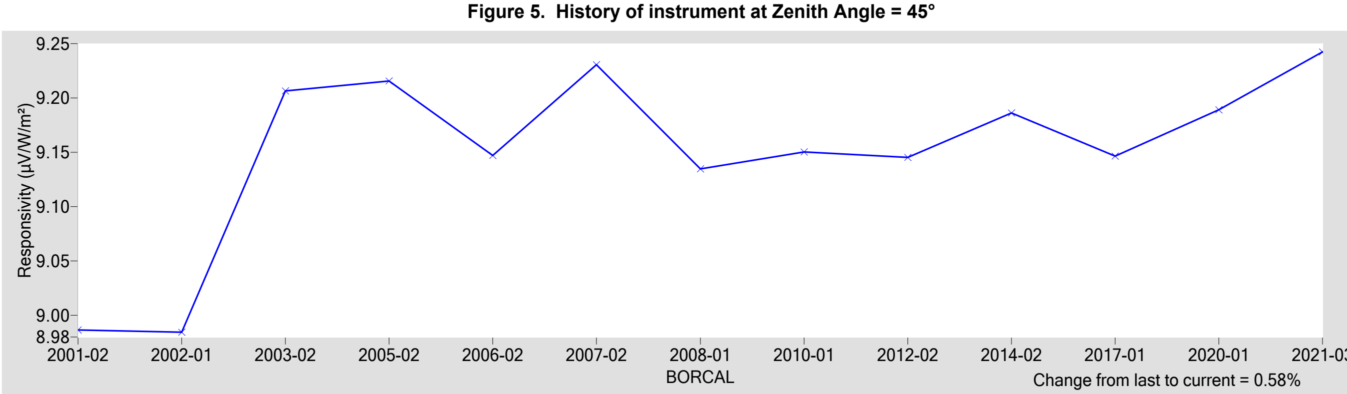
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.2422	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+3.6 / -1.5
Expanded Uncertainty, U (%)	+4.5 / -2.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33251
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

_______________________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33251 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

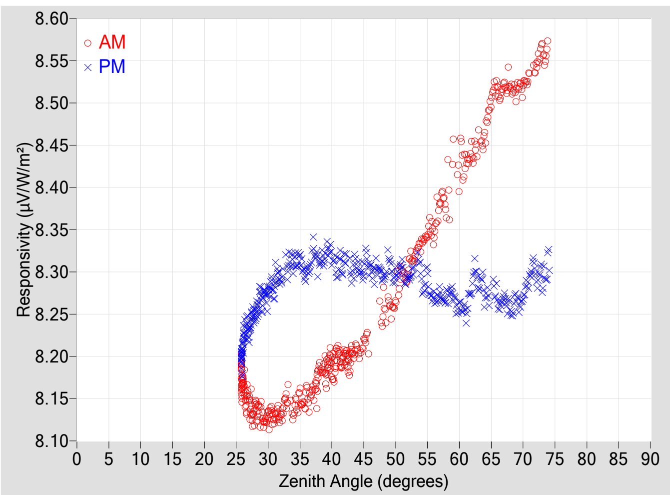


Figure 2. Responsivity vs Local Standard Time

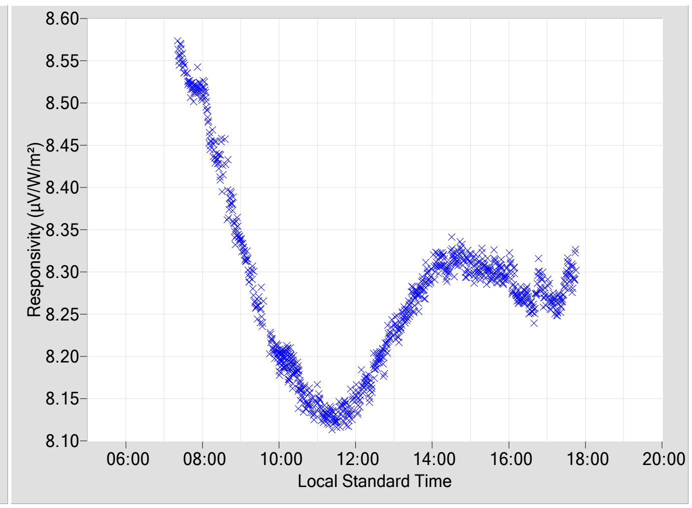


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2031	0.31	113.91	8.3042	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2523	0.36	111.23	8.2937	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2622	0.32	109.07	8.2963	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3036	0.35	106.91	8.2931	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3329	0.35	104.99	8.2970	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3458	0.36	103.02	8.2683	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3878	0.38	101.31	8.2693	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4237	0.46	99.58	8.2610	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4389	0.40	97.82	8.2861	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4604	0.39	96.23	8.2701	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5181	0.40	94.62	8.2682	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5177	N/A	93.04	8.2555	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5191	N/A	91.54	8.2687	N/A	268.69
26	8.1718	0.31	173.54	8.2069	0.31	186.47	72	8.5418	N/A	90.03	8.2963	N/A	270.19
28	8.1360	0.30	153.89	8.2518	0.30	206.03	74	8.5687	N/A	88.71	8.3105	N/A	271.64
30	8.1284	0.29	144.86	8.2741	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1290	0.32	138.25	8.2919	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1357	0.31	132.87	8.3132	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1520	0.34	128.57	8.2987	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1805	0.35	125.45	8.3077	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1887	0.34	121.62	8.3181	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2007	0.32	118.58	8.3122	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2097	0.31	116.26	8.3055	0.35	244.37	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

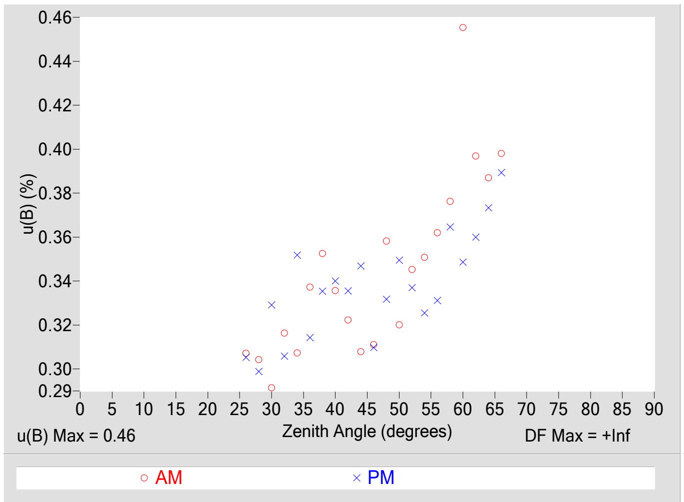


Figure 4. Residuals from Spline Interpolation

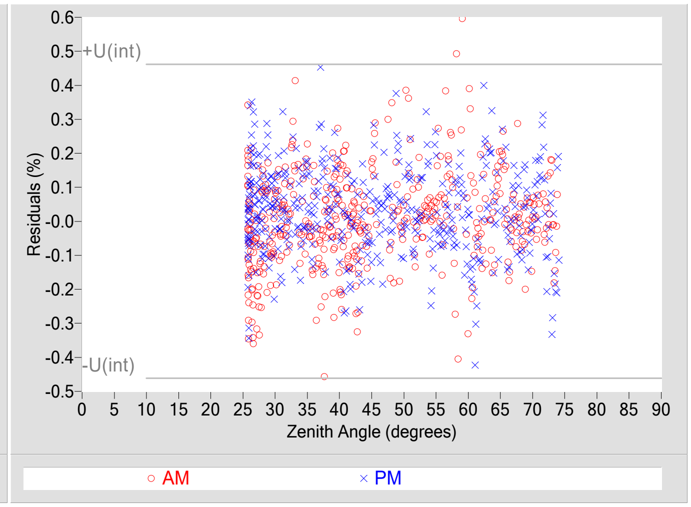


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	19712
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

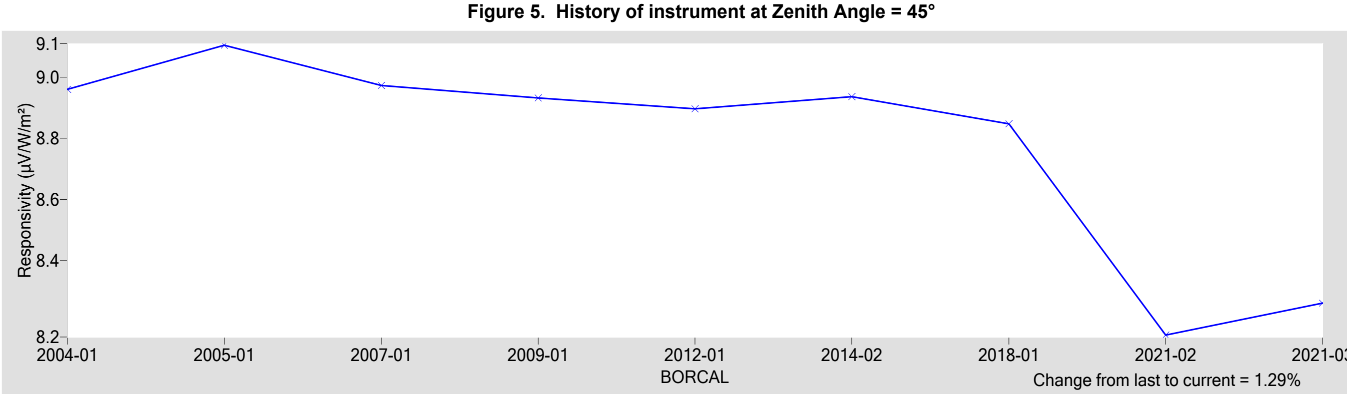
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.2609	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+2.0 / -1.6
Expanded Uncertainty, U (%)	+2.9 / -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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33262
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33262 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

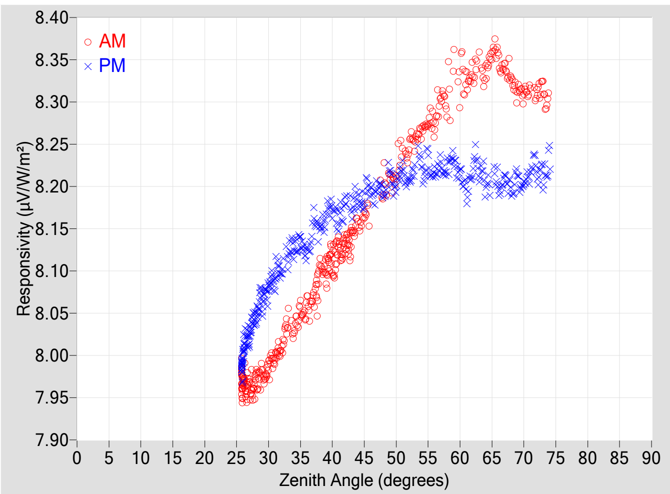


Figure 2. Responsivity vs Local Standard Time

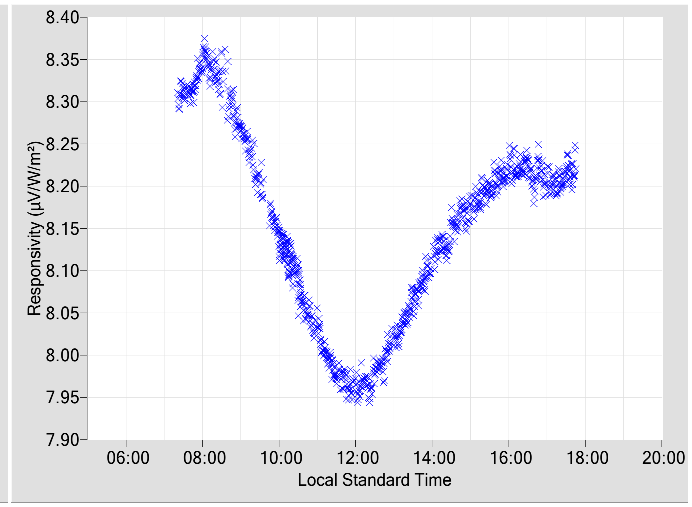


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.1529	0.31	113.91	8.1954	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1989	0.36	111.23	8.1921	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2077	0.32	109.07	8.2029	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2443	0.35	106.91	8.2077	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2658	0.35	104.99	8.2234	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2720	0.36	103.02	8.2154	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3043	0.38	101.31	8.2214	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3276	0.46	99.58	8.2175	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3320	0.40	97.82	8.2214	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3319	0.39	96.23	8.2000	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3545	0.40	94.62	8.2019	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.3262	N/A	93.04	8.1967	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.3095	N/A	91.54	8.2027	N/A	268.69
26	7.9697	0.31	173.54	7.9952	0.31	186.47	72	8.3093	N/A	90.03	8.2180	N/A	270.19
28	7.9689	0.30	153.89	8.0465	0.30	206.03	74	8.3072	N/A	88.71	8.2310	N/A	271.64
30	7.9855	0.29	144.86	8.0779	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.0070	0.32	138.25	8.0994	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.0309	0.31	132.87	8.1302	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0578	0.34	128.57	8.1217	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0972	0.35	125.45	8.1475	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1126	0.34	121.62	8.1733	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1338	0.32	118.58	8.1784	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1588	0.31	116.26	8.1821	0.35	244.37	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

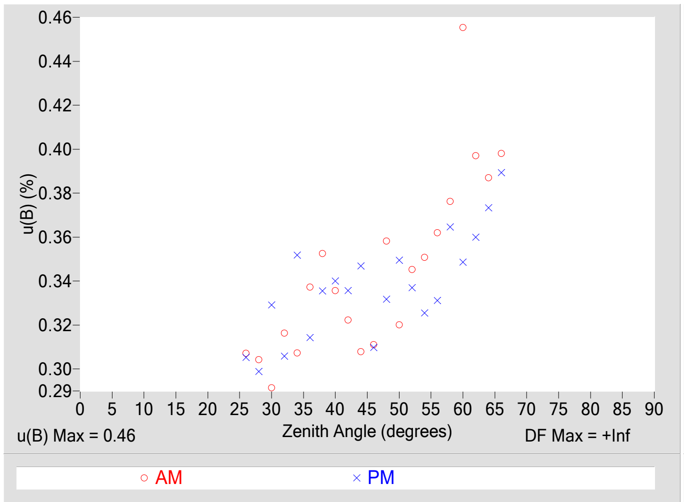


Figure 4. Residuals from Spline Interpolation

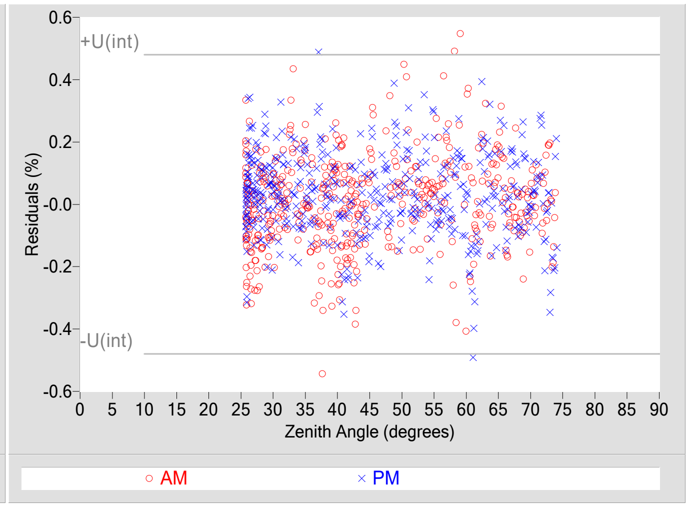


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	17355
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

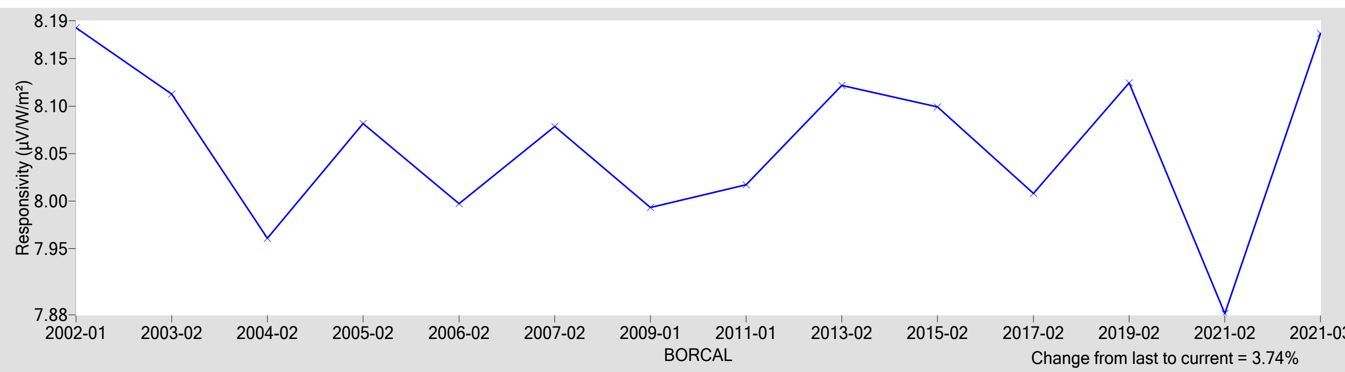
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1765	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+1.8 / -2.3
Expanded Uncertainty, U (%)	+2.7 / -3.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33267
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ____________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33267 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

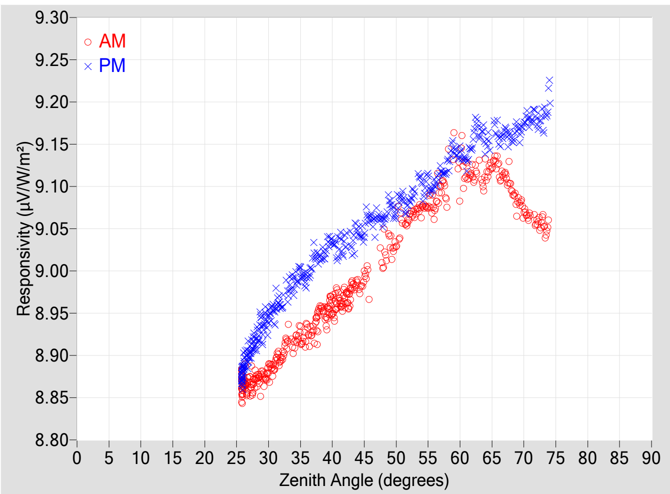


Figure 2. Responsivity vs Local Standard Time

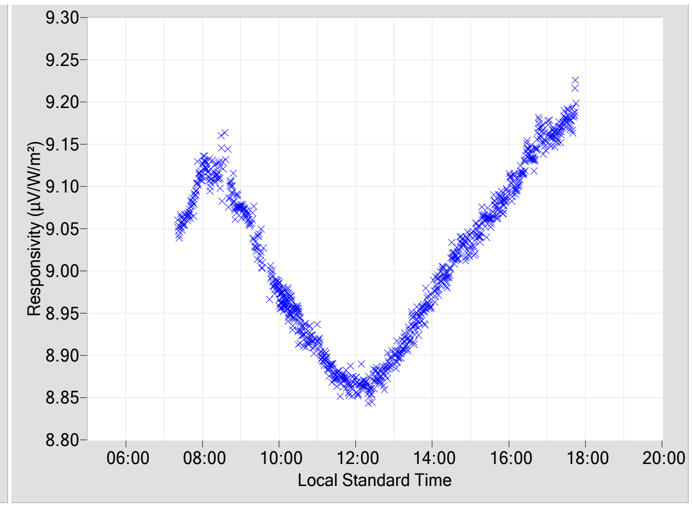


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.9663	0.31	113.91	9.0635	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0178	0.36	111.23	9.0586	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0308	0.32	109.07	9.0721	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0626	0.35	106.91	9.0818	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0766	0.36	104.99	9.1026	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0729	0.36	103.02	9.1019	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0980	0.38	101.31	9.1224	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1196	0.46	99.58	9.1410	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1131	0.40	97.82	9.1553	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1126	0.39	96.23	9.1491	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.1251	0.40	94.62	9.1611	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.0973	N/A	93.04	9.1576	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.0703	N/A	91.54	9.1732	N/A	268.69
26	8.8659	0.31	173.54	8.8798	0.31	186.47	72	9.0567	N/A	90.03	9.1788	N/A	270.19
28	8.8717	0.30	153.89	8.9170	0.30	206.03	74	9.0559	N/A	88.71	9.2072	N/A	271.64
30	8.8812	0.29	144.86	8.9425	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.8962	0.32	138.25	8.9597	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.9131	0.31	132.87	8.9882	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9264	0.34	128.57	8.9900	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.9508	0.35	125.45	9.0140	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9586	0.34	121.62	9.0340	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9700	0.32	118.58	9.0328	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9858	0.31	116.26	9.0470	0.35	244.37	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

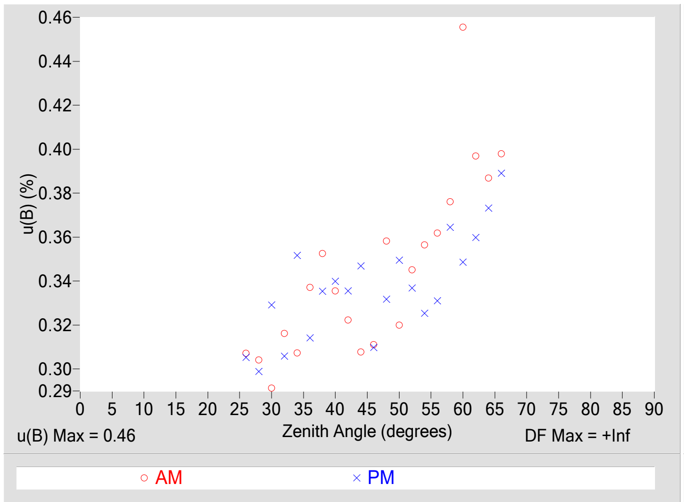


Figure 4. Residuals from Spline Interpolation

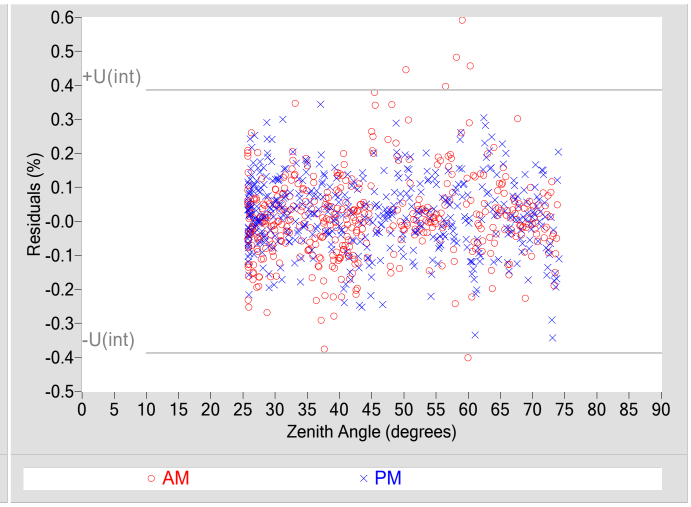


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	35081
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

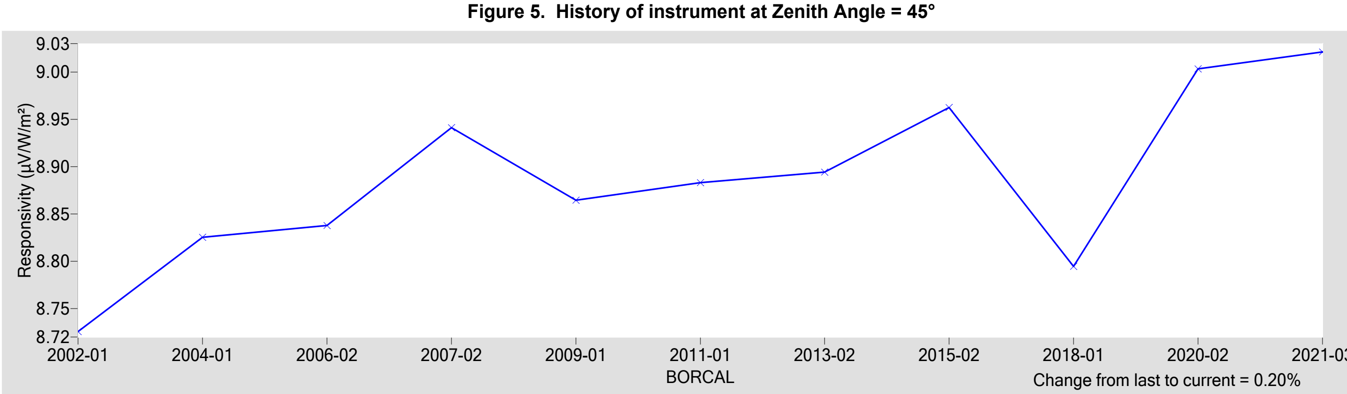
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0212	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+1.3 / -1.6
Expanded Uncertainty, U (%)	+2.2 / -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

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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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33273
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33273 Eppley 8-48

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

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

where,

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

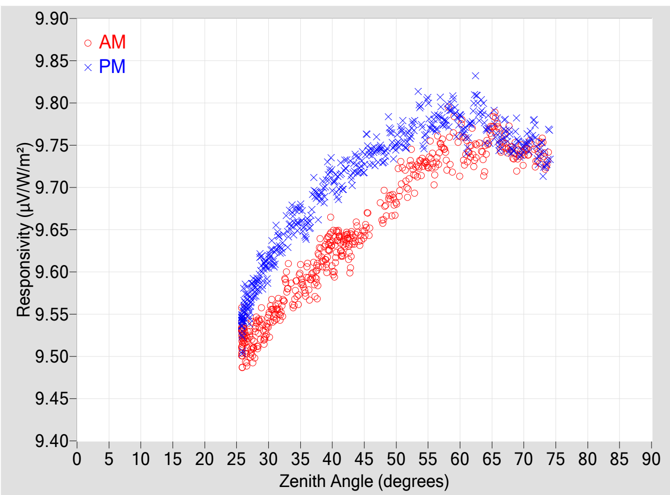


Figure 2. Responsivity vs Local Standard Time

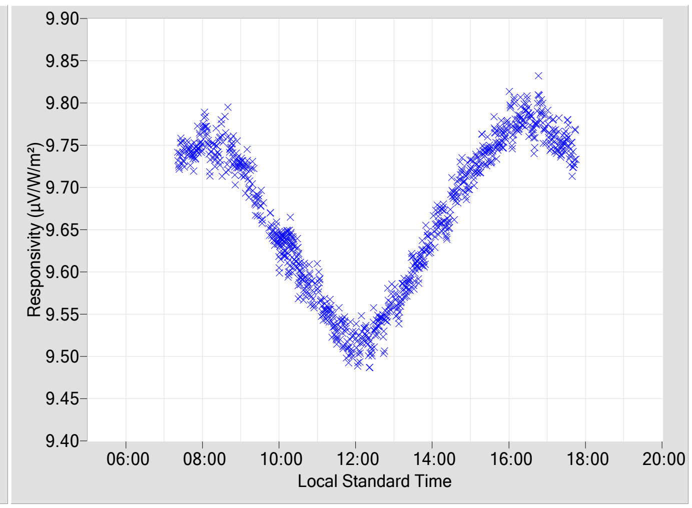


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.6474	0.31	113.84	9.7382	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.6710	0.36	111.23	9.7355	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6765	0.32	109.07	9.7518	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7108	0.35	106.91	9.7603	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7273	0.35	104.99	9.7771	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7200	0.36	103.02	9.7741	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7473	0.38	101.31	9.7833	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7509	0.46	99.58	9.7824	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.7431	0.40	97.82	9.7904	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.7354	0.39	96.23	9.7671	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7672	0.40	94.62	9.7574	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.7436	N/A	93.04	9.7489	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.7390	N/A	91.54	9.7478	N/A	268.69
26	9.5219	0.31	173.54	9.5447	0.31	186.47	72	9.7349	N/A	90.03	9.7485	N/A	270.19
28	9.5249	0.30	153.89	9.5825	0.30	206.03	74	9.7367	N/A	88.71	9.7508	N/A	271.64
30	9.5399	0.29	144.86	9.6082	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	9.5534	0.32	138.25	9.6303	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.5690	0.31	132.87	9.6647	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.5915	0.34	128.57	9.6520	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.6172	0.35	125.45	9.6830	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.6263	0.34	121.62	9.7131	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.6392	0.32	118.58	9.7214	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.6493	0.31	116.26	9.7241	0.35	244.37	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

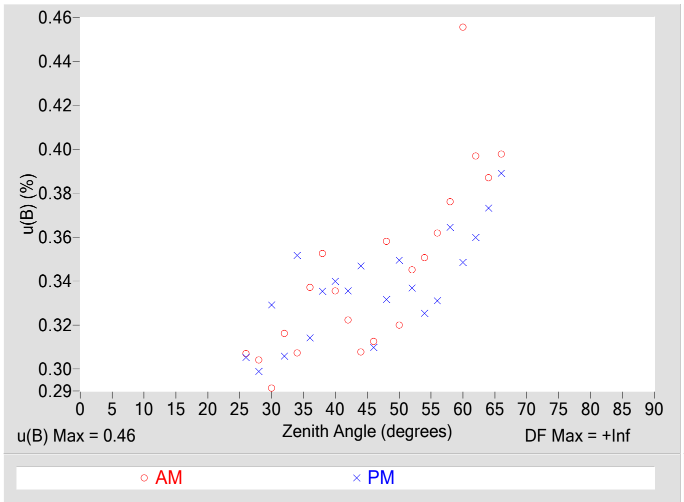


Figure 4. Residuals from Spline Interpolation

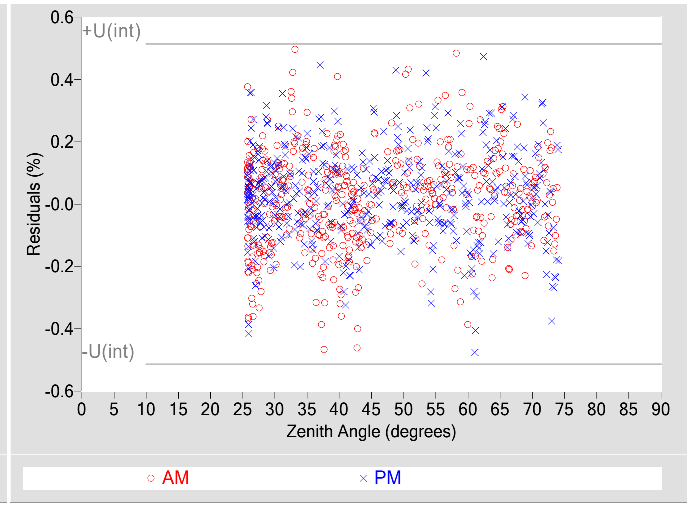


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	14186
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

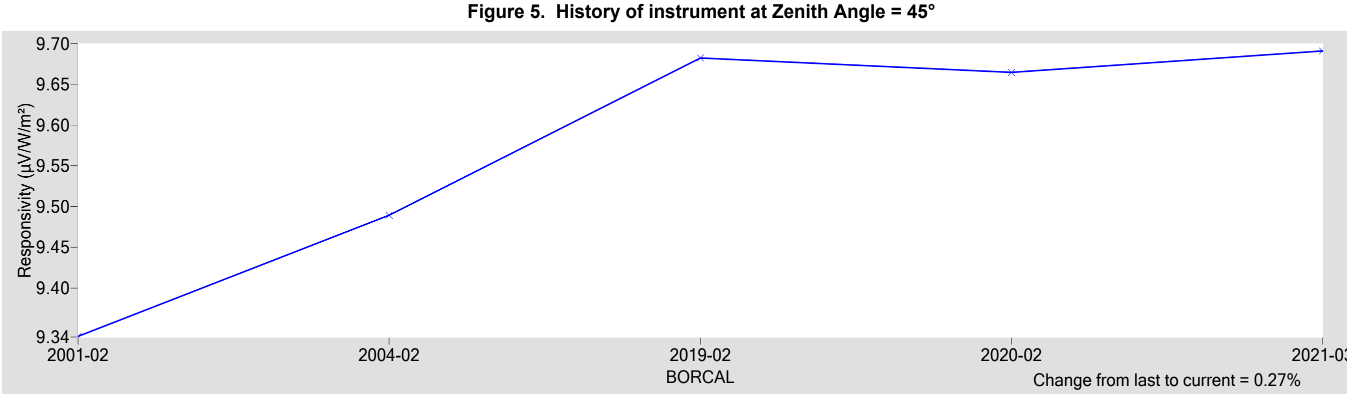
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.6908	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+0.95 / -1.6
Expanded Uncertainty, U (%)	+1.8 / -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

[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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33279
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33279 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 - 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

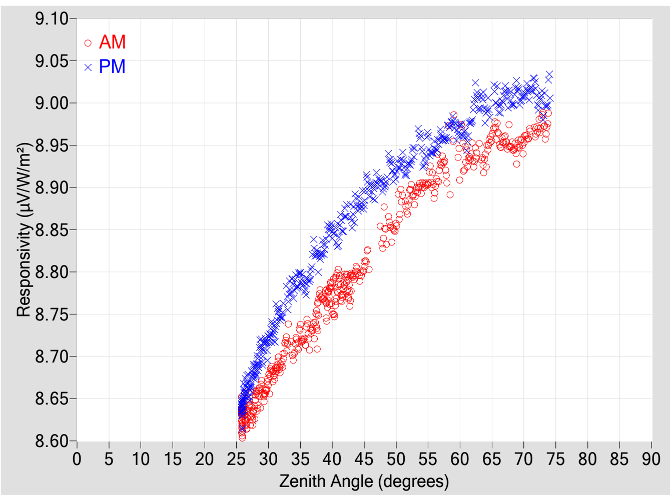


Figure 2. Responsivity vs Local Standard Time

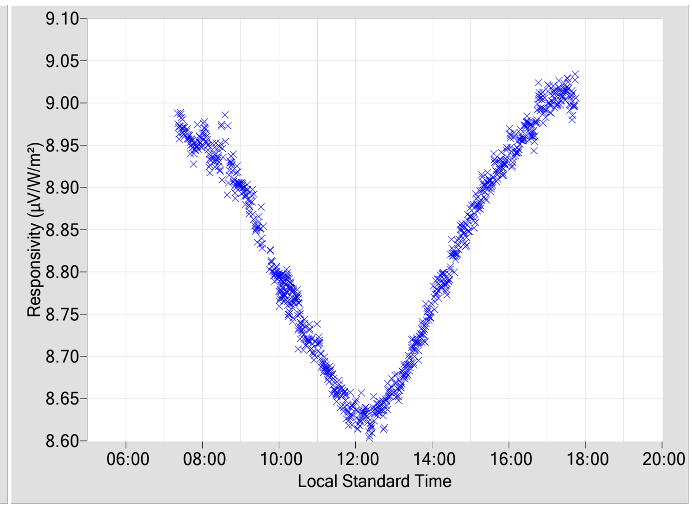


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.8029	0.31	113.91	8.8987	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8460	0.36	111.23	8.9012	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8533	0.32	109.07	8.9192	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8856	0.35	106.91	8.9273	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9013	0.35	104.99	8.9468	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8992	0.36	103.02	8.9460	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9282	0.38	101.31	8.9638	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9413	0.46	99.58	8.9712	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9357	0.40	97.82	8.9905	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9329	0.39	96.23	8.9881	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9637	0.40	94.62	9.0006	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.9486	N/A	93.04	9.0028	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.9530	N/A	91.54	9.0086	N/A	268.69
26	8.6293	0.31	173.54	8.6430	0.31	186.47	72	8.9662	N/A	90.03	9.0081	N/A	270.19
28	8.6464	0.30	153.89	8.6863	0.30	206.03	74	8.9816	N/A	88.71	9.0163	N/A	271.64
30	8.6702	0.29	144.86	8.7177	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.6901	0.32	138.25	8.7491	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.7070	0.31	132.87	8.7854	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7284	0.34	128.57	8.7841	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7631	0.35	125.45	8.8150	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7700	0.34	121.62	8.8483	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7866	0.32	118.58	8.8666	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8013	0.31	116.26	8.8797	0.35	244.37	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

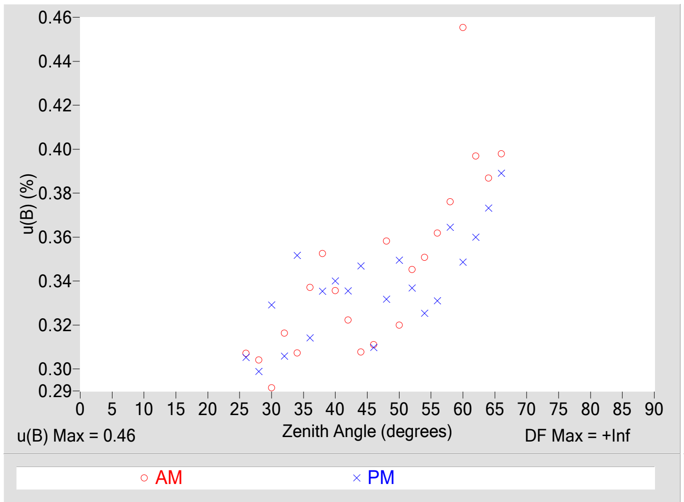


Figure 4. Residuals from Spline Interpolation

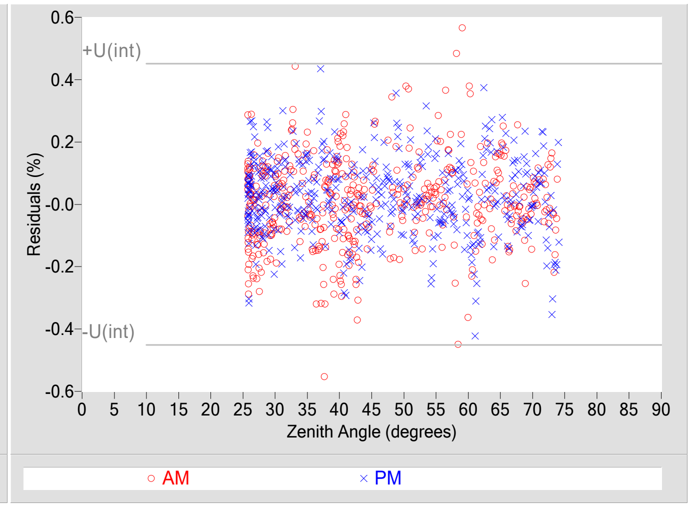


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	21203
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

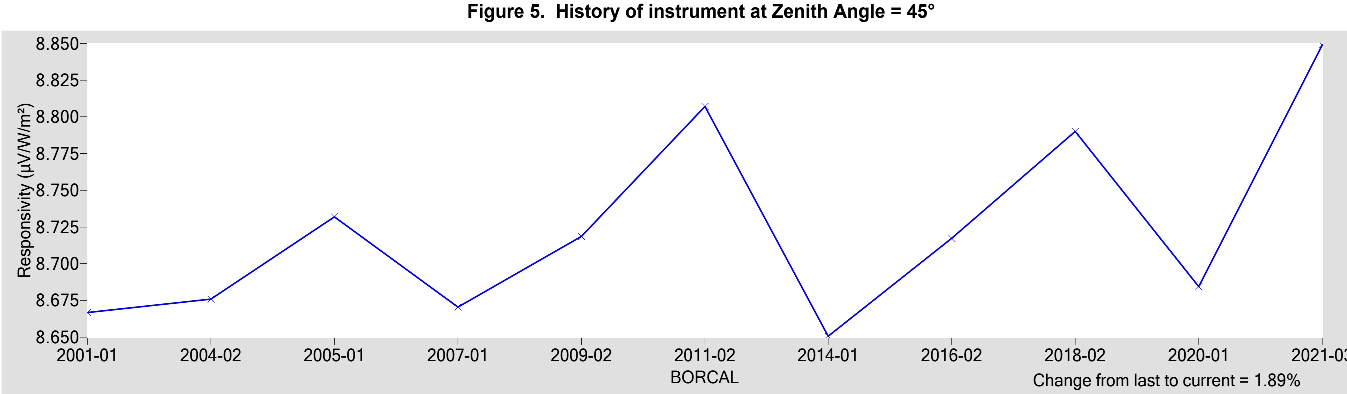
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8488	0

† 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 / -2.0
Expanded Uncertainty, U (%)	+2.3 / -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 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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33386
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________________ __________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

33386 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 - σ * Tc^4*

where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,

Tc = case temperature of pyrgeometer (K).

I = reference irradiance (W/m²), beam (B) or global (G)

where, *G = B * COS(Z) + D,*

Z = zenith angle (degrees),

D = reference diffuse irradiance (W/m²).

Figure 1. Responsivity vs Zenith Angle

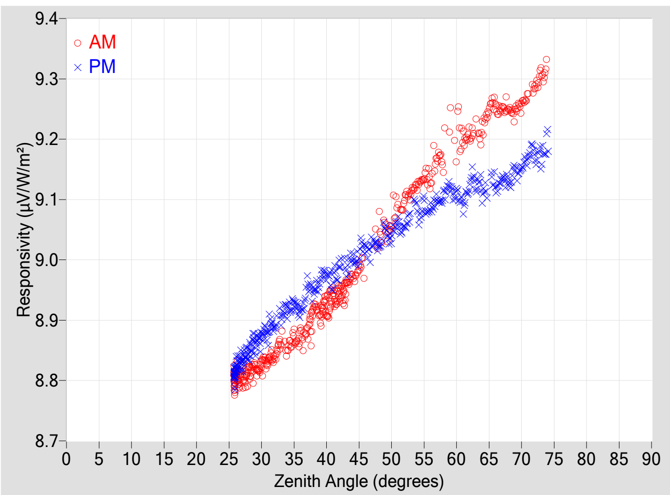


Figure 2. Responsivity vs Local Standard Time

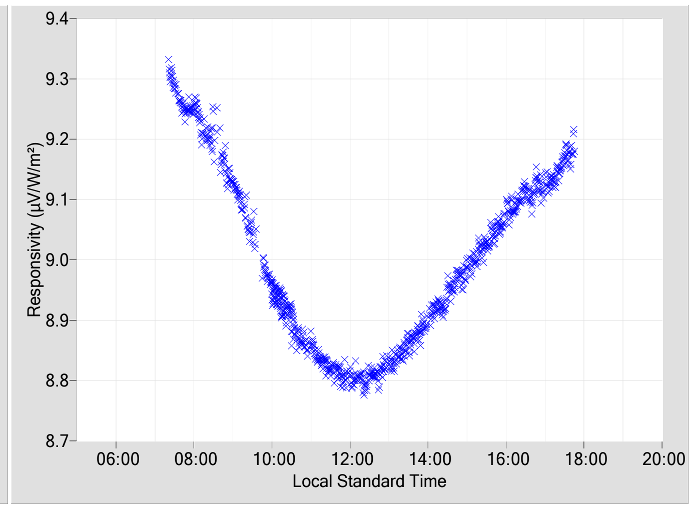


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.9694	0.31	113.91	9.0195	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0427	0.37	111.23	9.0224	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0541	0.32	109.07	9.0407	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0980	0.35	106.91	9.0559	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1238	0.35	104.99	9.0812	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1306	0.36	103.02	9.0851	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1709	0.38	101.31	9.1045	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2022	0.43	99.55	9.1121	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2054	0.40	97.82	9.1237	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2147	0.39	96.23	9.1097	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2577	0.40	94.62	9.1250	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	9.2491	N/A	93.04	9.1289	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	9.2568	N/A	91.54	9.1509	N/A	268.69
26	8.8027	0.31	173.74	8.8135	0.31	186.47	72	9.2847	N/A	90.03	9.1737	N/A	270.19
28	8.8128	0.30	153.89	8.8469	0.30	206.03	74	9.3241	N/A	88.71	9.1949	N/A	271.64
30	8.8253	0.29	144.86	8.8709	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.8386	0.32	138.25	8.8904	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8524	0.31	132.87	8.9200	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8736	0.34	128.57	8.9145	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.9144	0.35	125.45	8.9448	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9238	0.34	121.62	8.9746	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9469	0.32	118.58	8.9887	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9734	0.31	116.26	9.0008	0.35	244.37	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

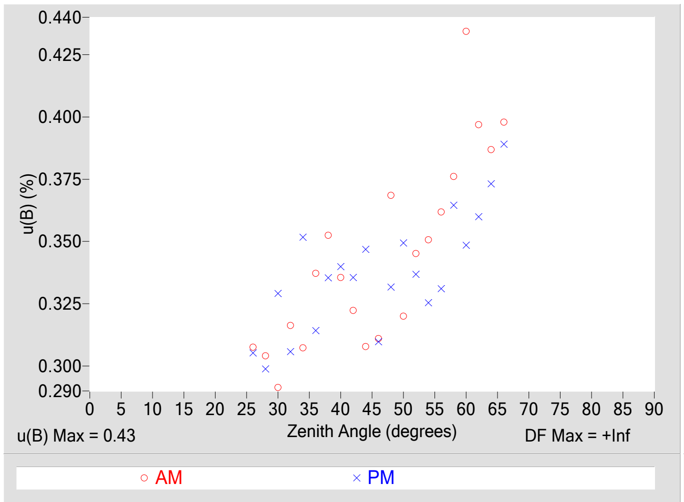


Figure 4. Residuals from Spline Interpolation

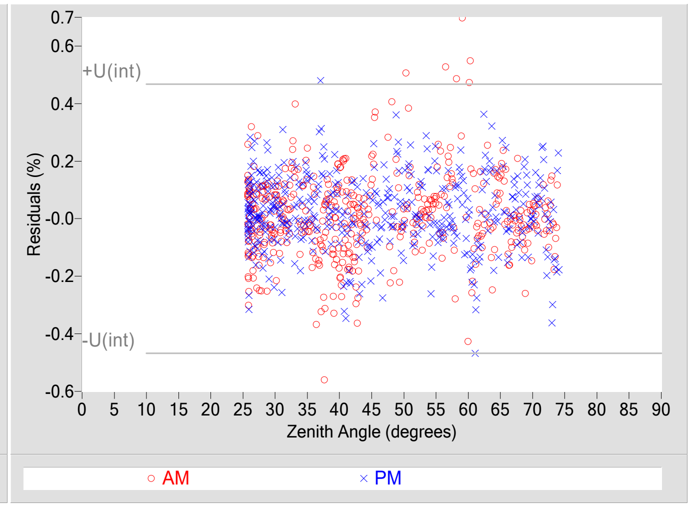


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	16112
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

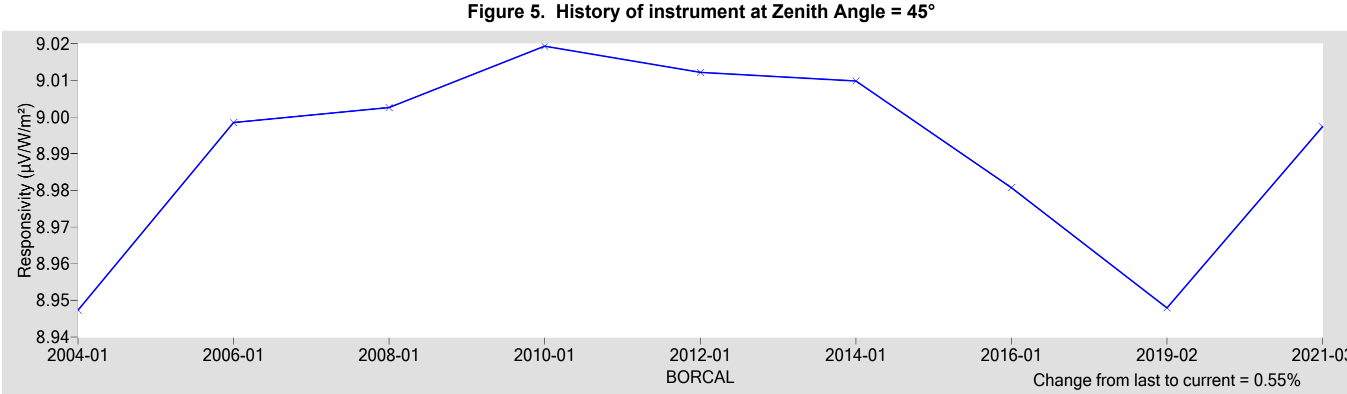
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.9973	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.85
Offset Uncertainty, U(off) (%)	+2.3 / -1.9
Expanded Uncertainty, U (%)	+3.1 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	34281
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____________________________________ ________________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

34281 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

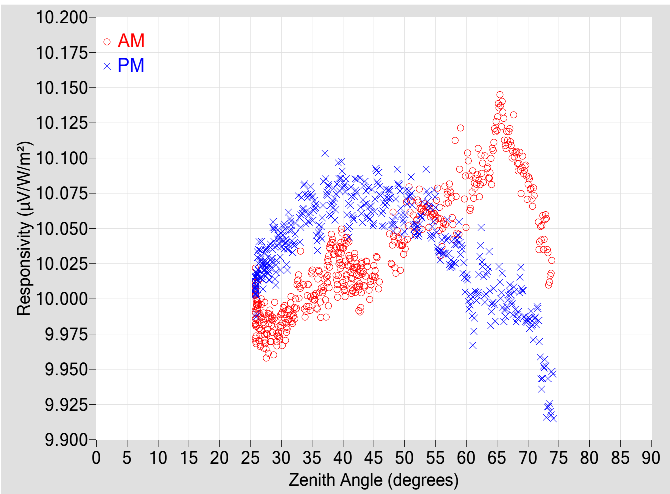


Figure 2. Responsivity vs Local Standard Time

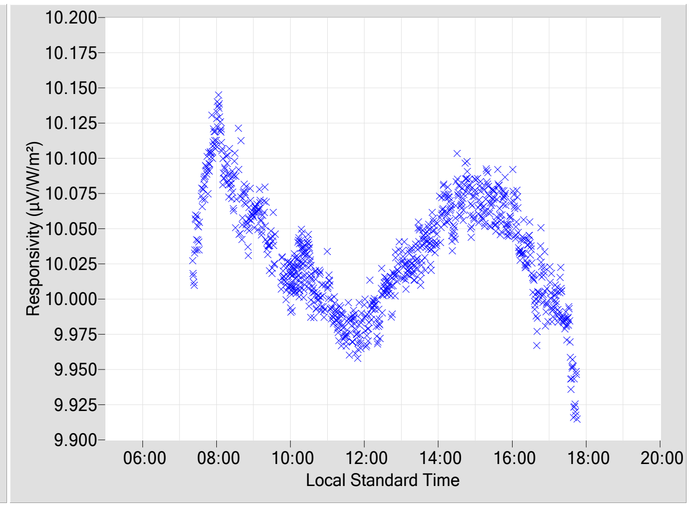


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.010	0.31	113.84	10.076	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.039	0.36	111.23	10.056	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.036	0.32	109.07	10.061	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.059	0.35	106.91	10.049	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.061	0.35	104.99	10.064	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.046	0.36	103.02	10.034	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.066	0.38	101.31	10.031	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.078	0.46	99.58	10.012	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.087	0.40	97.82	10.018	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.093	0.39	96.23	9.9943	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.128	0.40	94.62	9.9970	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	10.102	N/A	93.04	9.9925	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	10.082	N/A	91.54	9.9837	N/A	268.69
26	9.9935	0.31	173.54	10.012	0.31	186.47	72	10.044	N/A	90.03	9.9583	N/A	270.19
28	9.9800	0.30	153.89	10.024	0.30	206.03	74	10.023	N/A	88.71	9.9319	N/A	271.64
30	9.9814	0.29	144.86	10.039	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	9.9895	0.32	138.25	10.042	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.9963	0.31	132.87	10.070	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	10.007	0.34	128.57	10.045	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	10.033	0.35	125.45	10.063	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	10.027	0.34	121.62	10.086	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.020	0.32	118.58	10.075	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.021	0.31	116.26	10.066	0.35	244.37	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

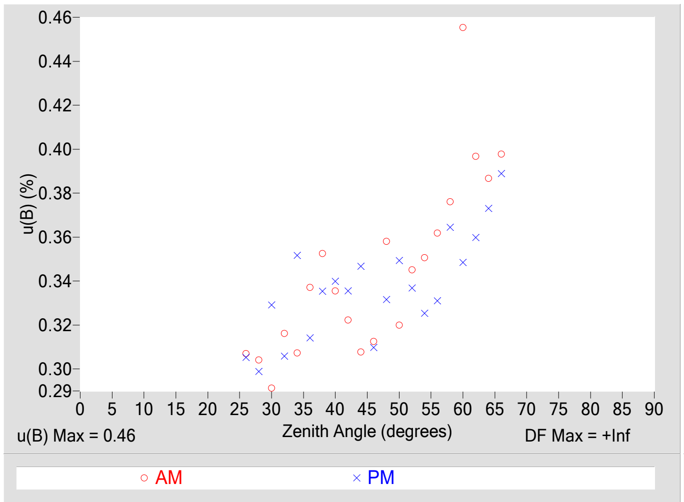


Figure 4. Residuals from Spline Interpolation

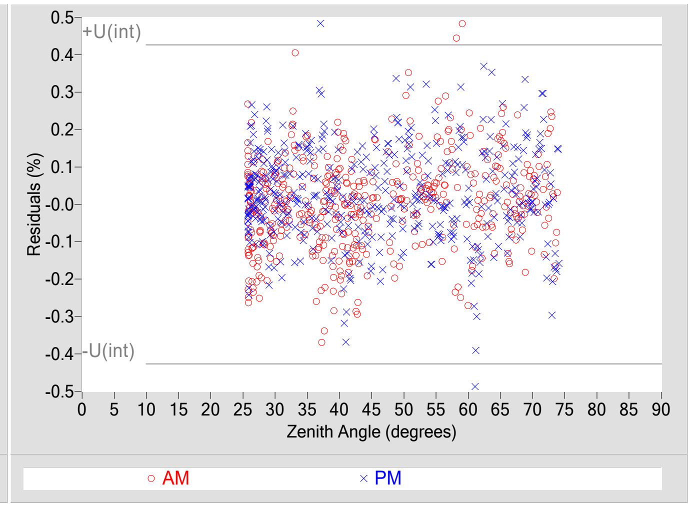


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	25561
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

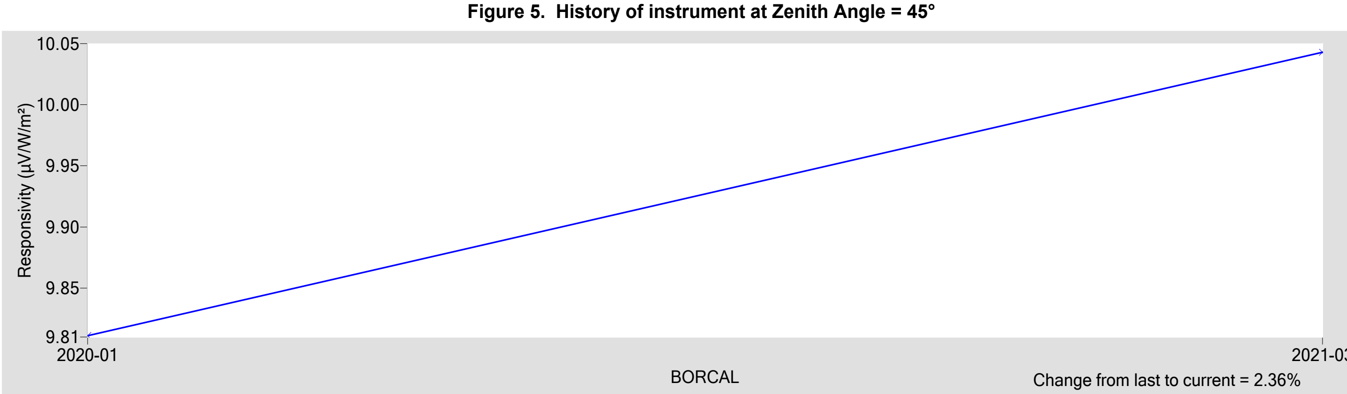
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.043	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+0.43 / -0.61
Expanded Uncertainty, U (%)	+1.3 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	35830F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	AMF#2	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ____________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

35830F3 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

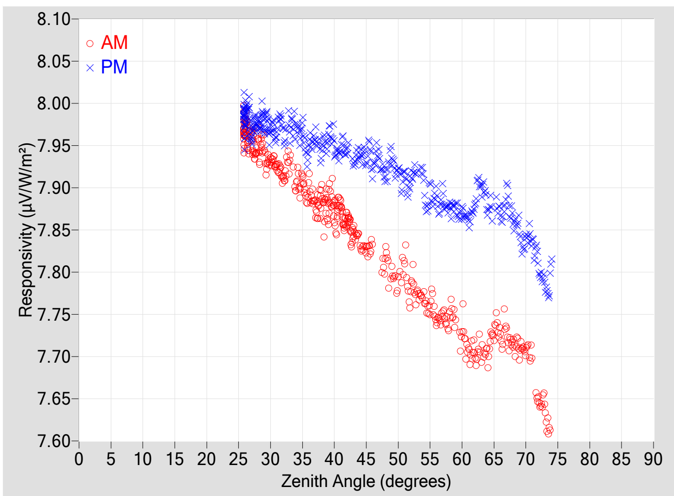


Figure 2. Responsivity vs Local Standard Time

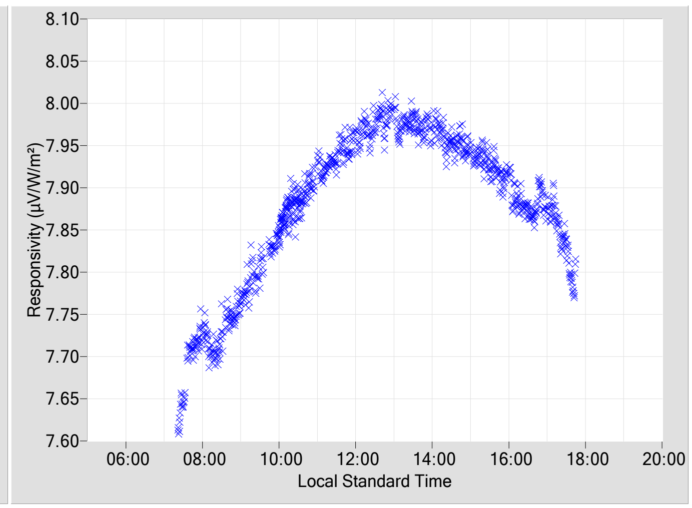


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8321	0.39	113.84	7.9225	0.36	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8150	0.38	111.23	7.9124	0.33	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7872	0.38	109.04	7.9208	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7809	0.35	106.91	7.9096	0.36	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7681	0.34	104.90	7.9038	0.37	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7428	0.37	103.07	7.8892	0.35	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7461	0.38	101.23	7.8742	0.36	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7303	0.42	99.50	7.8710	0.37	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7034	0.43	97.87	7.8788	0.39	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7030	0.47	96.17	7.8763	0.40	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7224	0.41	94.62	7.8683	0.42	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.7152	N/A	93.08	7.8629	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.7074	N/A	91.58	7.8379	N/A	268.74
26	7.9696	0.32	173.50	7.9851	0.33	186.71	72	7.6471	N/A	90.07	7.8047	N/A	270.24
28	7.9472	0.30	153.71	7.9755	0.32	206.00	74	7.6130	N/A	88.71	7.8080	N/A	271.64
30	7.9316	0.31	144.83	7.9683	0.33	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.9104	0.30	138.24	7.9624	0.30	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9055	0.30	132.90	7.9704	0.35	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8948	0.33	128.57	7.9456	0.32	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8871	0.34	125.41	7.9443	0.32	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8749	0.35	121.67	7.9504	0.33	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8627	0.33	118.61	7.9454	0.35	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8350	0.39	116.20	7.9403	0.35	244.37	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

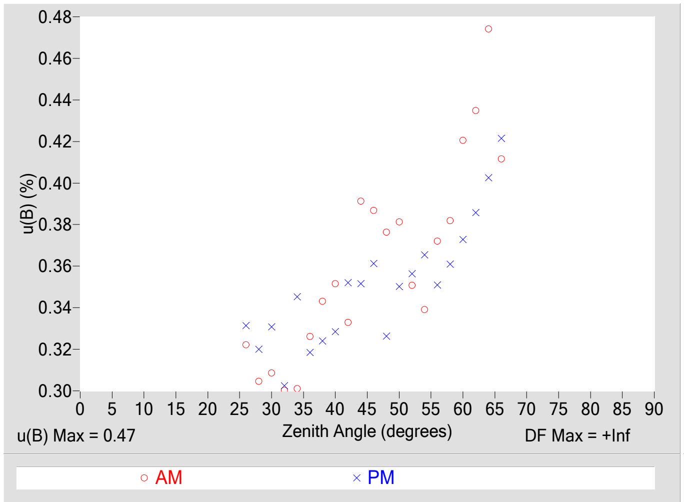


Figure 4. Residuals from Spline Interpolation

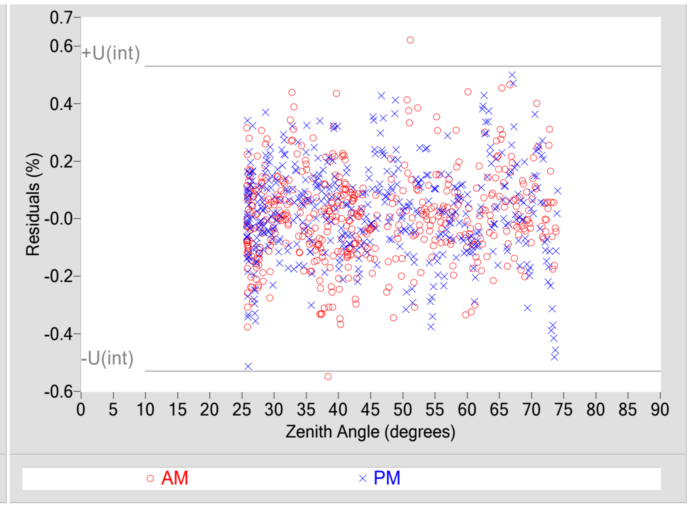


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.47
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	14725
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

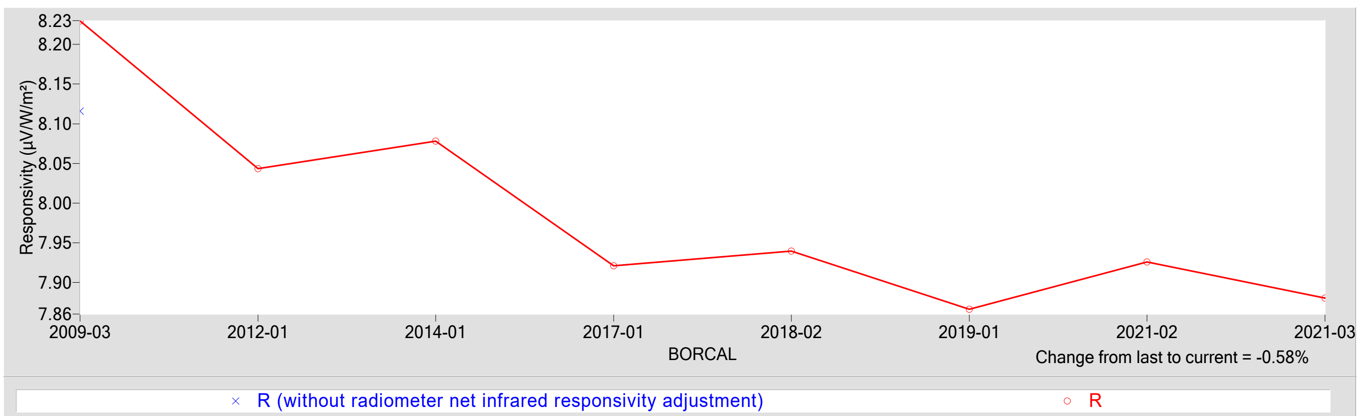
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8801	0.54714

† Rnet determination date: 08/05/2009

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.82
Offset Uncertainty, U(off) (%)	+1.1 / -1.9
Expanded Uncertainty, U (%)	+2.0 / -2.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated)
Manufacturer: Eppley
Model: 8-48
Serial Number: 35864
Calibration Date: 8/25/2021
Due Date: 8/25/2022
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 8/24-25

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

35864 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

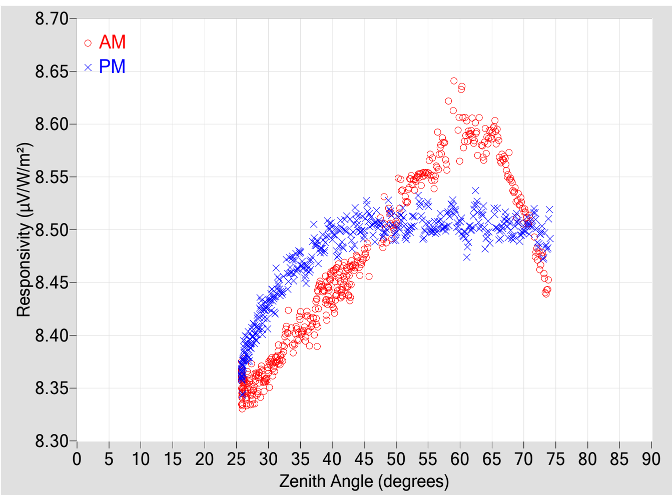


Figure 2. Responsivity vs Local Standard Time

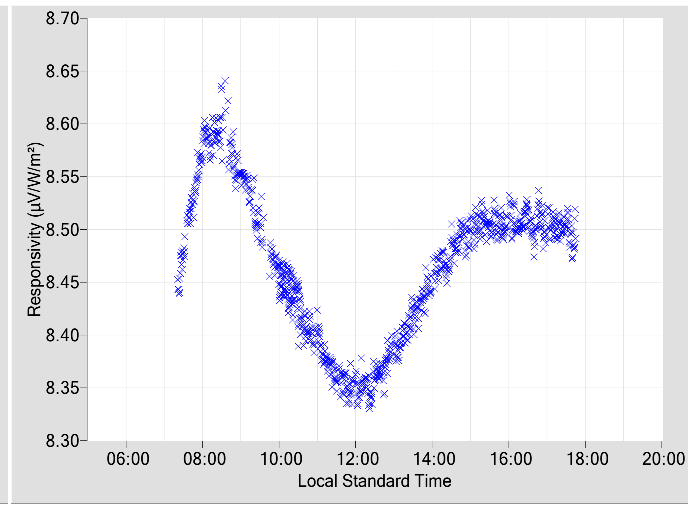


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.4557	0.31	113.91	8.5093	0.31	246.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4996	0.36	111.23	8.4972	0.33	249.17
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5061	0.32	109.07	8.4990	0.35	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5401	0.35	106.91	8.4999	0.34	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5525	0.36	104.99	8.5119	0.33	255.39
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5497	0.36	103.02	8.5008	0.33	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5767	0.38	101.31	8.5076	0.36	259.08
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5996	0.46	99.58	8.5063	0.35	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5906	0.40	97.82	8.5115	0.36	262.51
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5809	0.39	96.23	8.4933	0.37	264.13
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5840	0.40	94.62	8.5027	0.39	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5448	N/A	93.04	8.4978	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5157	N/A	91.54	8.4990	N/A	268.69
26	8.3532	0.31	173.54	8.3697	0.31	186.47	72	8.4769	N/A	90.03	8.4996	N/A	270.19
28	8.3541	0.30	153.89	8.4047	0.30	206.03	74	8.4478	N/A	88.71	8.5010	N/A	271.64
30	8.3660	0.29	144.86	8.4267	0.33	214.96	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3792	0.32	138.25	8.4427	0.31	221.66	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3945	0.31	132.87	8.4674	0.35	226.88	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4096	0.34	128.57	8.4595	0.31	231.28	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4397	0.35	125.45	8.4785	0.34	235.26	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4437	0.34	121.62	8.4981	0.34	238.57	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4558	0.32	118.58	8.5005	0.34	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4720	0.31	116.26	8.5059	0.35	244.37	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

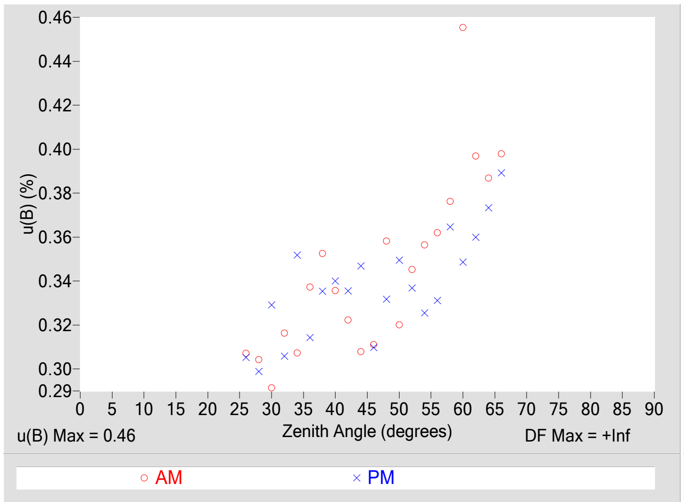


Figure 4. Residuals from Spline Interpolation

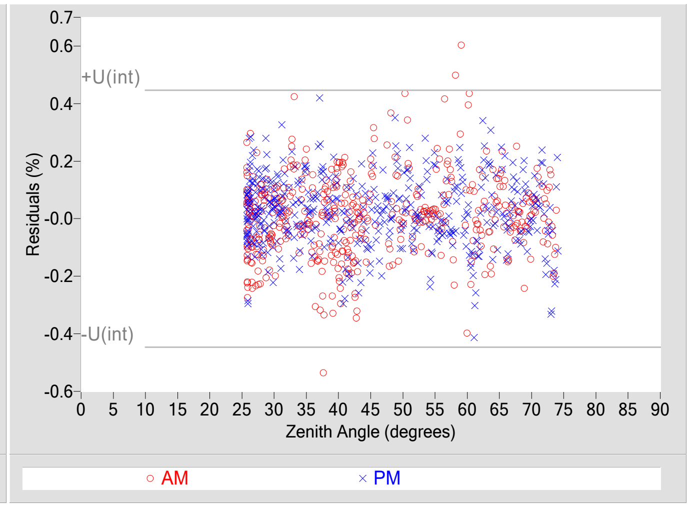


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	21874
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

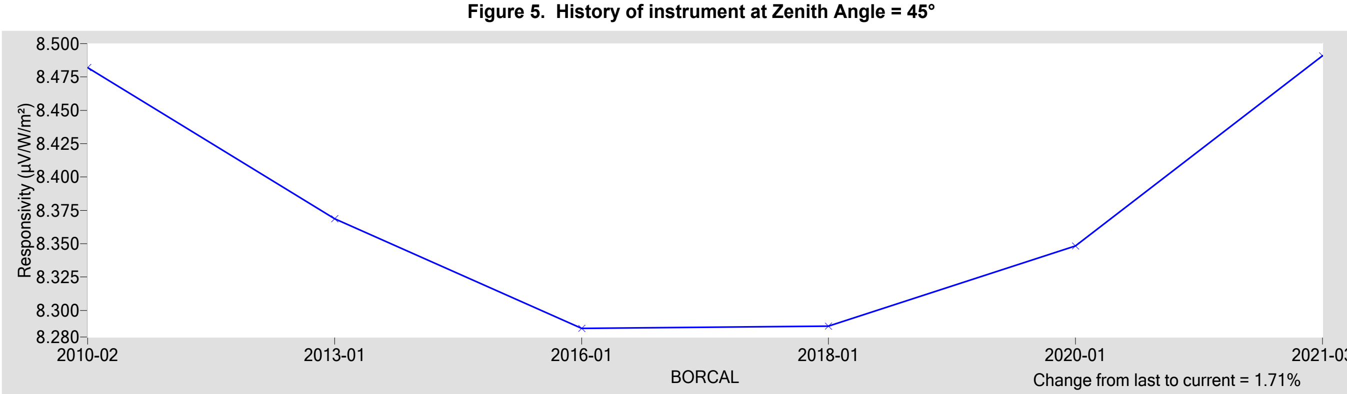
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4908	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.89
Offset Uncertainty, U(off) (%)	+1.3 / -1.5
Expanded Uncertainty, U (%)	+2.2 / -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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	36291F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	AMF#2	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

36291F3 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

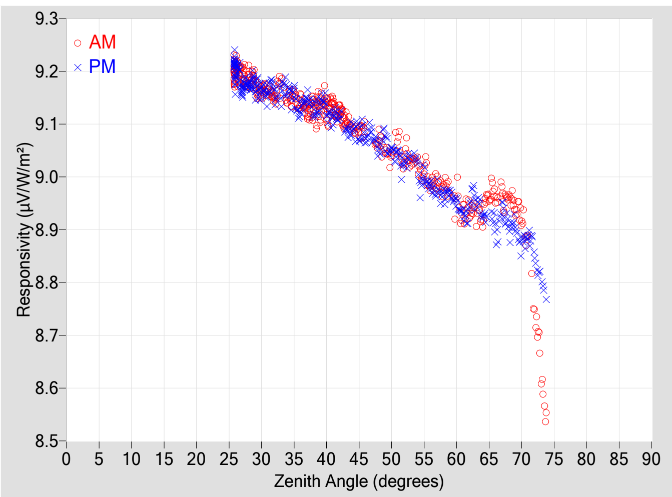


Figure 2. Responsivity vs Local Standard Time

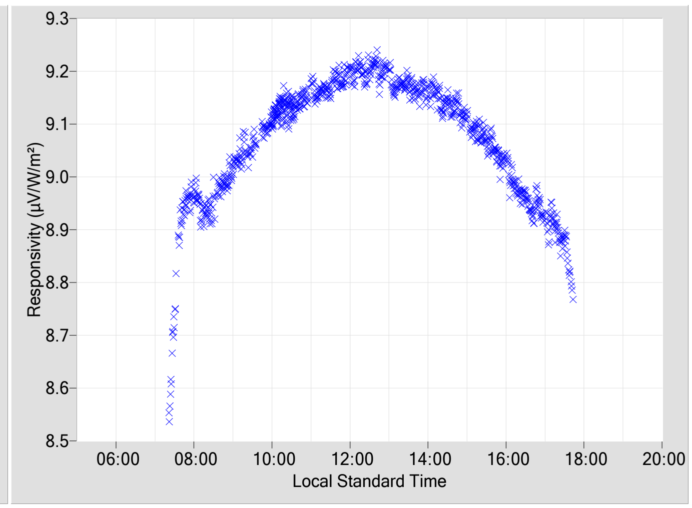


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.0946	0.40	113.84	9.0706	0.39	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0692	0.39	111.23	9.0480	0.36	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0353	0.40	109.04	9.0538	0.38	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0385	0.37	106.91	9.0298	0.39	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0226	0.36	104.90	9.0173	0.41	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9832	0.40	103.07	8.9858	0.40	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9816	0.41	101.23	8.9626	0.41	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9605	0.47	99.50	8.9512	0.43	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9363	0.46	97.87	8.9396	0.45	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9277	0.50	96.17	8.9265	0.47	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9609	0.44	94.62	8.9022	0.50	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.9612	N/A	93.08	8.9062	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.9190	N/A	91.58	8.8752	N/A	268.74
26	9.2012	0.34	173.50	9.2046	0.35	186.73	72	8.7379	N/A	90.04	8.8467	N/A	270.24
28	9.1839	0.32	153.71	9.1739	0.34	206.00	74	8.5531	N/A	88.71	8.7680	N/A	271.55
30	9.1631	0.33	144.83	9.1612	0.35	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	9.1473	0.32	138.24	9.1550	0.32	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	9.1482	0.32	132.90	9.1667	0.36	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1396	0.34	128.57	9.1276	0.34	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1357	0.37	125.33	9.1261	0.35	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1330	0.37	121.67	9.1291	0.35	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1255	0.35	118.61	9.1159	0.38	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0936	0.41	116.20	9.0919	0.38	244.37	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

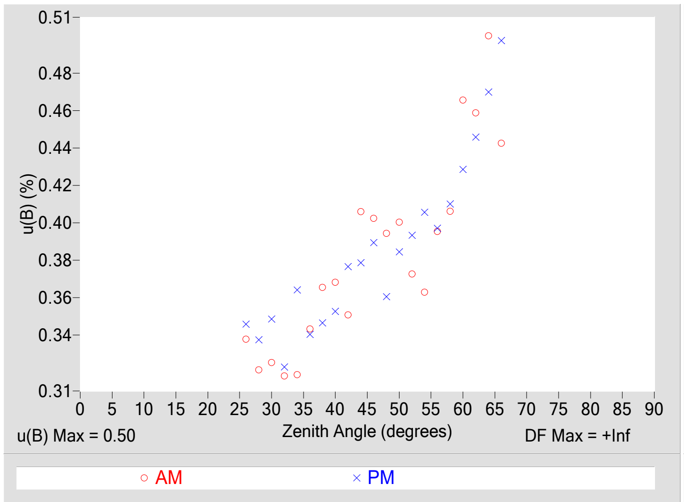


Figure 4. Residuals from Spline Interpolation

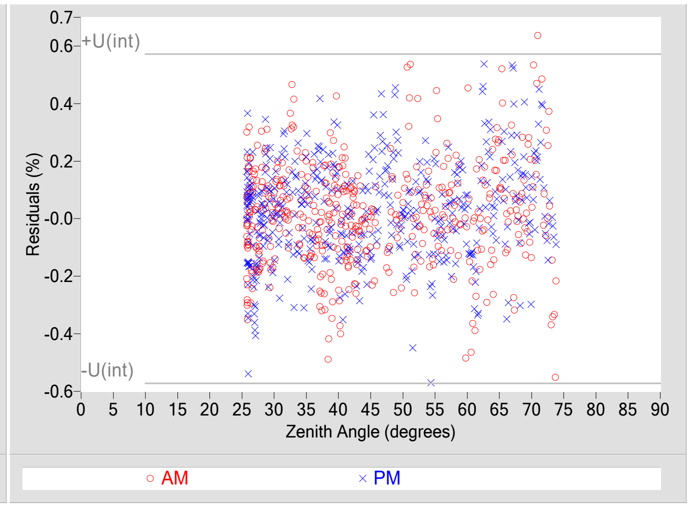


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.50
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	13623
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

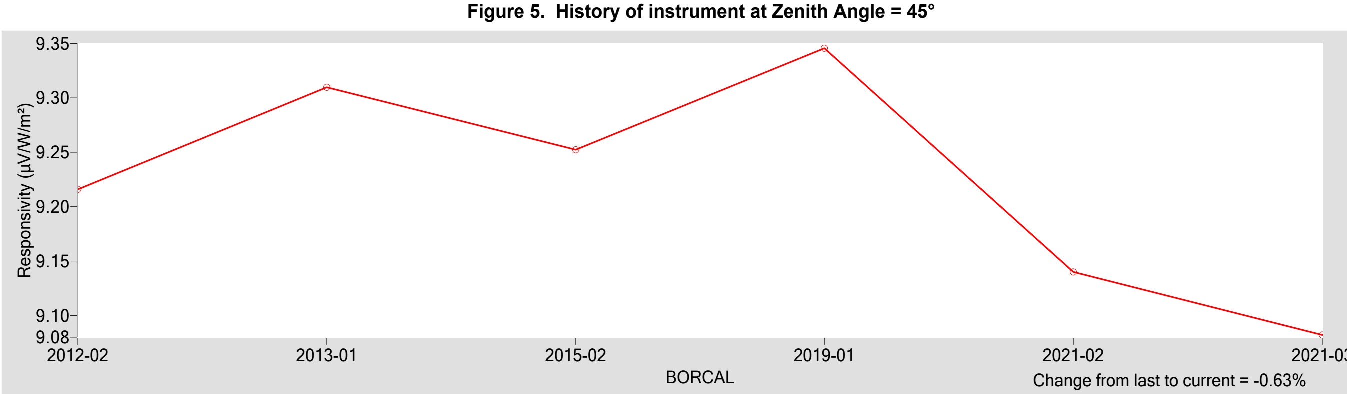
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.0822	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.91
Offset Uncertainty, U(off) (%)	+0.93 / -1.4
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	37286E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

_______________________________ _______________

Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37286E6 Eppley NIP

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

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

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

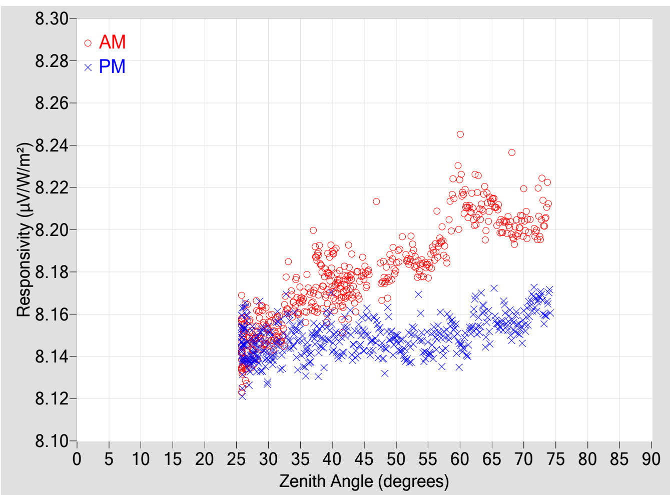


Figure 2. Responsivity vs Local Standard Time

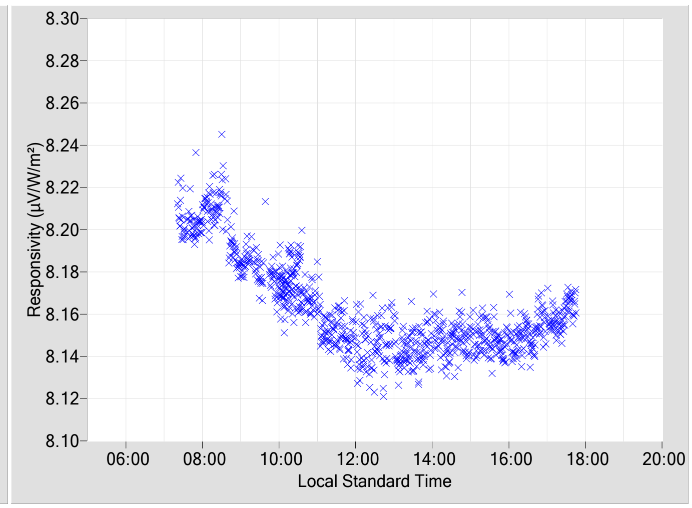


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1788	0.29	113.93	8.1450	0.30	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1758	0.31	111.25	8.1401	0.30	249.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1813	0.32	109.09	8.1490	0.31	251.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1852	0.29	106.93	8.1435	0.31	253.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1818	0.31	104.89	8.1497	0.31	255.41
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1896	0.31	103.04	8.1473	0.31	257.34
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1919	0.30	101.23	8.1508	0.30	259.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2222	0.34	99.47	8.1439	0.30	260.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2085	0.30	97.83	8.1594	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2099	0.30	96.24	8.1528	0.30	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2050	0.30	94.59	8.1546	0.33	265.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.1998	N/A	93.08	8.1541	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2053	N/A	91.55	8.1544	N/A	268.70
26	8.1441	0.30	173.47	8.1465	0.30	186.51	72	8.2021	N/A	90.04	8.1649	N/A	270.21
28	8.1503	0.30	153.88	8.1413	0.30	205.96	74	8.2173	N/A	88.71	8.1668	N/A	271.65
30	8.1533	0.31	144.87	8.1419	0.30	215.00	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.1505	0.30	138.19	8.1432	0.31	221.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1654	0.30	132.97	8.1516	0.31	226.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1670	0.29	128.56	8.1399	0.31	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1804	0.32	125.27	8.1439	0.31	235.23	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1805	0.31	121.68	8.1514	0.29	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1731	0.31	118.64	8.1517	0.31	241.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1737	0.31	116.17	8.1471	0.29	244.36	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

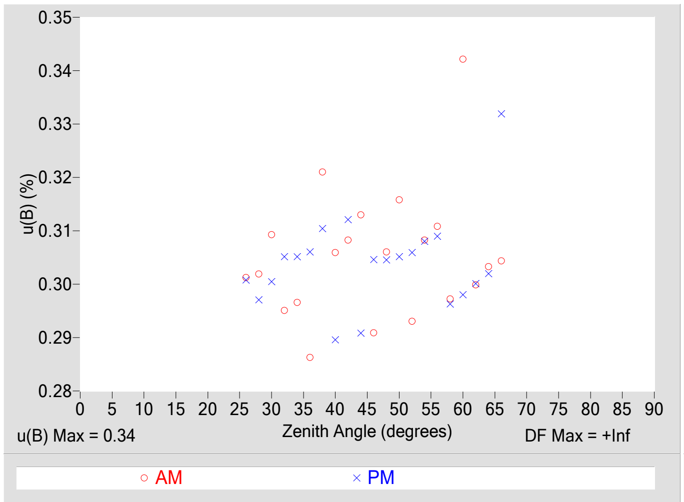


Figure 4. Residuals from Spline Interpolation

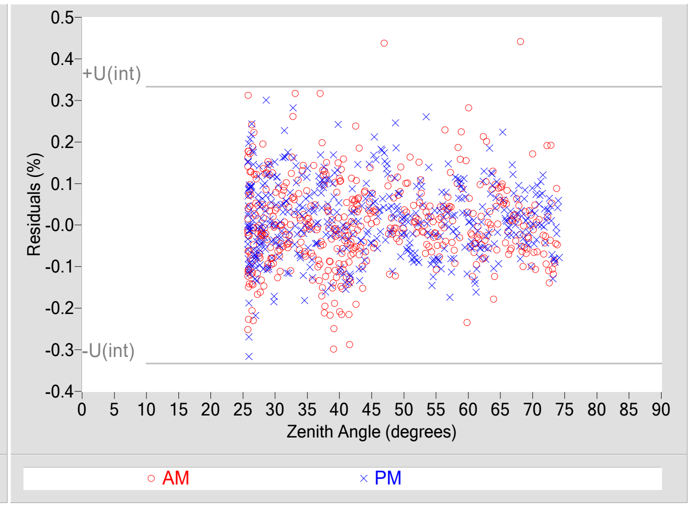


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	22755
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

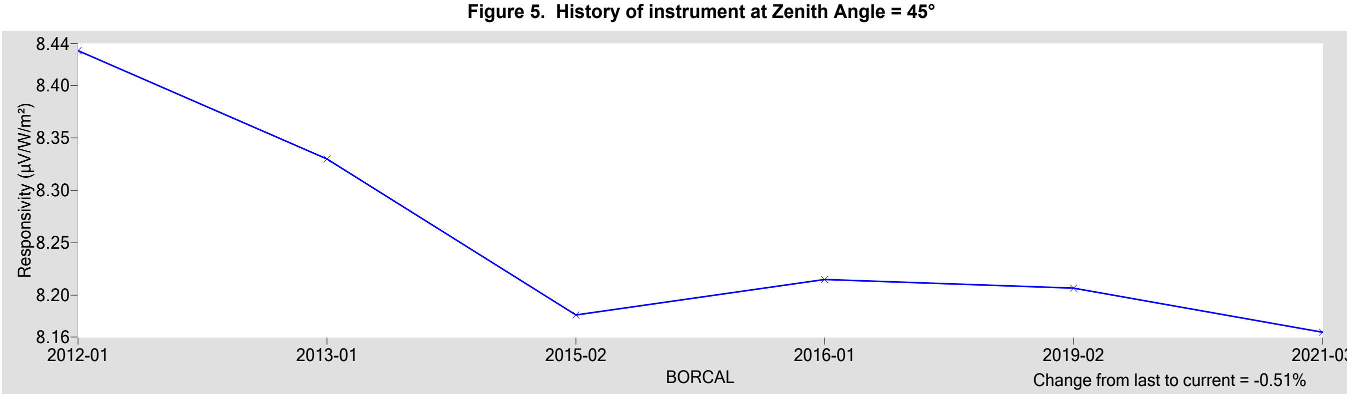
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.1646	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.71 / -0.30
Expanded Uncertainty, U (%)	+1.4 / -0.97
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	37297F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____　________________
Peter Gotseff, Technical Manager　Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37297F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

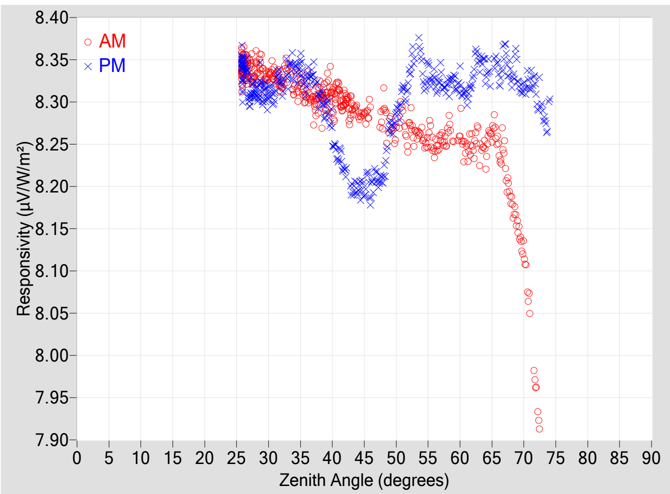


Figure 2. Responsivity vs Local Standard Time

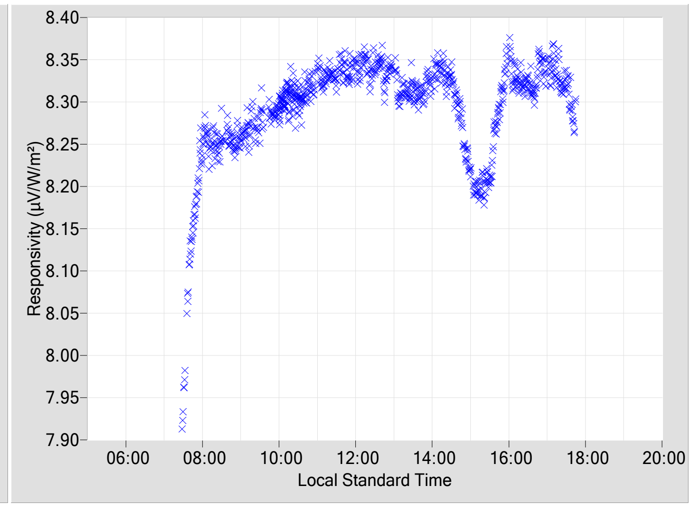


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.2927	0.41	113.84	8.1924	0.40	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2890	0.40	111.23	8.2117	0.37	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2641	0.41	109.04	8.2870	0.39	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2676	0.38	106.91	8.3284	0.40	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2604	0.37	104.90	8.3442	0.41	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2439	0.40	103.07	8.3274	0.41	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2625	0.41	101.23	8.3170	0.42	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2664	0.41	99.45	8.3208	0.44	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2469	0.46	97.87	8.3271	0.46	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2412	0.51	96.17	8.3374	0.48	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2450	0.45	94.62	8.3329	0.51	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.1857	N/A	93.08	8.3319	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.1202	N/A	91.58	8.3162	N/A	268.74
26	8.3423	0.34	173.50	8.3400	0.35	186.71	72	7.9573	N/A	90.09	8.3019	N/A	270.24
28	8.3380	0.33	153.71	8.3109	0.34	206.00	74	N/A	N/A	N/A	8.3019	N/A	271.68
30	8.3317	0.33	144.83	8.3068	0.35	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3190	0.32	138.24	8.3185	0.33	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3178	0.32	132.90	8.3402	0.37	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3127	0.35	128.57	8.3243	0.35	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3090	0.36	125.41	8.3058	0.35	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3071	0.37	121.67	8.2631	0.36	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3029	0.36	118.61	8.2193	0.38	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2881	0.41	116.20	8.1985	0.39	244.37	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

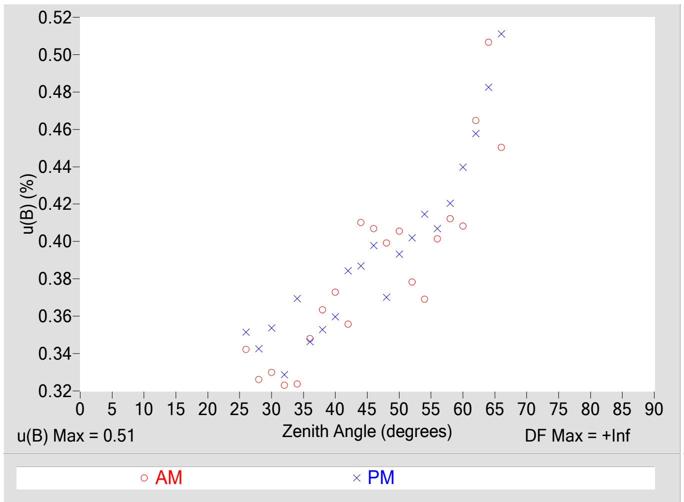


Figure 4. Residuals from Spline Interpolation

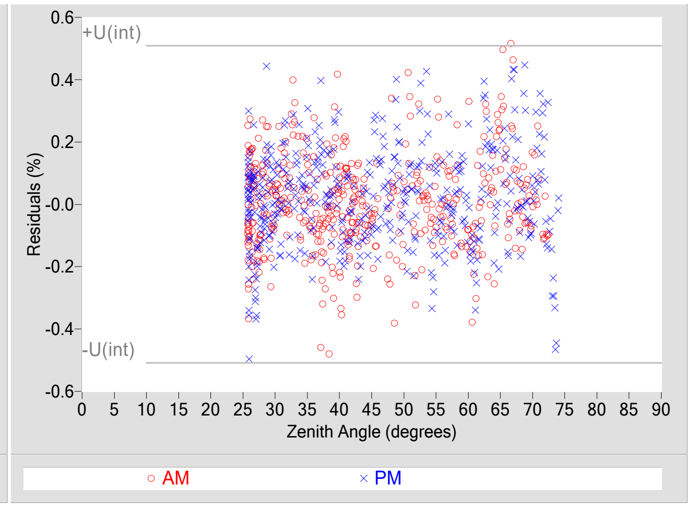


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.51
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	21140
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

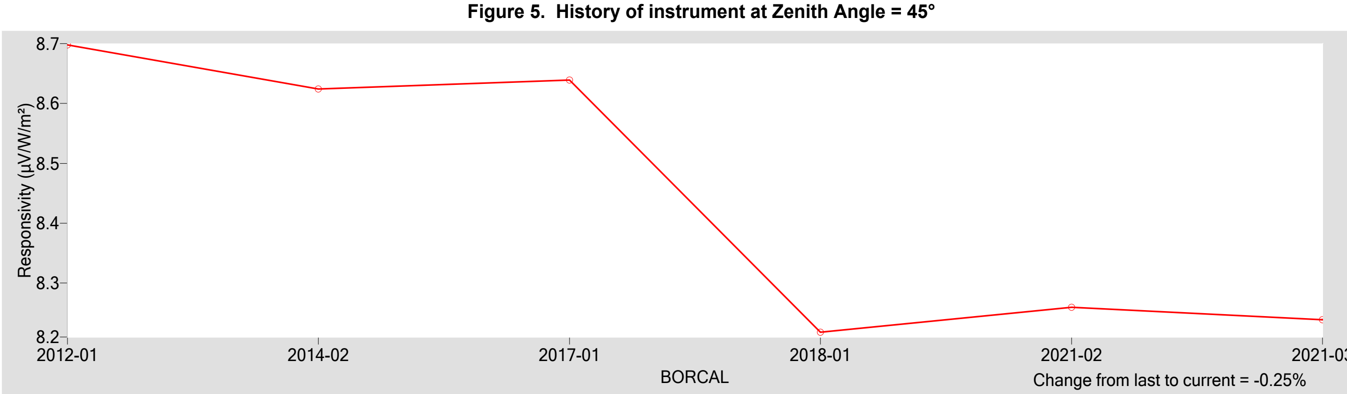
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.2387	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.86
Offset Uncertainty, U(off) (%)	+1.3 / -0.56
Expanded Uncertainty, U (%)	+2.1 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Precision Spectral Pyranometer (Ventilated)
Manufacturer: Eppley
Model: PSP
Serial Number: 37300F3
Calibration Date: 8/25/2021
Due Date: 8/25/2022
Customer: NSA
Environmental Conditions: see page 4
Test Dates: 8/24-25

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ _______________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37300F3 Eppley PSP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

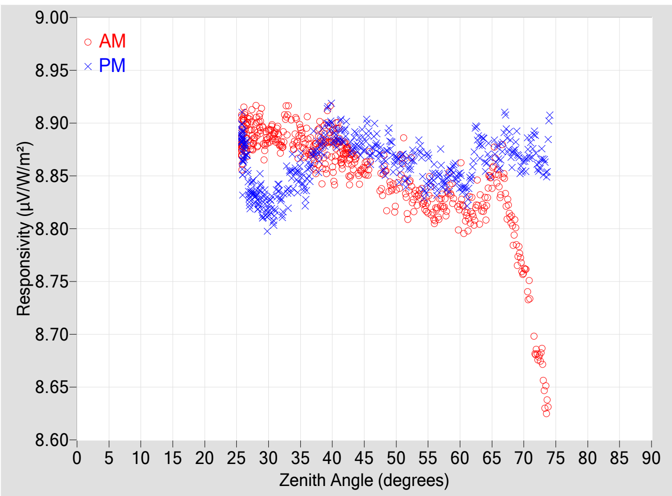


Figure 2. Responsivity vs Local Standard Time

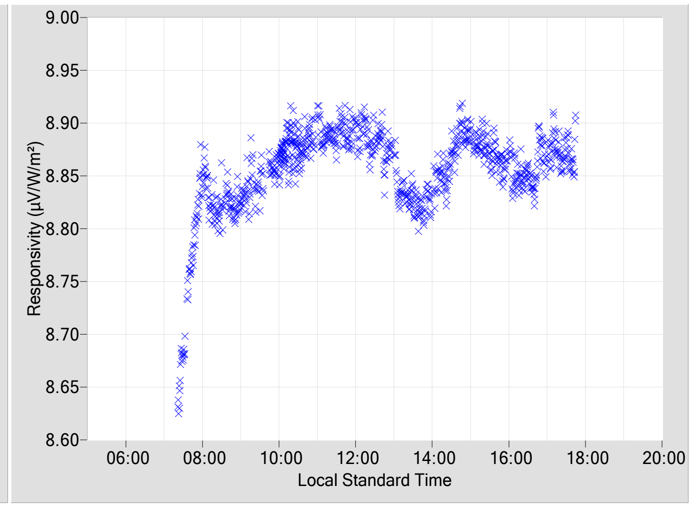


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.8640	0.40	113.84	8.8695	0.39	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8507	0.40	111.23	8.8576	0.36	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8294	0.40	109.04	8.8665	0.39	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8360	0.37	106.91	8.8574	0.40	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8287	0.36	104.90	8.8611	0.41	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8113	0.40	103.07	8.8498	0.40	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8303	0.41	101.23	8.8442	0.41	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8259	0.45	99.50	8.8464	0.43	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8150	0.46	97.87	8.8588	0.45	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8217	0.50	96.17	8.8655	0.47	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8439	0.44	94.62	8.8673	0.50	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.8091	N/A	93.08	8.8746	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.7595	N/A	91.58	8.8607	N/A	268.74
26	8.8868	0.34	173.50	8.8779	0.35	186.73	72	8.6810	N/A	90.07	8.8663	N/A	270.24
28	8.8929	0.32	153.71	8.8292	0.34	206.00	74	8.6312	N/A	88.71	8.8980	N/A	271.64
30	8.8876	0.33	144.83	8.8166	0.35	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.8778	0.32	138.24	8.8205	0.33	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.8846	0.32	132.90	8.8508	0.37	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8827	0.34	128.57	8.8430	0.34	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8829	0.37	125.33	8.8713	0.35	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8778	0.37	121.67	8.8945	0.35	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8751	0.35	118.61	8.8916	0.38	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8563	0.41	116.20	8.8809	0.38	244.37	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

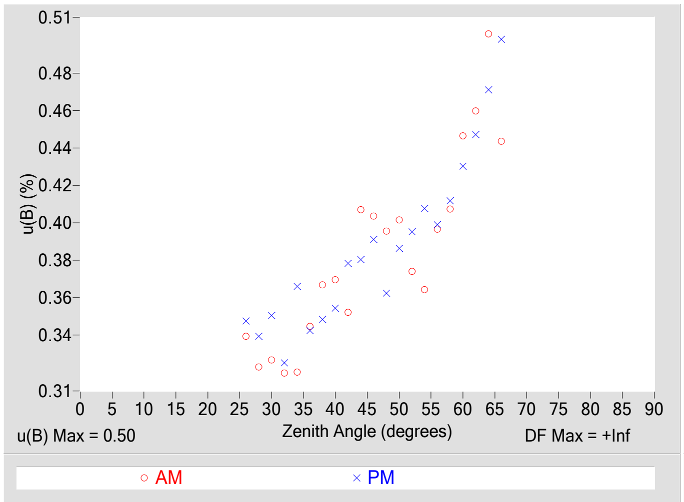


Figure 4. Residuals from Spline Interpolation

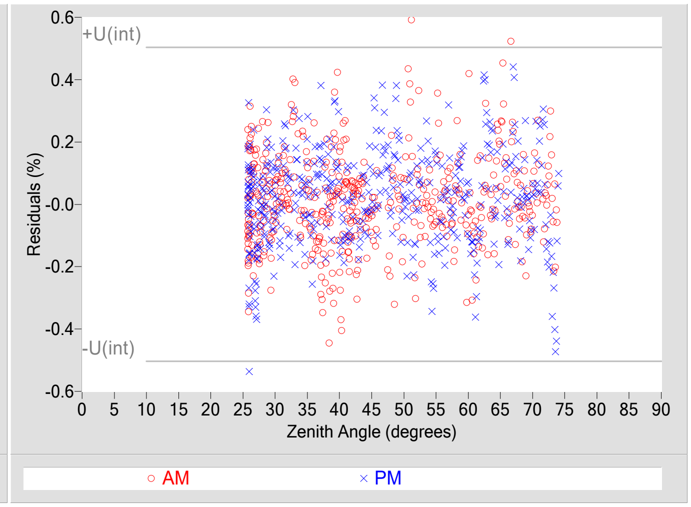


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.50
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.56
Effective degrees of freedom, DF(c)	20520
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

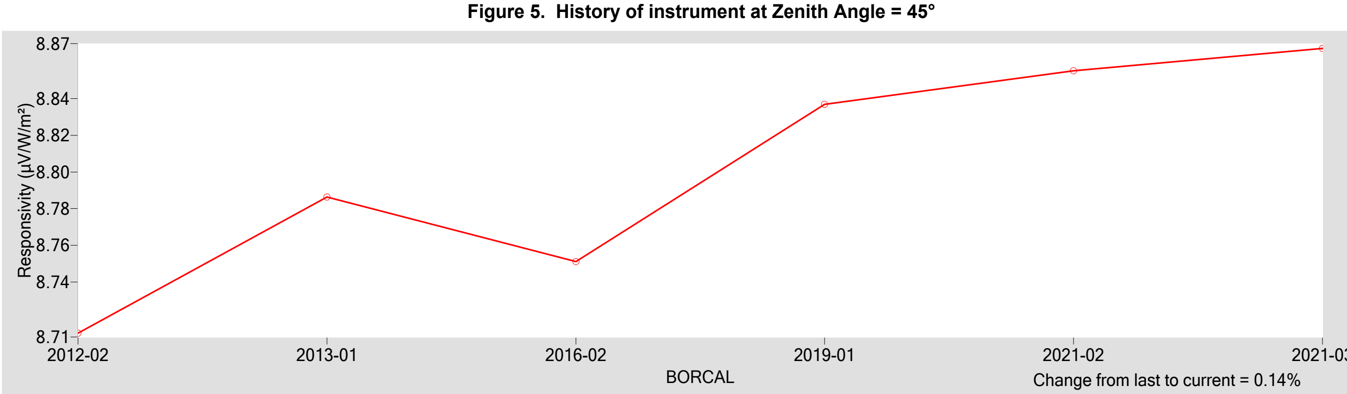
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8673	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.88
Offset Uncertainty, U(off) (%)	+0.31 / -0.63
Expanded Uncertainty, U (%)	+1.2 / -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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37945E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____ ________________

Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37945E6 Eppley sNIP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

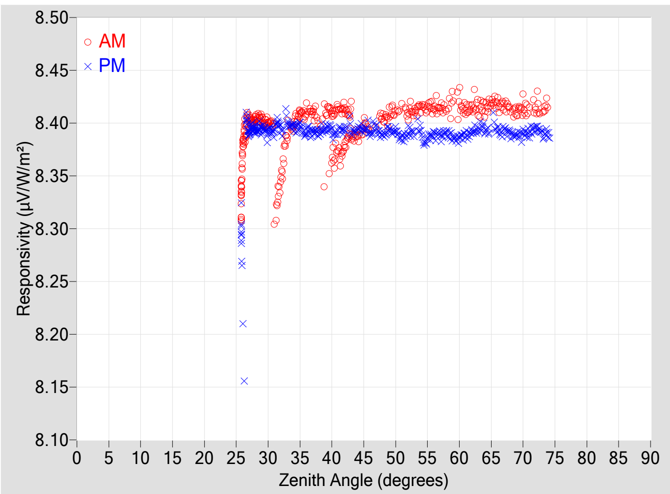


Figure 2. Responsivity vs Local Standard Time

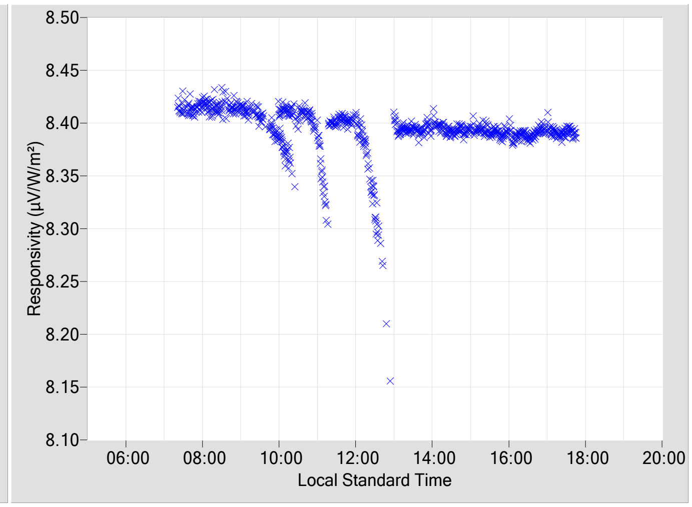


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3942	0.29	113.93	8.3897	0.30	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4038	0.31	111.25	8.3889	0.30	249.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4094	0.29	109.16	8.3932	0.31	251.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4085	0.29	106.93	8.3923	0.31	253.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4149	0.31	104.89	8.3917	0.31	255.41
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4126	0.31	103.04	8.3891	0.31	257.34
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4125	0.30	101.23	8.3899	0.30	259.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4171	0.34	99.47	8.3855	0.30	260.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4144	0.30	97.83	8.3917	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4152	0.30	96.24	8.3935	0.30	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4167	0.30	94.59	8.3941	0.33	265.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.4135	N/A	93.15	8.3904	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.4142	N/A	91.55	8.3890	N/A	268.70
26	8.3557	0.30	173.47	8.2743	0.29	183.61	72	8.4153	N/A	90.04	8.3947	N/A	270.21
28	8.4023	0.30	153.88	8.3933	0.30	205.96	74	8.4193	N/A	88.71	8.3886	N/A	271.65
30	8.4004	0.31	144.87	8.3928	0.30	215.07	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3462	0.30	138.19	8.3942	0.31	221.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3981	0.30	132.97	8.3975	0.31	226.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4109	0.29	128.56	8.3913	0.31	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3979	0.34	124.82	8.3903	0.31	235.23	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3910	0.31	121.53	8.3920	0.29	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3957	0.31	118.64	8.3938	0.31	241.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3884	0.31	116.17	8.3942	0.29	244.36	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

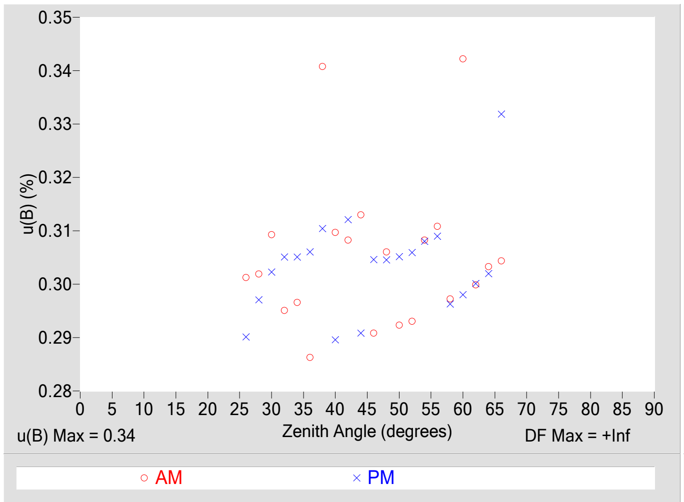


Figure 4. Residuals from Spline Interpolation

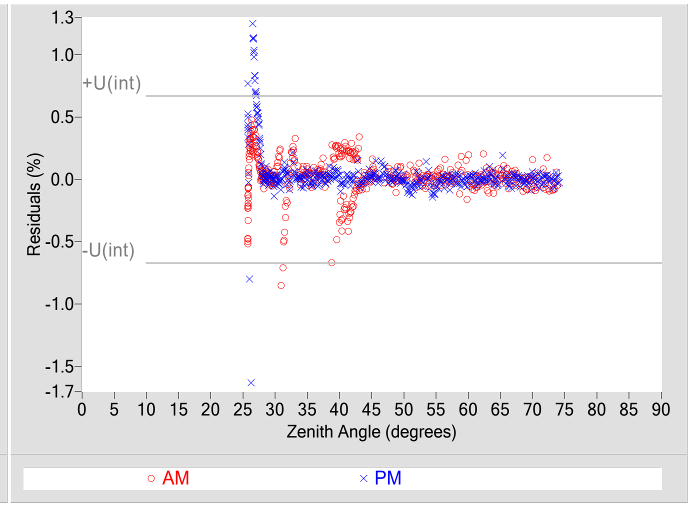


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	3264
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.94
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

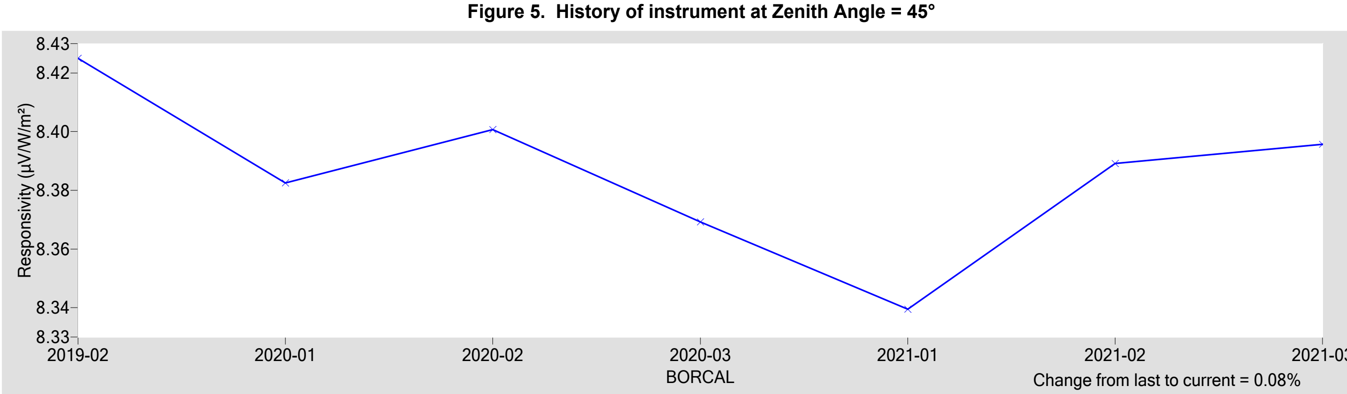
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3957	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.26 / -0.59
Expanded Uncertainty, U (%)	+0.93 / -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 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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37946E6
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022

† Through the World Radiometric Reference (WRR)

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

____________________________ ____________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

37946E6 Eppley sNIP

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

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

where,

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

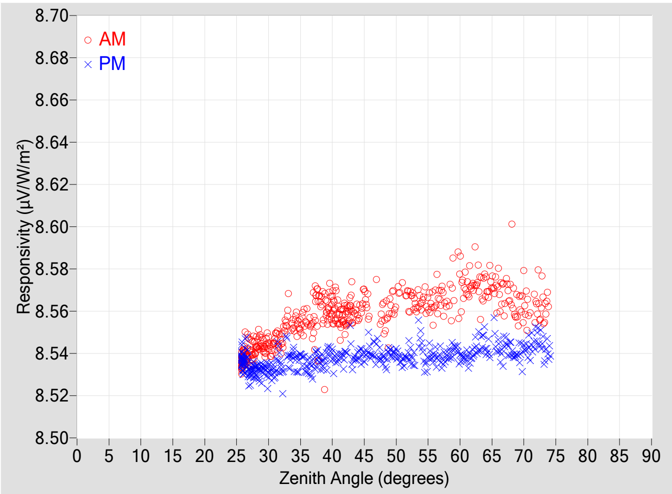


Figure 2. Responsivity vs Local Standard Time

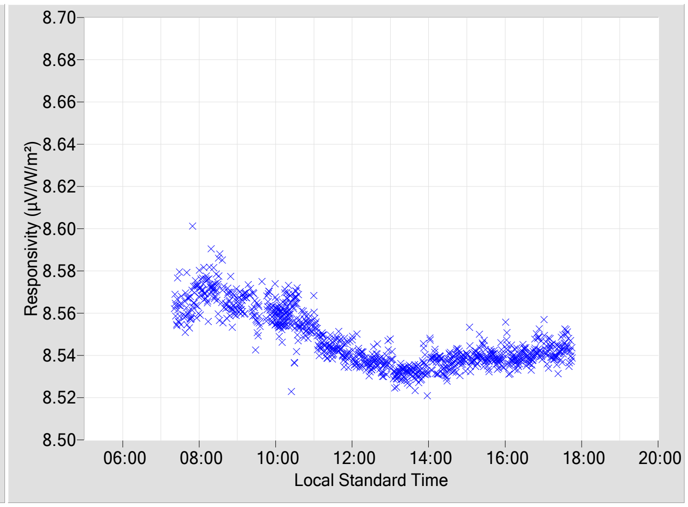


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5576	0.29	113.93	8.5398	0.30	246.88
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5575	0.31	111.25	8.5379	0.30	249.19
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5612	0.29	109.16	8.5400	0.31	251.38
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5655	0.29	106.93	8.5408	0.31	253.45
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5641	0.31	104.89	8.5452	0.31	255.41
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5620	0.31	103.04	8.5382	0.31	257.34
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5631	0.30	101.23	8.5386	0.30	259.09
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5707	0.34	99.47	8.5382	0.30	260.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5716	0.30	97.83	8.5402	0.30	262.52
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5732	0.30	96.24	8.5442	0.30	264.10
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5677	0.30	94.59	8.5428	0.33	265.64
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.5655	N/A	93.08	8.5428	N/A	267.21
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.5644	N/A	91.55	8.5399	N/A	268.70
26	8.5373	0.30	173.47	8.5365	0.30	186.51	72	8.5642	N/A	90.04	8.5485	N/A	270.21
28	8.5424	0.30	153.88	8.5317	0.30	205.96	74	8.5655	N/A	88.71	8.5399	N/A	271.65
30	8.5445	0.31	144.87	8.5322	0.30	215.07	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.5452	0.30	138.19	8.5323	0.31	221.56	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.5540	0.30	132.97	8.5385	0.31	226.94	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5560	0.29	128.56	8.5327	0.31	231.31	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5582	0.31	125.40	8.5361	0.31	235.23	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5617	0.31	121.68	8.5373	0.29	238.52	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5564	0.31	118.64	8.5387	0.31	241.58	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5587	0.31	116.17	8.5389	0.29	244.36	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

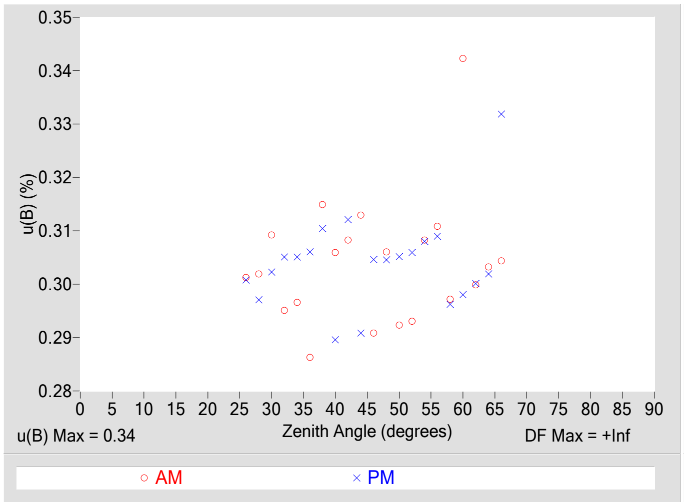


Figure 4. Residuals from Spline Interpolation

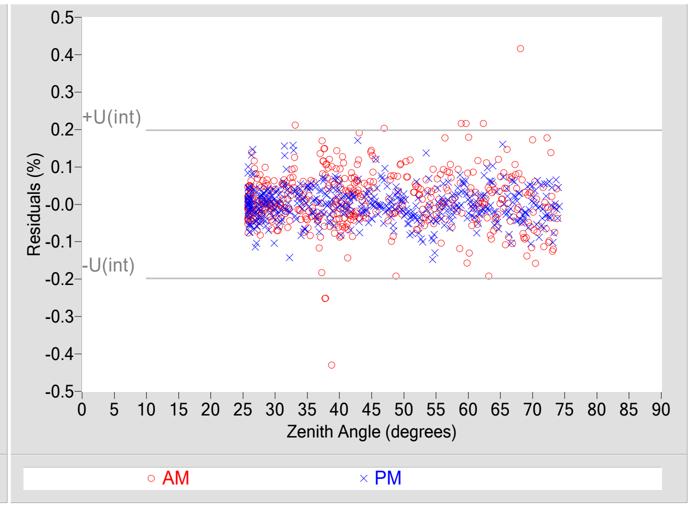


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.34
Type-A Interpolating Function, u(int) (%)	±0.099
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	138791
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.70
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

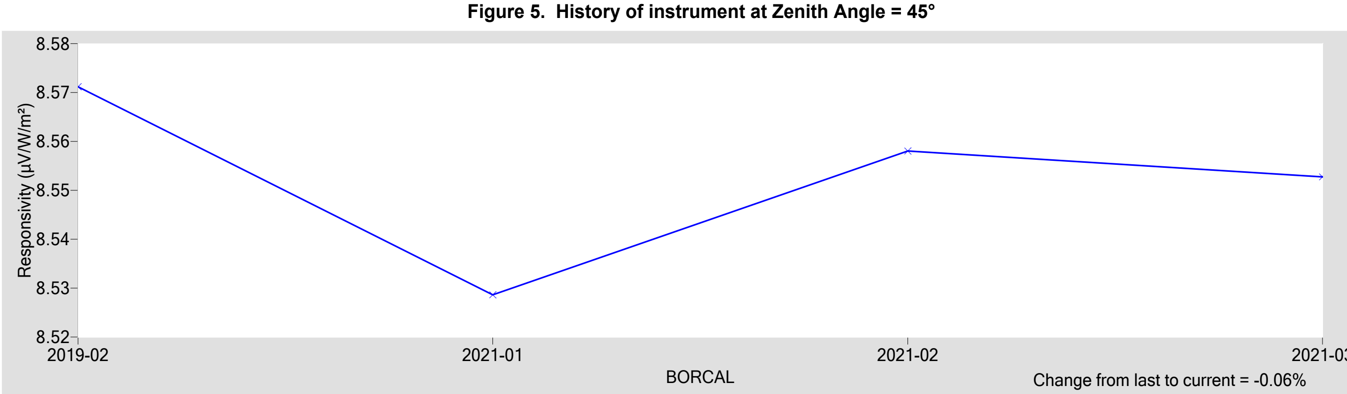
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5527	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.67
Offset Uncertainty, U(off) (%)	+0.21 / -0.24
Expanded Uncertainty, U (%)	+0.88 / -0.91
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Standard Precision Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	SPP	**Serial Number:**	38909F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

______________________________ ____________
Peter Gotseff, Technical Manager Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

38909F3 Eppley SPP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

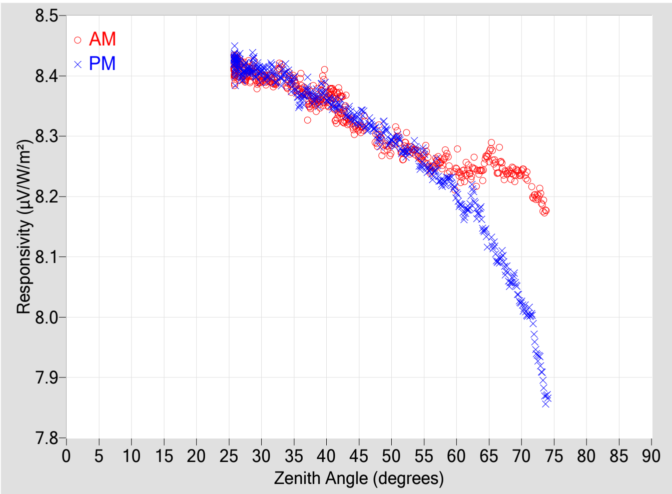


Figure 2. Responsivity vs Local Standard Time

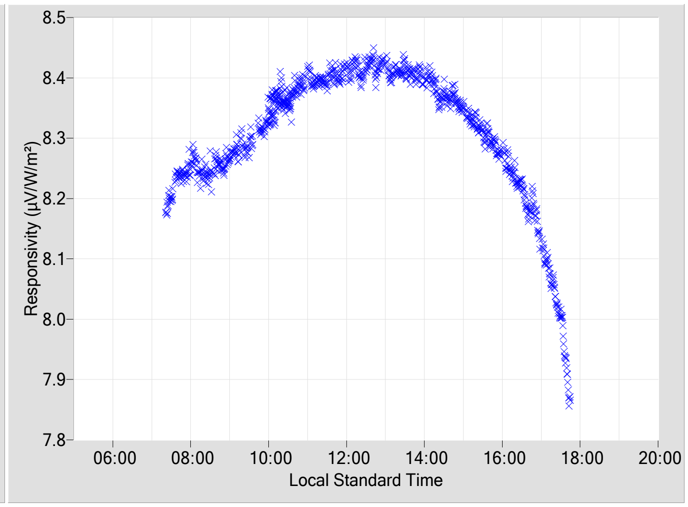


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3242	0.38	113.84	8.3150	0.36	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2988	0.37	111.23	8.2935	0.32	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2785	0.38	109.04	8.2942	0.34	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2820	0.35	106.91	8.2734	0.35	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2687	0.33	104.90	8.2693	0.36	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2456	0.37	103.07	8.2439	0.34	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2599	0.38	101.23	8.2226	0.35	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2446	0.42	99.50	8.2030	0.36	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2404	0.43	97.87	8.1853	0.37	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2422	0.47	96.17	8.1556	0.39	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2516	0.41	94.62	8.1061	0.41	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	8.2399	N/A	93.08	8.0655	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	8.2391	N/A	91.58	8.0209	N/A	268.74
26	8.4134	0.32	173.50	8.4226	0.33	186.71	72	8.1993	N/A	90.07	7.9612	N/A	270.24
28	8.4051	0.30	153.71	8.4085	0.32	206.00	74	8.1766	N/A	88.71	7.8692	N/A	271.64
30	8.3941	0.31	144.83	8.4053	0.33	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	8.3870	0.30	138.24	8.3964	0.30	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.3884	0.30	132.90	8.4037	0.34	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3838	0.32	128.57	8.3579	0.31	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3616	0.35	125.33	8.3628	0.32	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3633	0.35	121.66	8.3690	0.32	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3545	0.33	118.61	8.3514	0.35	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3173	0.39	116.20	8.3304	0.35	244.37	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

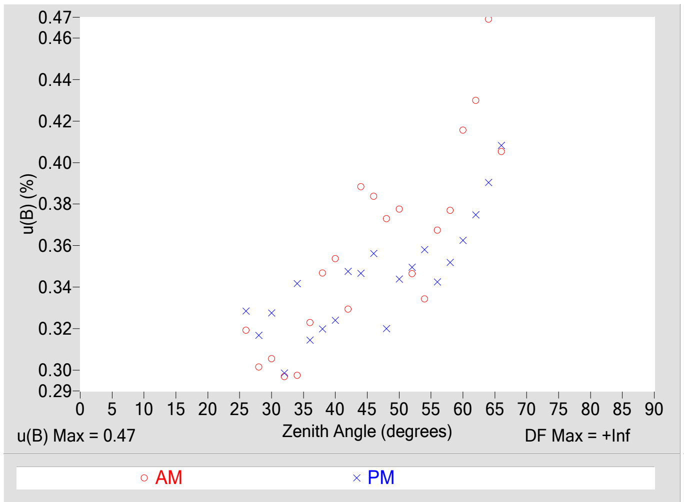


Figure 4. Residuals from Spline Interpolation

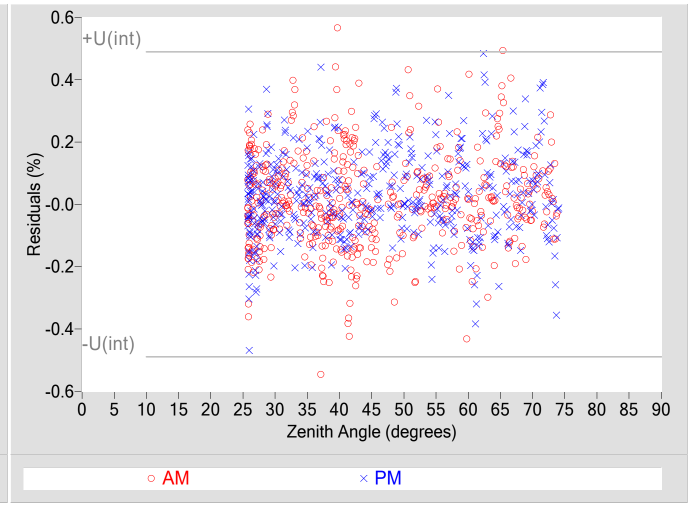


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.47
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	18269
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

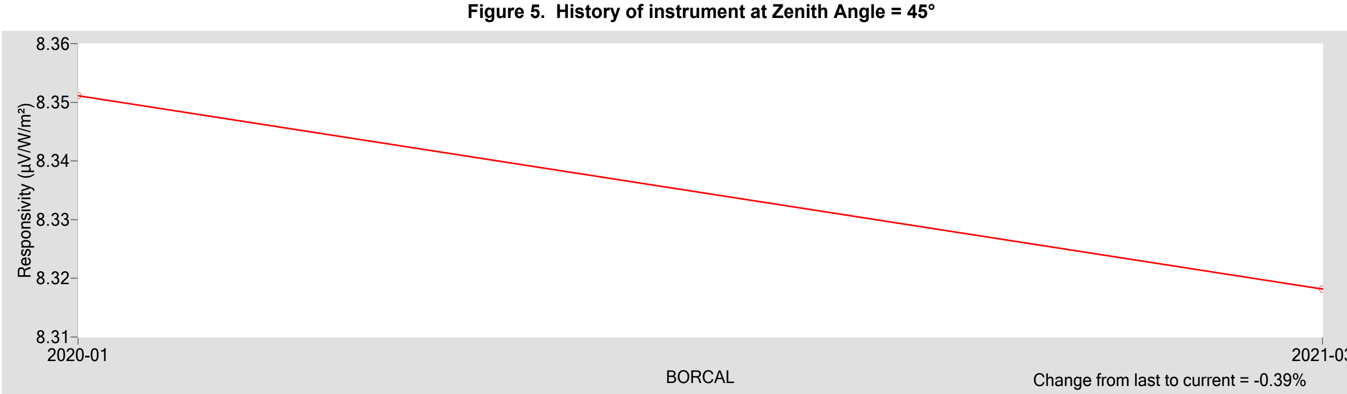
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3182	0.22000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.81
Offset Uncertainty, U(off) (%)	+1.0 / -1.4
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).

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Standard Precision Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	SPP	**Serial Number:**	38910F3
Calibration Date:	8/25/2021	**Due Date:**	8/25/2022
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	8/24-25		

This certifies that the above product was calibrated in compliance with procedure listed below. 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 29222	09/23/2019	09/23/2021
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2551	07/01/2020	07/01/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2552	07/01/2020	07/01/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2021	04/26/2022
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2021	04/26/2022
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 29926F3	02/19/2020	02/19/2022

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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: Craig Webb

________________________________ ____________
Peter Gotseff, Technical Manager   Date

For questions or comments, please contact the technical manager at:
Peter.Gotseff@nrel.gov; 303-384-6327; 15013 Denver West Parkway, Golden, CO 80401, USA

Calibration Results

38910F3 Eppley SPP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

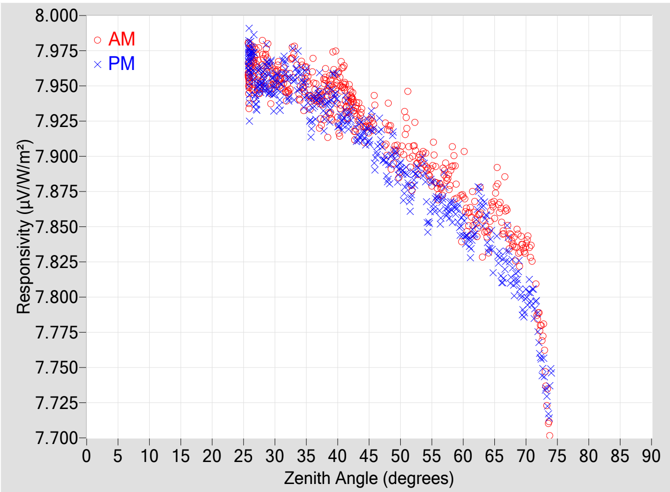


Figure 2. Responsivity vs Local Standard Time

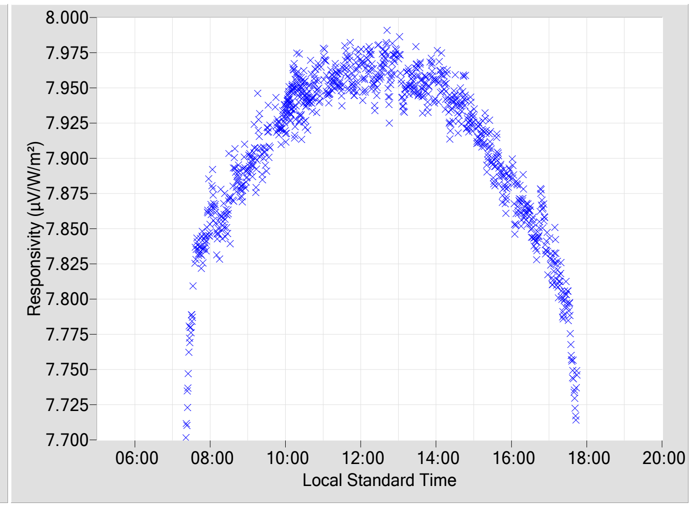


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.9342	0.38	113.84	7.8977	0.36	246.92
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9177	0.37	111.23	7.8853	0.32	249.24
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8960	0.38	109.04	7.8924	0.34	251.42
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8989	0.35	106.91	7.8806	0.35	253.49
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8947	0.33	104.90	7.8771	0.36	255.44
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8762	0.37	103.07	7.8705	0.34	257.32
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8890	0.38	101.23	7.8612	0.35	259.13
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8713	0.42	99.50	7.8512	0.36	260.82
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8557	0.43	97.87	7.8515	0.38	262.46
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8444	0.47	96.17	7.8396	0.39	264.07
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8576	0.41	94.62	7.8193	0.41	265.67
22	N/A	N/A	N/A	N/A	N/A	N/A	68	7.8384	N/A	93.08	7.8139	N/A	267.20
24	N/A	N/A	N/A	N/A	N/A	N/A	70	7.8355	N/A	91.58	7.7975	N/A	268.74
26	7.9609	0.32	173.50	7.9669	0.33	186.71	72	7.7851	N/A	90.07	7.7697	N/A	270.24
28	7.9609	0.30	153.71	7.9533	0.32	206.00	74	7.7016	N/A	88.71	7.7441	N/A	271.64
30	7.9556	0.31	144.83	7.9487	0.33	215.02	76	N/A	N/A	N/A	N/A	N/A	N/A
32	7.9454	0.30	138.24	7.9485	0.30	221.72	78	N/A	N/A	N/A	N/A	N/A	N/A
34	7.9495	0.30	132.90	7.9571	0.34	226.90	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9492	0.32	128.57	7.9303	0.32	231.37	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9494	0.35	125.33	7.9318	0.32	235.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9454	0.35	121.67	7.9347	0.32	238.50	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9422	0.33	118.61	7.9281	0.35	241.55	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9233	0.39	116.20	7.9162	0.35	244.37	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

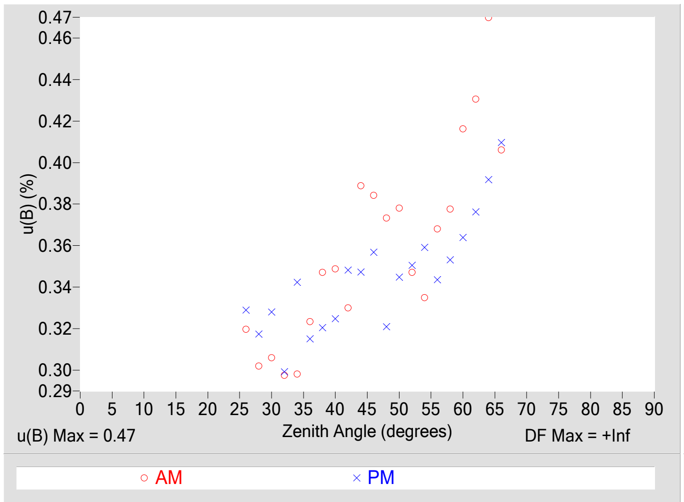


Figure 4. Residuals from Spline Interpolation

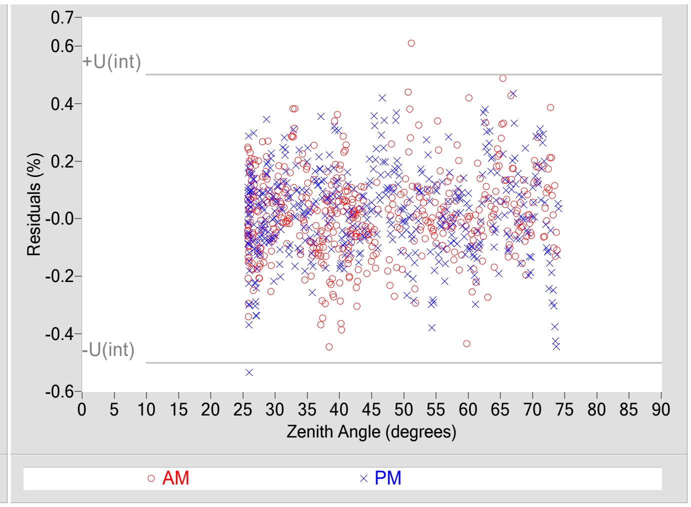


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.47
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	17032
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	26° to 66°
PM Valid zenith angle range	26° to 66°

‡ An illustration for how to reduce the uncertainty in calculating the irradiance using a function rather than R@45°.

Table 4. Calibration Label Values

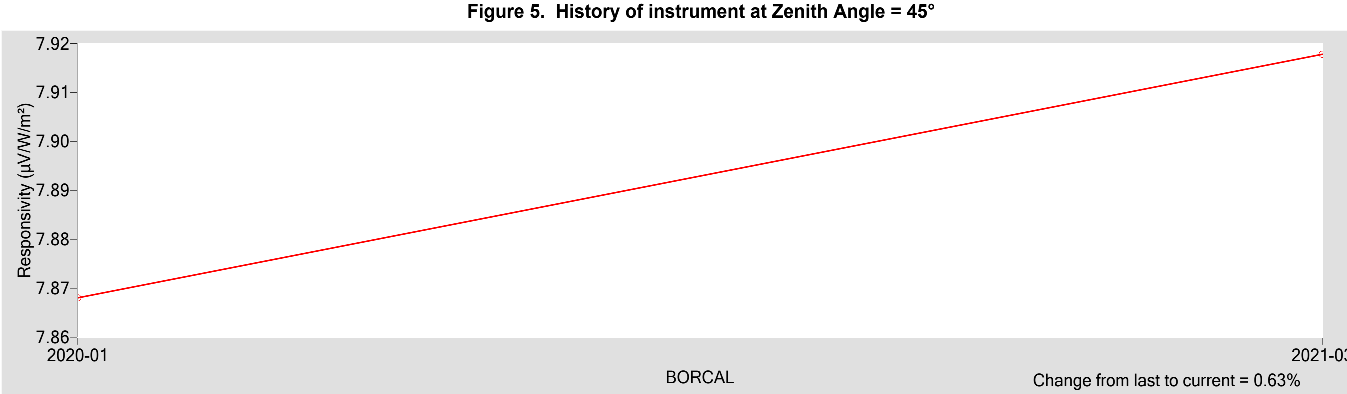
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9178	0.22000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.82
Offset Uncertainty, U(off) (%)	+0.50 / -0.84
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).

Environmental and Sky Conditions for BORCAL-SW 2021-03

Calibration Facility: Southern Great Plains

Latitude: 36.605°N Longitude: 97.488°W Elevation: 317.0 meters AMSL Time Zone: -6.0

Reference Irradiance:

Figure 6. Reference Irradiance

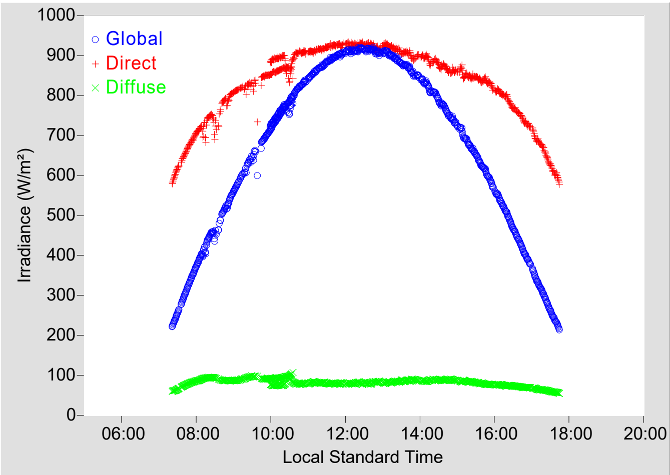
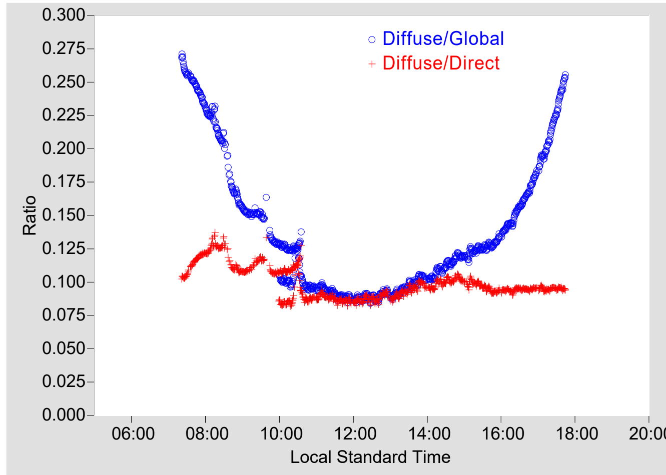


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

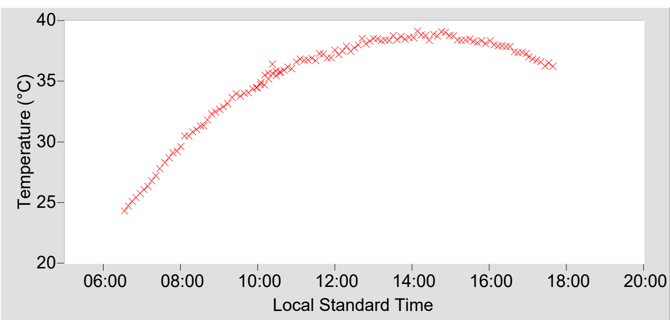


Figure 9. Humidity

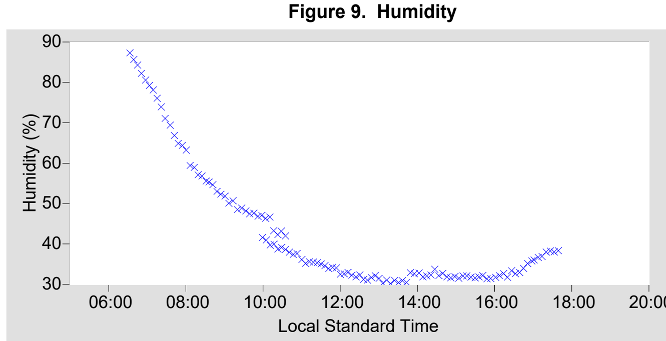


Figure 10. Pressure

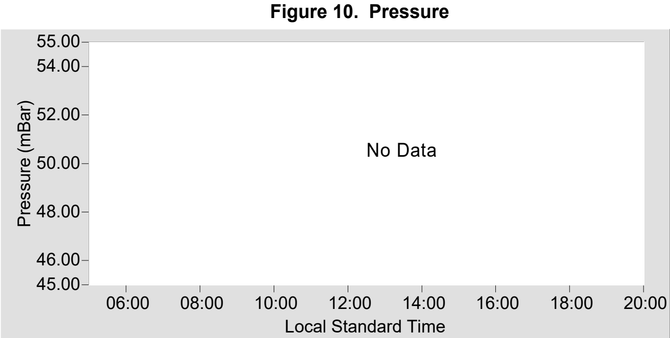


Figure 11. Effective Net Infrared

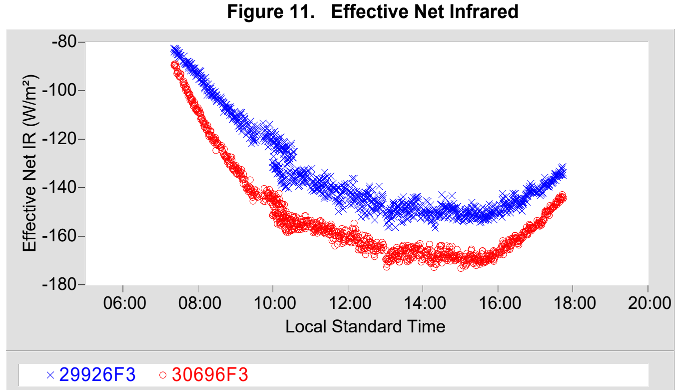


Figure 12. Estimated Broadband Aerosol Optical Depth

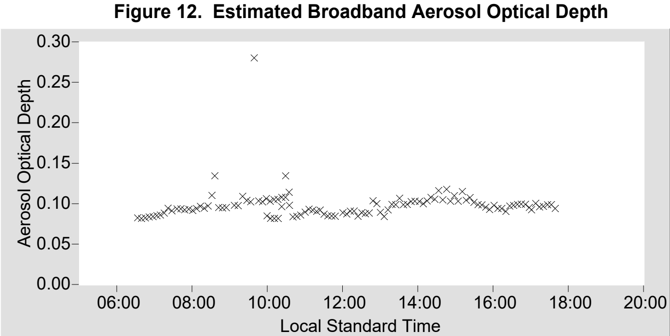


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	35.26	24.31	39.12
Humidity (%)	42.72	30.14	87.29
Pressure (mBar)	N/A	N/A	N/A
Est. Aerosol Optical Depth (BB)	0.098	0.081	0.280

For other information about the calibration facility visit: https://www.arm.gov/capabilities/observatories/sgp

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Southern Great Plains
Comments:
Avg. Station Pressure and Temperature is for Tulsa, OK, which is used for the Solar Position Algorithm (SPA).

30673F3 Eppley PSP
Comments:
IAW radiometer and the factory calibration sheet that I have factory cali. should be 8.52 as of May 10, 1999. C. Webb

---

30891F3 Eppley PSP
Comments:
Cal factor was recorded as 8.46 instead of 8.49 as per cal sheet, dated Sept 7, 1995.

31388E6 Eppley NIP
Comments:
Instrument repaired June 2011. New factory cal of 7.895 assigned. Old cal 8.73.

31875E6 Eppley NIP
Comments:
This instrument is for TWP.

29926F3 Eppley PIR-V
Comments:
Ventilated PIR

30696F3 Eppley PIR
Comments:
Unventilated PIR

Appendix 3
Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL 2021-03 Session Configuration Audit Report

LOCATION

Facility	Facility Abbrev.	Contact	Latitude	Longitude	Elevation (m)	Avg press (mbr)	Avg temp (C)	Time zone	ISO
Southern Great Plains	SGP	Craig Webb	36.605	-97.488	317.0	992.0	15.0	-6.0	

SYSTEM

% Error Thresholds

Cav1 / Cav2	2.0
Dif1 / Dif2	5.0
Global Ctrl / Ref	5.0
Direct Ctrl / Ref	5.0
Test(x) / Test(x-1)	0.5

Delta Thresholds

Temp(x) - Temp(x-1)	2.0
Hum(x) - Hum(x-1)	10.0
Bar(x) - Bar(x-1)	2.0
Thrm(x) - Thrm(x-1)	1.0
Thm (Dome-Case)	3.0
Case Thm (Inst-Pyrg)	5.0

Shade/Unshade

Enabled	☐
Port	1
Shaded Wait (s)	85
Unshaded Wait (s)	15

Scan Rate (sec)

Radiometers	30
Meteorological	300

ASR Setup

Scan Rate (s)	1
ASR Readings	2
Threshold 1 (Blue)	1.000
Threshold 2 (Green)	2.000
Threshold 3 (Brown)	3.000
Diffuse scaling factor	1.00

Clock

Reset Interval (m)	30
Warning Threshold (s)	3
Delta UT1	-0.200

Uncertainty

Zenith Angle (deg)	0.003
Significant Figures	2
45° Offsets: -	-15.00
45° Offsets: +	15.00
Min. Legal Direct	700
Max. Legal Diffuse	200
Max. Diffuse/Direct (%)	45.0

Miscellaneous

PW: Slope	1.23	Intercept	1.00
Tilt: Zenith	0.00	Azimuth	0.00
W in: Min	150	Max	500
Zenith Angle (Auto Mode): Startup	90	Shutdown	90
Intervals (m): Cavity Calibration	60	Oper. Log	20
SPA: Atmos. Refraction	0.5667	Delta T	69.384

ASR RADIOMETERS

	Channel	Junction Box	Cable	Location
ASR 1: PY22693 Licor LI200	60		2	2
ASR 2: None				

METEOROLOGICAL INSTRUMENTS

	Channel	Junction Box	Cable	Location	Scale	Offset
Temperature: E0710026T Vaisala HMP155 T	239		AT	AT	100	-40
Humidity: E0710026H Vaisala HMP155 H	255		RH	RH	100	0
Pressure: None					0	0

GPS TIME RECIEVER

SGP Symmetricom NTP

Type	Port	Baud	Parity	Stop bits	Data bits
RS232	1	9600	0	1	8

DATALOGGER

	Logger/Relay	DMM
Unit 0	2009-1206 NREL RAP-DAQ	MY42002863 Agilent 34420A
Unit 1	2009-1207 NREL RAP-DAQ	MY42002864 Agilent 34420A
Unit 2	2009-1208 NREL RAP-DAQ	MY42002866 Agilent 34420A
Unit 3	2014-1302 NREL RAP-DAQ	SG42000596 Agilent 34420A

	Unit 0	Unit 1	Unit 2	Unit 3
Cal Date	04/26/2021	04/26/2021	04/26/2021	04/26/2021
Cal Due Date	04/26/2022	04/26/2022	04/26/2022	04/26/2022
System Offsets: Volts DC (µV)	0.92	0.92	0.92	0.92
2-Wire Res. (mOhms)	2680.00	2680.00	2680.00	2680.00
4-Wire Res. (mOhms)	0.00	0.00	0.00	0.00

Communications

	Unit	Type	Addr.	Board	Parity	Stop	Data
DMM	0	GPIB	21	0	0	0	0
Relay	0	GPIB	24	1	0	0	0
DMM	1	GPIB	22	0	0	0	0
Relay	1	GPIB	25	1	0	0	0
DMM	2	GPIB	23	0	0	0	0
Relay	2	GPIB	26	1	0	0	0
DMM	3	GPIB	1	0	0	0	0
Relay	3	GPIB	4	1	0	0	0

CAVITIES, CONTROL UNITS, AND DIGITAL MULTI METERS

	Cavity 1	Cavity 2
Unwindowed WRR	1.000000	1.000000
Windowed WRR	1.057560	1.057970
Unwindowed Uncert (%)	0.00	0.00
Windowed Uncert (%)	0.38	0.39
Heater Resistance	153.90	154.40
Heater Lead Resistance	0.0660	0.0660
Mfg Calibration Factor	1.99980	1.99990
Default Sensitivity	0.01041	0.01050
Cal Date	09/23/2019	09/23/2019
Cal Due Date	09/23/2021	09/23/2021

	Unit 1	Unit 2
Cavity Head	29222 Eppley HF	30495 Eppley HF
Control Unit	US37037985 NREL Reda	MY58006669 NREL Reda
Digital Multi Meter	US37037985 Hewlett Packard 34970A	MY58006669 Hewlett Packard 34970A
Cavity Location	T2-A	T5

	Control Unit 1	Control Unit 2
Current Shunt	1.000	1.000
Circuit Resist	3.700	2.600
Cal Date	08/19/2020	08/19/2020
Cal Due Date	08/19/2021	08/19/2021

Calibration Waits (Seconds)

	Cavity 1	Cavity 2
TP-solar	0	0
TP-heated	45	45
TP-zero	60	60
Dwell	15	15
Active	✔	✔
Window in Use	✔	✔

Communications

	Type	Port	Bd.	Parity	Stop bits	Data bits
Control Unit 1	GPIB	10	0	0	0	0
DMM 1		0	0	0	0	0
Control Unit 2	GPIB	9	0	0	0	0
DMM 2		0	0	0	0	0

BORCAL 2021-03 Session Configuration Audit Report

DIFFUSE REFERENCE INSTRUMENTS

Responsivity	Cal Date	Cal Due Date	Shading Disk Diameter (cm)	Shading Disk Arm Length (cm)	Shading Disk Subtended Angle	Uncertainty Percent	Uncertainty Offset (W/m^2)	Max Out (mV)	Channel	J Box	Cable	Location	Tilt	Active
Diffuse 1: 2551 Hukseflux SR25-T2														
10.132	07/01/2020	07/01/2022	6.2	70.0	5.1	1.30	0.0	50	176		T3	T3	☐	✔
Diffuse 1: Case NONE Temperature									n/a	n/a	n/a			
Diffuse 1: Dome NONE Temperature									n/a	n/a	n/a			
Diffuse 2: 2552 Hukseflux SR25-T2														
8.225	07/01/2020	07/01/2022	6.2	70.0	5.1	1.20	0.0	50	177		T4	T4	☐	✔
Diffuse 2: Case NONE Temperature									n/a	n/a	n/a			
Diffuse 2: Dome NONE Temperature									n/a	n/a	n/a			

PYRGEOMETER INSTRUMENTS

Cal Date	Cal Due Date	K0	K1	K2	K3	Kr	Uncert. (W/m^2)	Max Out (mV)	Channel	J Box	Cable	Location	Active
Pyrgeometer 1: 30696F3 Eppley PIR													
02/19/2020	02/19/2022	-0.10000	0.23590	0.99130	-4.32000	7.04400E-4	3.00	9	208		30	30	✔
Pyrgeometer 1: Case 10K Temperature									216		30		
Pyrgeometer 1: Dome 10K Temperature									224		30		
Pyrgeometer 2: 29926F3 Eppley PIR-V (Ventilated)													
02/19/2020	02/19/2022	-0.90000	0.28368	1.00190	-4.65000	7.04400E-4	2.40	9	232		83	83	✔
Pyrgeometer 2: Case 10K Temperature									240		83		
Pyrgeometer 2: Dome 10K Temperature									248		83		

BORCAL 2021-03 Session Configuration Audit Report

INSTRUMENT GROUPS

Group	Calib. Type	Out (mV)	Instrument Type	Instrument Grouping Type	Correcting Pyrgeometer	Count
1	Global	50	Eppley 8-48	Eppley 8-48	none	10
2	Direct	50	Eppley NIP	Eppley NIP	none	10
3	Direct	50	Eppley NIP	Eppley NIP	none	4
			Eppley sNIP			2
4	Direct	20	Kipp & Zonen CHP1	Kipp & Zonen CHP1	none	1
5	Global	50	Eppley PSP	Eppley PSP	29926F3 Eppley PIR-V	10
6	Global	50	Eppley PSP	Eppley PSP	29926F3 Eppley PIR-V	10
7	Global	50	Eppley PSP	Eppley PSP	29926F3 Eppley PIR-V	6
			Eppley SPP			2
8	Global	50	Kipp & Zonen CMP22	Kipp & Zonen CM22	29926F3 Eppley PIR-V	2
9	Global	50	Eppley PSP	Eppley PSP	30696F3 Eppley PIR	10
10	Global	50	Eppley PSP	Eppley PSP	30696F3 Eppley PIR	4
Total						71

BORCAL 2021-03 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
200695 ©	CMP22	SGP	8	2	128		57	No	Yes	Yes	TOT	57	12
		(Case 10K Temperature)			136								
200710 ©	CMP22	SGP	8	1	114		56	No	Yes	Yes	TOT	56	12
		(Case 10K Temperature)			122								
200803	CHP1	SGP	4	1	214		T11	No	Yes	No	DIR	T11	12
27973F3 ©	PSP	TWP	9	1	96		31	No	Yes	No	TOT	31	12
29554E6	NIP	SGP	2	1	236		T17	No	Yes	No	DIR	T17	12
29619F3 ©	PSP	SGP	5	1	126		49	No	Yes	Yes	TOT	49	12
29743E6	NIP	SGP	2	2	245		T26	No	Yes	No	DIR	T26	12
29856E6	NIP	SGP	2	3	205		T23	No	Yes	No	DIR	T23	12
29869E6	NIP	TWP	2	4	229		T8	No	Yes	No	DIR	T8	12
29913F3 ©	PSP	TWP	9	2	1		5	No	Yes	No	TOT	5	12
29915F3 ©	PSP	TWP	5	2	110		38	No	Yes	Yes	TOT	38	12
29934E6	NIP	TWP	2	5	212		T9	No	Yes	No	DIR	T9	12
29938E6	NIP	SGP	2	6	242		T29	No	Yes	No	DIR	T29	12
30617F3 ©	PSP	SGP	5	3	133		51	No	Yes	Yes	TOT	51	12
30653F3 ©	PSP	SGP	5	4	158		75	No	Yes	Yes	TOT	75	12
30665F3 ©	PSP	SGP	5	5	161		84	No	Yes	Yes	TOT	84	12
30673F3 ©	PSP	SGP	9	3	61		3	No	Yes	No	TOT	3	12
30709F3 ©	PSP	SGP	5	6	164		76	No	Yes	Yes	TOT	76	12
30717E6	NIP	SGP	2	7	234		T20	No	Yes	No	DIR	T20	12
30718E6	NIP	SGP	2	8	226		T15	No	Yes	No	DIR	T15	12
30722E6	NIP	SGP	2	9	237		T24	No	Yes	No	DIR	T24	12
30776F3 ©	PSP	SGP	5	7	141		59	No	Yes	Yes	TOT	59	12
30820F3 ©	PSP	SGP	5	8	129		58	No	Yes	Yes	TOT	58	12
30891F3 ©	PSP	SGP	5	9	174		86	No	Yes	Yes	TOT	86	12
30900F3 ©	PSP	SGP	9	4	64		12	No	Yes	No	TOT	12	12
30951F3 ©	PSP	SGP	9	5	20		34	No	Yes	No	TOT	34	12
30953F3 ©	PSP	SGP	9	6	0		4	No	Yes	No	TOT	4	12
31096F3 ©	PSP	SGP	5	10	162		85	No	Yes	Yes	TOT	85	12
31099F3 ‡©	PSP	Calibration System	6	1	130		64	No	Yes	Yes	TOT	64	12
		(Case 10K Temperature)			138		64						
31100F3 ‡©	PSP	Calibration System	6	2	145		73	No	Yes	Yes	TOT	73	12
		(Case 10K Temperature)			153		73						
31101F3 ‡©	PSP	Calibration System	6	3	160		82	No	Yes	Yes	TOT	82	12
		(Case 10K Temperature)			168		82						
31120E6 ‡	NIP	Calibration System	2	10	210		T32	No	Yes	No	DIR	T32	12
31122E6 ‡	NIP	Calibration System	3	1	230		T16	No	Yes	No	DIR	T16	12
31149F3 ‡©	PSP	Calibration System	6	4	98		37	No	Yes	Yes	TOT	37	12
		(Case 10K Temperature)			106		37						
31150F3 ‡©	PSP	Calibration System	6	5	112		46	No	Yes	Yes	TOT	46	12
		(Case 10K Temperature)			120		46						
31151F3 ‡©	PSP	Calibration System	6	6	113		55	No	Yes	Yes	TOT	55	12
		(Case 10K Temperature)			121		55						
31152F3 ‡©	PSP	Calibration System	9	7	80		19	No	Yes	No	TOT	19	12
		(Case 10K Temperature)			88		19						
31153F3 ‡©	PSP	Calibration System	9	8	81		28	No	Yes	No	TOT	28	12
		(Case 10K Temperature)			89		28						
31154F3 ‡©	PSP	Calibration System	9	9	82		29	No	Yes	No	TOT	29	12
		(Case 10K Temperature)			90		29						

‡ Control Instrument

© Effective Net IR Corrected Instrument

BORCAL 2021-03 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
31158F3 ‡©	PSP	Calibration System	9	10	48		1	No	Yes	No	TOT	1	12
		(Case 10K Temperature)			56		1						
31159F3 ‡©	PSP	Calibration System	10	1	49		10	No	Yes	No	TOT	10	12
		(Case 10K Temperature)			57		10						
31160F3 ‡©	PSP	Calibration System	10	2	50		11	No	Yes	No	TOT	11	12
		(Case 10K Temperature)			58		11						
31277F3 ©	PSP	TWP	6	7	108		39	No	Yes	Yes	TOT	39	12
31283F3 ©	PSP	TWP	6	8	156		66	No	Yes	Yes	TOT	66	12
31284F3 ©	PSP	TWP	10	3	92		20	No	Yes	No	TOT	20	12
31289F3 ©	PSP	TWP	6	9	144		65	No	Yes	Yes	TOT	65	12
31291F3 ©	PSP	TWP	10	4	93		21	No	Yes	No	TOT	21	12
31294F3 ©	PSP	NSA	6	10	149		67	No	Yes	Yes	TOT	67	12
31388E6	NIP	SGP	-	-	244		T18	No	Yes	No	DIR	T18	12
31636F3 ©	PSP	SGP	7	1	146		74	No	Yes	Yes	TOT	74	12
31763E6	NIP	NSA	3	2	249		T30	No	Yes	No	DIR	T30	12
31875E6	NIP	TWP	3	3	213		T10	No	Yes	No	DIR	T10	12
32026F3 ©	PSP	NSA	7	2	150		68	No	Yes	Yes	TOT	68	12
32882	8-48	TWP	1	1	38		81	No	Yes	Yes	TOT	81	12
33247	8-48	SGP	1	2	28		70	No	Yes	Yes	TOT	70	12
33251	8-48	TWP	1	3	24		43	No	Yes	Yes	TOT	43	12
33262	8-48	SGP	1	4	32		52	No	Yes	Yes	TOT	52	12
33267	8-48	SGP	1	5	45		89	No	Yes	Yes	TOT	89	12
33273	8-48	SGP	1	6	44		88	No	Yes	Yes	TOT	88	12
33279	8-48	SGP	1	7	29		71	No	Yes	Yes	TOT	71	12
33386	8-48	TWP	1	8	26		45	No	Yes	Yes	TOT	45	12
34281	8-48	TWP	1	9	37		80	No	Yes	Yes	TOT	80	12
35830F3 ©	PSP	AMF#2	7	3	157		69	No	Yes	Yes	TOT	69	12
35864	8-48	SGP	1	10	34		54	No	Yes	Yes	TOT	54	12
36291F3 ©	PSP	AMF#2	7	4	124		47	No	Yes	Yes	TOT	47	12
37286E6	NIP	AMF	3	4	225		T7	No	Yes	No	DIR	T7	12
37297F3 ©	PSP	AMF	7	5	116		40	No	Yes	Yes	TOT	40	12
37300F3 ©	PSP	NSA	7	6	125		48	No	Yes	Yes	TOT	48	12
37945E6	sNIP	SGP	3	5	178		T12	No	Yes	No	DIR	T12	12
37946E6	sNIP	SGP	3	6	209		T28	No	Yes	No	DIR	T28	12
38909F3 ©	SPP	SGP	7	7	165		77	No	Yes	Yes	TOT	77	12
38910F3 ©	SPP	SGP	7	8	166		78	No	Yes	Yes	TOT	78	12

‡ Control Instrument © Effective Net IR Corrected Instrument

BORCAL 2021-03 Session Configuration Audit Report

Effective Net IR Corrected Instruments

Instrument	Vent	Correcting Pyrgeometer	Inst. RSnet	RSnet uncert.	RSnet Date
200695 Kipp & Zonen CMP22	Yes	29926F3 Eppley PIR-V	0.0870	20.0000	Estimated
200710 Kipp & Zonen CMP22	Yes	29926F3 Eppley PIR-V	0.0870	20.0000	Estimated
27973F3 Eppley PSP	No	30696F3 Eppley PIR	0.6000	20.0000	Estimated
29619F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6905	10.0000	04/24/2007
29913F3 Eppley PSP	No	30696F3 Eppley PIR	0.5390	10.0000	03/31/2006
29915F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6327	10.0000	06/09/2006
30617F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6703	10.0000	04/24/2007
30653F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6100	10.0000	04/18/2006
30665F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6820	10.0000	04/26/2007
30673F3 Eppley PSP	No	30696F3 Eppley PIR	0.5741	10.0000	04/26/2007
30709F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6150	10.0000	06/07/2006
30776F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6486	10.0000	04/24/2007
30820F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6350	10.0000	05/09/2007
30891F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5755	10.0000	06/08/2006
30900F3 Eppley PSP	No	30696F3 Eppley PIR	0.6338	10.0000	05/08/2007
30951F3 Eppley PSP	No	30696F3 Eppley PIR	0.6427	10.0000	07/06/2006
30953F3 Eppley PSP	No	30696F3 Eppley PIR	0.6708	10.0000	05/08/2007
31096F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.7148	10.0000	05/08/2007
31099F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5787	10.0000	05/08/2006
31100F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6473	10.0000	05/09/2006
31101F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6483	10.0000	05/09/2006
31149F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5490	10.0000	03/30/2006
31150F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5510	10.0000	03/30/2006
31151F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5330	10.0000	03/30/2006
31152F3 Eppley PSP	No	30696F3 Eppley PIR	0.6339	10.0000	05/09/2006
31153F3 Eppley PSP	No	30696F3 Eppley PIR	0.6429	10.0000	05/09/2006
31154F3 Eppley PSP	No	30696F3 Eppley PIR	0.5616	10.0000	05/09/2006
31158F3 Eppley PSP	No	30696F3 Eppley PIR	0.5240	10.0000	03/30/2006
31159F3 Eppley PSP	No	30696F3 Eppley PIR	0.5320	10.0000	03/30/2006
31160F3 Eppley PSP	No	30696F3 Eppley PIR	0.4900	10.0000	03/30/2006
31277F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5040	10.0000	04/03/2006
31283F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6017	10.0000	04/26/2007
31284F3 Eppley PSP	No	30696F3 Eppley PIR	0.5460	10.0000	03/31/2006
31289F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6523	10.0000	05/08/2007
31291F3 Eppley PSP	No	30696F3 Eppley PIR	0.6184	10.0000	04/26/2007
31294F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5470	10.0000	04/03/2006
31636F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6211	10.0000	06/06/2006
32026F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6242	10.0000	06/13/2006
35830F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.5471	10.0000	08/05/2009
36291F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6000	20.0000	Estimated
37297F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6000	20.0000	Estimated
37300F3 Eppley PSP	Yes	29926F3 Eppley PIR-V	0.6000	20.0000	Estimated
38909F3 Eppley SPP	Yes	29926F3 Eppley PIR-V	0.2200	20.0000	Estimated
38910F3 Eppley SPP	Yes	29926F3 Eppley PIR-V	0.2200	20.0000	Estimated

Appendix 4
Operator Session Logs

Operator session logs for the BORCAL

BORCAL 2021-03 Operator Session Log

```
==========================================================================================================
Session: 1
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-22-2021     07:24:22       08:24:23       29222          06:45            970.8          970.2
                                             30495          06:45            956.0          955.8
-------------------------------------------------------------------------------------------------
Observations:
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
07:44:54        64.68         Blue            421.5              44.8      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
first run for 2021-03 signal is low but everything looks good, temp 26C, hum 68%, hpa 983, wnd dir 120 @ 6
mph.
==========================================================================================================
Session: 2
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-22-2021     08:24:23       09:16:26       29222          06:45            970.2          969.6
                                             30495          06:45            955.8          955.5
-------------------------------------------------------------------------------------------------
Observations:
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
08:42:21        53.20         Blue            533.5              37.9      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
hazy low signal, temp 29C, hum 57%, hpa 983, wnd dir 140 @ 11 mph.
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
08:46:54        52.28         Blue            541.3              37.2      Craig Webb
-----------------------------------------------------------------------------------------
Comments: [None]
==========================================================================================================
Session: 3
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-22-2021     09:16:26       10:16:26       29222          06:45            969.6          968.8
                                             30495          06:45            955.5          955.0
-------------------------------------------------------------------------------------------------
Observations:
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
09:26:35        44.38         Blue            604.4              33.4      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
hazy sky, temp 30Cmhum 51%, hpa 983, wnd dir 138 @ 14 mph.
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
09:48:08        40.11         Blue            625.1              32.2      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
no change.
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
10:08:45        36.12         Blue            649.1              30.9      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
temp 31C, hum 49%, hpa 983, wnd dir 135 @ 16 mph, hazy
==========================================================================================================
Session: 4
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
07-22-2021     10:16:26       11:14:30       29222          06:45            968.8          969.1
                                             30495          06:45            955.0          954.9
-------------------------------------------------------------------------------------------------
```

BORCAL 2021-03 Operator Session Log

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:27:40	32.53	Blue	651.4	31.3	Craig Webb

Comments:
clouds moving into the area, temp 31C, hum 50%, hpa 983, wnd dir 140 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:48:54	28.65	Green	677.2	33.2	Craig Webb

Comments:
shutting down due to clouds in the area. temp 31C, hum 50%, hpa 982, wnd dir 135 @ 6 mph.

Session: 5

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	11:14:30	12:09:38	29222	06:45	969.1	968.2
			30495	06:45	954.9	954.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:45:13	19.93	Blue	655.6	37.2	Craig Webb

Comments:
lots of clouds

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:06:23	17.74	Green	666.8	33.4	Craig Webb

Comments:
shutting down to install 2 spp

Session: 6

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	12:28:16	13:25:21	29222	0:00	968.0	967.7
			30495	0:00	953.8	954.1

Observations: [None]

Session: 7

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	13:25:21	14:25:23	29222	0:00	967.7	967.0
			30495	0:00	954.1	953.9

Observations: [None]

Session: 8

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	14:25:23	15:22:25	29222	0:00	967.0	967.9
			30495	0:00	953.9	953.7

Observations: [None]

Session: 9

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	15:22:25	16:22:27	29222	0:00	967.9	967.0
			30495	0:00	953.7	953.1

Observations: [None]

BORCAL 2021-03 Operator Session Log

Session: 10

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	16:22:27	17:22:28	29222	0:00	967.0	967.3
			30495	0:00	953.1	953.7

Observations: [None]

Session: 11

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	17:22:28	18:22:33	29222	0:00	967.3	967.1
			30495	0:00	953.7	954.0

Observations: [None]

Session: 12

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	18:22:33	19:23:34	29222	0:00	967.1	968.5
			30495	0:00	954.0	954.6

Observations: [None]

Session: 13

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-22-2021	19:23:34	19:45:10	29222	0:00	968.5	969.0
			30495	0:00	954.6	954.9

Observations: [None]

Session: 14

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2021	05:33:39	06:33:42	29222	0:00	971.8	971.6
			30495	0:00	957.2	957.0

Observations: [None]

Session: 15

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2021	06:33:42	07:33:45	29222	0:00	971.6	970.6
			30495	0:00	957.0	956.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:23:28	69.05	Blue	547.5	30.8	RCC

Comments:
31184F3 see no bugs or anything causing signal variance

Session: 16

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2021	07:33:45	08:33:47	29222	0:00	970.6	969.3
			30495	0:00	956.4	955.8

Observations: [None]

Session: 17

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2021	08:33:47	09:33:50	29222	0:00	969.3	968.8
			30495	0:00	955.8	955.1

```
Observations: [None]
=============================================================================================
Session: 18
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    09:33:50      10:34:51      29222         0:00            968.8         968.0
                                          30495         0:00            955.1         954.2
---------------------------------------------------------------------------------------
Observations: [None]
=============================================================================================
Session: 19
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    10:34:51      11:16:15      29222         0:00            968.0         967.7
                                          30495         0:00            954.2         954.0
---------------------------------------------------------------------------------------
Observations: [None]
=============================================================================================
Session: 20
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    11:16:15      12:16:18      29222         0:00            967.7         967.4
                                          30495         0:00            954.0         953.7
---------------------------------------------------------------------------------------
Observations:
--------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
12:07:18       17.87        Blue           816.0            22.1      RCC
--------------------------------------------------------------------------------
Comments:
clouds moving into area and farmer burning a wheat field southeast of siteabout three miles away.
=============================================================================================
Session: 21
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    12:16:18      13:16:19      29222         0:00            967.4         966.1
                                          30495         0:00            953.7         953.0
---------------------------------------------------------------------------------------
Observations: [None]
=============================================================================================
Session: 22
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    13:16:19      14:16:21      29222         0:00            966.1         967.2
                                          30495         0:00            953.0         953.6
---------------------------------------------------------------------------------------
Observations: [None]
=============================================================================================
Session: 23
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    14:16:21      15:17:22      29222         0:00            967.2         966.6
                                          30495         0:00            953.6         953.0
---------------------------------------------------------------------------------------
Observations: [None]
=============================================================================================
Session: 24
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    15:17:22      16:18:24      29222         0:00            966.6         966.2
                                          30495         0:00            953.0         953.0
---------------------------------------------------------------------------------------
Observations: [None]
=============================================================================================
Session: 25
---------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
07-23-2021    16:18:24      17:18:26      29222         0:00            966.2         966.2
                                          30495         0:00            953.0         952.7
---------------------------------------------------------------------------------------
```

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Observations: [None]

Session: 26

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2021	17:18:26	18:19:27	29222	0:00	966.2	966.3
			30495	0:00	952.7	952.6

Observations: [None]

Session: 27

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2021	18:19:27	19:22:29	29222	0:00	966.3	968.3
			30495	0:00	952.6	953.8

Observations: [None]

Session: 28

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-23-2021	19:22:29	19:44:27	29222	0:00	968.3	968.4
			30495	0:00	953.8	954.3

Observations: [None]

Session: 29

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	05:34:26	06:34:30	29222	0:00	971.6	971.0
			30495	0:00	956.5	956.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:04:05	84.41	Blue	112.2	80.3	RCC

Comments: [None]

Session: 30

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	06:34:30	07:34:31	29222	0:00	971.0	969.9
			30495	0:00	956.9	955.7

Observations: [None]

Session: 31

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	07:34:31	08:34:32	29222	0:00	969.9	969.1
			30495	0:00	955.7	955.0

Observations: [None]

Session: 32

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	08:34:32	09:34:34	29222	0:00	969.1	968.5
			30495	0:00	955.0	954.8

Observations: [None]

Session: 33

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	09:34:34	10:35:34	29222	0:00	968.5	967.4
			30495	0:00	954.8	954.0

Observations: [None]

Session: 34

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	10:35:34	11:36:37	29222	0:00	967.4	966.9
			30495	0:00	954.0	953.5

Observations: [None]

Session: 35

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	11:36:37	12:36:40	29222	0:00	966.9	966.9
			30495	0:00	953.5	953.3

Observations: [None]

Session: 36

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	12:36:40	13:36:41	29222	0:00	966.9	966.7
			30495	0:00	953.3	953.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:49:39	17.15	Blue	750.6	21.8	RCC

Comments: [None]

Session: 37

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	13:36:41	14:36:41	29222	0:00	966.7	966.0
			30495	0:00	953.1	952.0

Observations: [None]

Session: 38

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	14:36:41	15:37:43	29222	0:00	966.0	965.9
			30495	0:00	952.0	952.1

Observations: [None]

Session: 39

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	15:37:43	16:37:45	29222	0:00	965.9	966.7
			30495	0:00	952.1	953.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:45:33	44.44	Blue	641.4	30.3	RCC

Comments: [None]

Session: 40

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-24-2021	16:37:45	17:31:57	29222	0:00	966.7	967.5
			30495	0:00	953.1	952.9

BORCAL 2021-03 Operator Session Log

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:28:56	65.10	Red	-0.5	100.5	RCC

Comments:
raining shuting down.

Session: 41

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-25-2021	05:35:11	06:35:12	29222	0:00	0.0	-0.0
			30495	0:00	0.0	0.0

Observations: [None]

Session: 42

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-25-2021	06:35:12	07:35:14	29222	0:00	-0.0	0.0
			30495	0:00	0.0	0.0

Observations: [None]

Session: 43

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-25-2021	07:35:14	08:31:21	29222	0:00	0.0	0.0
			30495	0:00	0.0	0.0

Observations: [None]

Session: 44

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-27-2021	11:08:25	12:08:28	29222	10:45	970.2	968.2
			30495	10:45	956.3	954.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:34:02	22.27	Blue	843.2	14.0	Craig Webb

Comments:
shy was clear so started BORCAL, temp 35C, hum 61%, hpa 979, wnd dir 070 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:07:36	18.81	Blue	849.7	14.4	Craig Webb

Comments:
small clouds starting to form to the south and noryh. temp34C, hum 57%, hpa 979, wnd dir

Session: 45

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-27-2021	12:08:28	13:00:47	29222	10:45	968.2	967.6
			30495	10:45	954.6	953.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:08:29	18.81	Blue	849.7	14.4	Craig Webb

Comments:
clouds starting to form to the south and north, temp 34C, hum 56%, hpa 979, wnd dir 080 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:48:08	17.76	Red	808.8	19.0	Craig Webb

Comments:
clouds pass by tem-34C, hum 52%, hpa 979, wnd dir 096 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:57:31	18.17	Red	637.9	25.3	Craig Webb

Comments:
quiting due to clouds,

Session: 46

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	07:14:07	08:16:09	29222	06:45	970.6	969.9
			30495	06:45	956.4	955.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:42:39	65.82	Blue	509.1	35.4	Craig Webb

Comments:
SOME CLOUDS AND LOW OUTPUT, TEMP 28c,HUM 84%, HPA 981, WND DIR 070 @ 3 MPH.

Session: 47

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	08:16:09	09:16:08	29222	06:45	969.9	968.6
			30495	06:45	955.8	954.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:19:21	58.49	Blue	600.8	29.3	Craig Webb

Comments:
hazy, temp 31C, hum 73%, hpa 981, wnd dir 090 @ 8 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:42:42	53.81	Green	641.2	27.2	Craig Webb

Comments:
no change

Session: 48

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	09:16:08	10:18:10	29222	06:45	968.6	967.8
			30495	06:45	954.8	954.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:17:03	46.97	Brown	695.9	23.7	Craig Webb

Comments:
clear, temp 33C, hum 60%, hpa 981, wnd dir 078 @ 4 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:37:38	42.91	Blue	729.2	22.1	Craig Webb

Comments:
no change

Session: 49

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	10:18:10	11:18:14	29222	06:45	967.8	967.0
			30495	06:45	954.0	953.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:20:58	34.58	Blue	771.1	19.6	Craig Webb

Comments:
clear but hazy, temp 34C, hum 53%, hpa 980, wnd dir 100 @ 11 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:28:57	33.11	Blue	773.6	19.6	Craig Webb

Comments:
been watching 31101F3 but don't see anything to cause alarms don't see any bugs or birds.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:03:55	26.99	Green	780.7	19.4	Craig Webb

Comments:
no change

Session: 50

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	11:18:14	12:16:14	29222	06:45	967.0	966.5
			30495	06:45	953.6	953.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:32:02	22.73	Blue	779.2	20.0	Craig Webb

Comments:
clouds moving into the area, temp 35C, hum 50%, hpa 980, wnd dir 120 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:52:13	20.28	Green	760.2	21.4	Craig Webb

Comments:
clouds in area, temp 35C, hum m48%, hpa 980, wnd dir 140 @ 9 mph.

Session: 51

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	12:16:14	13:14:17	29222	06:45	966.5	966.3
			30495	06:45	953.4	953.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:17:03	18.31	Red	21.2	92.3	Craig Webb

Comments:
clouds, temp 36C, hum 45%, hpa 980, wnd dir 110 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:37:22	17.81	Blue	778.5	23.3	Craig Webb

Comments:
no change,

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:55:52	18.30	Green	790.5	25.3	Craig Webb

Comments: [None]

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Session: 52

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	13:14:17	14:12:19	29222	06:45	966.3	966.1
			30495	06:45	953.2	953.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:16:08	19.83	Green	798.9	21.6	Craig Webb

Comments:
farmer burning wheat field to the south of the RCF. temp 36C, hum 44%, hpa 980 wnd dir 106 @ 8 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:36:48	22.20	Green	670.1	26.1	Craig Webb

Comments:
no change in sky, temp 36C, hum 47%, hpa 980, wnd dir 100 @ 5 mph. going to let system run to see what happens.

Session: 53

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	14:12:19	15:14:21	29222	06:45	966.1	966.2
			30495	06:45	953.1	952.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:19:57	28.85	Blue	788.5	21.2	Craig Webb

Comments:
clouds starting to disappear and sky is clearing. smoke is gone fire is out. temp 36C, hum 45%, hpa 980, wnd dir 060 @ 8 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:48:36	33.97	Blue	692.7	22.7	Craig Webb

Comments:
no change

Session: 54

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	15:14:21	16:15:23	29222	06:45	966.2	966.1
			30495	06:45	952.9	952.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:20:47	40.09	Green	767.3	19.1	Craig Webb

Comments: [None]

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:41:22	44.10	Green	761.7	19.6	Craig Webb

Comments:
no change

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:01:27	48.10	Blue	726.3	21.4	Craig Webb

Comments: [None]

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Session: 55

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	16:15:23	17:15:26	29222	06:45	966.1	966.4
			30495	06:45	952.5	952.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:21:53	52.18	Blue	677.8	23.5	Craig Webb

Comments:
temp 36C, hum 44%, hpa 978, wnd dir 150 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:42:01	56.22	Blue	673.1	23.9	Craig Webb

Comments:
a few clouds still hanging around, temp 35C, hum 45%, hpa 979, wnd dir 135 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:02:06	60.24	Green	634.6	26.0	Craig Webb

Comments: [None]

Session: 56

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-28-2021	17:15:26	17:58:09	29222	06:45	966.4	966.5
			30495	06:45	952.6	952.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:22:11	64.27	Blue	603.7	27.2	Craig Webb

Comments:
a few small clouds in area, temp 35C, hum 46%, hpa 978, wnd dir 160 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:42:15	68.26	Blue	555.2	30.4	Craig Webb

Comments:
haze on horizan ,temp 35C, hum 49%, hpa 978, wnd dir 132 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:53:35	70.50	Blue	249.5	47.9	Craig Webb

Comments: [None]

Session: 57

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-29-2021	06:43:08	07:40:07	29222	06:29	971.1	969.9
			30495	06:29	956.4	956.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:13:46	71.67	Blue	449.9	38.5	Craig Webb

Comments:
clear temp 27C, hum 90%, hpa 981, wnd dir 100 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:14:50	71.47	Blue	451.6	38.3	Craig Webb

Comments: [None]

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Session: 58

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-29-2021	07:40:07	08:40:10	29222	06:29	969.9	968.7
			30495	06:29	956.0	955.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:03:27	61.80	Blue	589.3	30.0	Craig Webb

Comments:
clear 31101F3 still getting alarms. temp 31C, hum 68%, hpa 981, wnd dir 175 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:35:51	55.31	Blue	646.2	26.7	Craig Webb

Comments:
no change

Session: 59

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-29-2021	08:40:10	09:40:12	29222	06:29	968.7	967.9
			30495	06:29	955.2	954.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:58:34	50.77	Blue	682.8	24.8	Craig Webb

Comments:
clear temp 33C, hum 56%, hpa 981, wnd dir 160 @ 10 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:35:05	43.53	Green	706.3	23.8	Craig Webb

Comments:
no change

Session: 60

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-29-2021	09:40:12	10:40:15	29222	06:29	967.9	967.0
			30495	06:29	954.4	954.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:11:00	36.59	Blue	733.5	22.6	Craig Webb

Comments:
clouds moving into the area, temp 35C, hum 50%, hpa 981, wnd dir 170 @ 11 mph.

Session: 61

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-29-2021	10:40:15	10:48:39	29222	06:29	967.0	967.4
			30495	06:29	954.0	954.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:44:48	30.40	Red	131.5	66.7	Craig Webb

Comments:
clouds going to shut down for now

Session: 62

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2021	10:50:04	11:50:07	29222	10:29	971.1	968.4
			30495	10:29	957.2	954.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:03:05	27.63	Blue	758.9	20.8	Craig Webb

Comments:
hazy and clouds starting to form to the northwest. temp 37C, hum 38%, hpa 979, wnd dir 160 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:27:48	23.89	Blue	777.0	23.4	Craig Webb

Comments:
more clouds moving into the area, temp 38C, hum 27%, hpa 979, wnd dir 133 @ 12 mph.

Session: 63

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
07-31-2021	11:50:07	12:09:43	29222	10:29	968.4	968.4
			30495	10:29	954.4	954.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:57:01	20.45	Red	428.8	42.5	Craig Webb

Comments:
clouds getting thicker, temp 38C, hum 35%, hpa 978, wnd dirt 190 @ 6 mph. will run till solar noon.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:08:50	19.49	Blue	0.5	99.8	Craig Webb

Comments:
clouds becoming too much total over cast quiting now.

Session: 64

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	06:37:22	07:40:26	29222	05:44	973.9	973.4
			30495	05:44	959.9	960.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:04:35	73.99	Blue	284.5	56.5	Craig Webb

Comments:
very hazy, temp 19C, hum 94%, hpa 985, wnd dir 180 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:24:40	70.03	Blue	346.8	51.6	Craig Webb

Comments:
still very hazy, temp 21C, hum 85%, hpa 985, wnd dir 020 @ 5 mph.

Session: 65

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	07:40:26	08:40:27	29222	05:44	973.4	972.3
			30495	05:44	960.1	958.1

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:09:38	61.05	Blue	467.8	41.8	Craig Webb

Comments:
still very hazy, temp 23C, hum 78%, hpa 984, wnd dir 010 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:33:08	56.35	Blue	521.7	38.5	Craig Webb

Comments:
very little chenge in sky conditions.

Session: 66

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	08:40:27	09:40:30	29222	05:44	972.3	971.0
			30495	05:44	958.1	957.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:02:30	50.48	Blue	578.1	35.0	Craig Webb

Comments:
haze getting thinner, temp 24C,. hum 73%, hpa 984, wnd dir 040 @ 7 mph.

Session: 67

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	09:40:30	10:37:30	29222	05:44	971.0	970.2
			30495	05:44	957.1	956.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:43:46	42.36	Blue	618.4	32.8	Craig Webb

Comments:
light haze, temp 26C, hum 68%, hpa 984, wnd dir 020 m@ 5 mph

Session: 68

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	10:37:30	11:37:32	29222	05:44	970.2	969.5
			30495	05:44	956.5	955.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:38:21	32.17	Blue	626.6	36.3	Craig Webb

Comments:
clouds moving/form in local area, temp 28C, hum 63%, hpa 983, wnd dir 020 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:11:30	26.66	Brown	643.2	39.1	Craig Webb

Comments:
clouds affecting readings, will keep running for a while.

Session: 69

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	11:37:32	12:37:36	29222	05:44	969.5	969.1
			30495	05:44	955.8	955.4

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:45:57	22.03	Brown	598.6	40.6	Craig Webb

Comments:
will run till after solar noon.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:26:05	19.17	Blue	651.3	34.4	Craig Webb

Comments:
still a few clouds in the area, temp 29C, hum 50%, hpa 983, wnd dir 030 @ 6 mph.

Session: 70

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	12:37:36	13:37:35	29222	05:44	969.1	968.5
			30495	05:44	955.4	955.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:58:29	19.67	Blue	638.1	36.7	Craig Webb

Comments:
a few clouds left in the area, temp 29C, hum 48%, hpa 982, wnd dir 020 @ 9 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:27:59	22.21	Blue	605.4	36.9	Craig Webb

Comments:
no change

Session: 71

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	13:37:35	14:37:39	29222	05:44	968.5	968.2
			30495	05:44	955.0	954.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:13:01	28.61	Green	592.9	36.3	Craig Webb

Comments:
some clouds, low signal strength, temp 29C, hum 46%, hpa 982, wnd dir 200 @ 10 mph.

Session: 72

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	14:37:39	15:34:40	29222	05:44	968.2	968.0
			30495	05:44	954.9	954.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:42:55	33.76	Blue	584.9	36.8	Craig Webb

Comments:
some clouds , temp 28C, hum 46%, hpa 982

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:08:05	38.45	Blue	592.3	36.2	Craig Webb

Comments:
no change

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:30:54	42.83	Blue	585.2	38.9	Craig Webb

Comments: [None]

Session: 73

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	15:34:40	16:34:43	29222	05:44	968.0	967.9
			30495	05:44	954.6	955.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:00:44	48.69	Blue	522.4	41.4	Craig Webb

Comments:
lot of haze, temp 29C, hum 45%, hpa 981, wnd dir 030 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:31:41	54.86	Blue	562.9	38.0	Craig Webb

Comments:
no change.

Session: 74

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-02-2021	16:34:43	16:54:48	29222	05:44	967.9	968.1
			30495	05:44	955.0	954.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:51:46	58.89	Red	388.7	46.0	Craig Webb

Comments:
closing down for the day .

Session: 75

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	06:39:52	07:39:51	29222	06:15	974.6	974.0
			30495	06:15	959.6	959.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:06:18	73.79	Blue	251.9	59.3	Craig Webb

Comments:
very hazy , temp 19C, hum 97%, hpa 982, wnd dir 035 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:09:53	73.09	Blue	267.6	58.0	Craig Webb

Comments:
condensation keeps form on unventilated radiometers.

Session: 76

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	07:39:51	08:39:54	29222	06:15	974.0	972.7
			30495	06:15	959.1	958.4

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:40:25	67.02	Blue	382.8	49.1	Craig Webb

Comments:
hazy, temp 20C, hum 91%, hpa 982, wnd dir 050 @ 4 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:30:29	57.00	Blue	526.0	38.7	Craig Webb

Comments:
hazy and smokie outside, temp 23C, hum 82%, hpa 982, wnd dir 060 @ 2 mph.

Session: 77

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	08:39:54	09:39:57	29222	06:15	972.7	971.7
			30495	06:15	958.4	957.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:53:38	52.37	Blue	549.9	36.6	Craig Webb

Comments:
hazy, temp 25C, hum 74%, hpa 982, wnd dir 033 @6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:32:49	44.62	Blue	615.4	33.0	Craig Webb

Comments:
no change in sky conditions, temp 26C, hum 63%, hpa 982, wnd dir 040 @ 4 mph.

Session: 78

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	09:39:57	10:07:02	29222	06:15	971.7	970.7
			30495	06:15	957.3	957.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:55:50	40.18	Blue	610.9	33.4	Craig Webb

Comments:
still hazy, no clouds yet, temp 27C, hum 58%, hpa 982, wnd dir 070 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:02:56	38.83	Blue	621.7	33.1	Craig Webb

Comments:
being there is no clouds forming now I will calibrate early getting ready for solar noon.

Session: 79

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	10:07:02	11:09:04	29222	06:15	970.7	970.3
			30495	06:15	957.1	956.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:43:26	31.46	Brown	543.3	37.3	Craig Webb

Comments:
small cirrus clouds forming, temp 27C, hum 57%, hpa 982, wnd dir 041 @ 3 mph.

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Time	Zenith	ASR	Direct	% Diffuse	Operator
11:03:44	28.06	Blue	651.5	31.9	Craig Webb

Comments:
clouds in the area causing alarms.

Session: 80

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	11:09:04	12:07:04	29222	06:15	970.3	969.6
			30495	06:15	956.5	956.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:25:52	24.75	Blue	690.3	29.1	Craig Webb

Comments:
some clouds in area, temp 28C, hum 47%, hpa 981, wnd dir 136 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:27:30	24.53	Blue	696.5	28.9	Craig Webb

Comments: [None]

Session: 81

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	12:07:04	13:07:07	29222	06:15	969.6	969.4
			30495	06:15	956.2	955.3

Observations: [None]

Session: 82

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	13:07:07	14:05:06	29222	06:15	969.4	969.3
			30495	06:15	955.3	955.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:45:29	24.64	Blue	688.7	27.9	Craig Webb

Comments:
still running, temp 29C, hum 43%, hpa 980, wnd dir 092 @ 4 mph.

Session: 83

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	14:05:06	15:02:09	29222	06:15	969.3	968.9
			30495	06:15	955.5	955.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:15:20	29.18	Green	709.8	26.6	Craig Webb

Comments:
A few small clouds in area, temp 29C, hum 41%, hpa 980, wnd dir 040 @ 5 mph.

Session: 84

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	15:02:09	16:02:14	29222	06:15	968.9	968.9
			30495	06:15	955.0	955.2

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:05:13	38.08	Blue	692.5	27.7	Craig Webb

Comments:
clouds seem to be clearing out, temp 29C, hum 43%, hpa 980, wnd dir 053 @ m5 mph,

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:31:14	43.07	Blue	655.7	29.1	Craig Webb

Comments:
no change,

Session: 85

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	16:02:14	17:02:17	29222	06:15	968.9	969.1
			30495	06:15	955.2	955.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:02:18	48.65	4	632.1	30.4	Craig Webb

Comments:
clear with a few clouds to the north, temp 29C, hum 40%, hpa 980, wnd dir 041 @ 2 mph.

Session: 86

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-03-2021	17:02:17	17:58:07	29222	06:15	969.1	968.9
			30495	06:15	955.3	955.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:02:21	60.65	4	511.9	37.2	Craig Webb

Comments:
clear with a few clouds to the North, temp 29C, hum 39%, hpa 980, wnd dir 080 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:53:22	71.35	Blue	395.7	45.2	Craig Webb

Comments:
a few alarms,temp 28C, hum 44%, hpa 980- wnd dir 045 @ 2 mph. going to quite for the day.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:57:18	71.78	Blue	393.2	45.5	Craig Webb

Comments: [None]

Session: 87

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	07:41:06	08:42:06	29222	07:15	972.7	971.7
			30495	07:15	958.5	957.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:51:09	65.25	Blue	416.4	44.6	Craig Webb

Comments:
clear but sky is smokie, temp 22C, hum 96%, hpa 979, wnd dir 070 @ 4 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:15:00	60.48	Blue	479.9	40.1	Craig Webb

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Comments:
still smokie sky, temp 24C, hum 88%, hpa 979, wnd dir 120 @ 6 mph. looks like I will run for a wile but probly shut down due to low readings.

Session: 88

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	08:42:06	09:42:08	29222	07:15	971.7	970.8
			30495	07:15	957.6	956.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:00:01	51.49	Blue	576.3	33.8	Craig Webb

Comments:
finally got above 500 watts, temp 26C, hum 77%, hpa 979, wnd dir 135 @ 8 mph.

Session: 89

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	09:42:08	10:40:11	29222	07:15	970.8	970.0
			30495	07:15	956.9	956.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:49:45	41.77	Blue	641.0	29.8	Craig Webb

Comments:
smokie, temp 28C, hum 70%, hpa 979, wnd dir 095 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:11:40	37.65	Blue	668.2	27.9	Craig Webb

Comments: [None]

Session: 90

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	10:40:11	11:03:27	29222	07:15	970.0	969.7
			30495	07:15	956.0	956.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:40:26	32.48	Blue	678.1	28.1	Craig Webb

Comments:
a few clouds starting to form, temp 31C, hum 62%, hpa 979, wnd dir 094 @ 2 mph. will calibrate early to get ready for solar noon.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:00:33	29.12	Green	635.9	30.7	Craig Webb

Comments: [None]

Session: 91

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	11:03:27	12:03:31	29222	07:15	969.7	968.7
			30495	07:15	956.1	955.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:20:43	26.09	Green	636.7	31.4	Craig Webb

Comments:
lots of smoke, temp 33C, hum 56%, hpa 979, wmd dir 1502 11 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:47:04	22.83	Green	646.3	31.0	Craig Webb

Comments: [None]

Session: 92

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	12:03:31	13:03:33	29222	07:15	968.7	968.2
			30495	07:15	955.3	955.2

Observations: [None]

Session: 93

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	13:03:33	13:59:35	29222	07:15	968.2	967.9
			30495	07:15	955.2	954.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:14:09	21.85	Blue	644.7	33.0	Craig Webb

Comments:
one cloud got in the way so far, temp 34C, hum 46%, hpa 977, wnd dir 130 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:35:05	24.03	Blue	579.9	35.8	Craig Webb

Comments: [None]

Session: 94

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	13:59:35	14:58:37	29222	07:15	967.9	967.5
			30495	07:15	954.6	953.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:02:51	27.86	Blue	592.1	34.4	Craig Webb

Comments:
still a few clouds in the area, temp 35C, hum 45%, hpa 977, wnd dir 145 @ 6 mph.

Session: 95

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	14:58:37	15:58:37	29222	07:15	967.5	967.4
			30495	07:15	953.9	953.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:58:52	37.47	Blue	605.6	34.1	Craig Webb

Comments:
some clouds in area, temp 35C, hum 38%, hpa 976, wnd dir 112 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:23:18	42.07	Blue	583.0	35.5	Craig Webb

Comments: [None]

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Session: 96

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	15:58:37	16:58:40	29222	07:15	967.4	967.2
			30495	07:15	953.9	953.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:59:16	49.09	Blue	539.1	38.0	Craig Webb

Comments:
some clouds in area, temp 35C, hum 42%, hpa 976, wnd dir 120 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:44:07	58.03	Blue	488.3	39.5	Craig Webb

Comments: [None]

Session: 97

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-06-2021	16:58:40	17:32:24	29222	07:15	967.2	967.8
			30495	07:15	953.7	953.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:05:11	62.25	Blue	427.0	42.7	Craig Webb

Comments:
some clouds in area, temp 34C, hum 46%, hpa 976, wnd dir 114 @ 7 mph. will run til 67 degrees where I started this morning.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:29:22	67.09	Blue	385.6	48.7	Craig Webb

Comments:
closing down for the day

Session: 98

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-09-2021	06:58:19	07:57:19	29222	06:25	972.6	970.4
			30495	07:15	958.5	956.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:22:02	71.45	Blue	330.1	50.7	Craig Webb

Comments:
a few clouds in area, temp 27C, hum 79%, hpa 975, wnd dir 132 @ 3 mph.

Session: 99

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-09-2021	07:57:19	08:57:21	29222	06:25	970.4	969.5
			30495	07:15	956.5	955.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:59:26	64.00	Blue	437.6	42.9	Craig Webb

Comments:
smokie, temp 30C, hum 68%, hpa 973, wnd dir 106 @ 10 mph

```
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
08:26:11        58.63         Blue            483.1              39.9      Craig Webb
-----------------------------------------------------------------------------------------
Comments: [None]
=========================================================================================================
Session: 100
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-09-2021     08:57:21       09:57:24       29222          06:25            969.5          968.7
                                             30495          07:15            955.9          955.4
-------------------------------------------------------------------------------------------------
Observations:
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
08:58:14        52.25         Blue            557.8              35.2      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
samokie, temp 31C, hum 61%, hpa 974, wnd dir 115 @ 18 mph.
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
09:31:00        45.81         Green           599.4              32.5      Craig Webb
-----------------------------------------------------------------------------------------
Comments: [None]
=========================================================================================================
Session: 101
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-09-2021     09:57:24       10:56:26       29222          06:25            968.7          968.1
                                             30495          07:15            955.4          955.1
-------------------------------------------------------------------------------------------------
Observations:
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
09:57:59        40.65         Blue            634.5              30.1      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
clear with smoke in sky, temp 33C, hum 58%, hpa 974 wnd dir 128 @ 19 mph.
=========================================================================================================
Session: 102
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-09-2021     10:56:26       11:56:30       29222          06:25            968.1          967.5
                                             30495          07:15            955.1          954.3
-------------------------------------------------------------------------------------------------
Observations:
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
10:56:59        30.27         Blue            643.4              30.2      Craig Webb
-----------------------------------------------------------------------------------------
Comments:
smokie but no clouds yet, temp 34C, hum 53%, hpa 974, wnd dir 145 @ 14 mph.
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
11:42:18        24.06         Blue            671.2              28.7      Craig Webb
-----------------------------------------------------------------------------------------
Comments: [None]
=========================================================================================================
Session: 103
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-09-2021     11:56:30       12:56:32       29222          06:25            967.5          967.2
                                             30495          07:15            954.3          954.1
-------------------------------------------------------------------------------------------------
Observations:
-----------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
12:02:52        22.18         Blue            685.6              27.7      Craig Webb
-----------------------------------------------------------------------------------------
```

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Comments:
this should catch solar noon, temp 35C, hum 48%, hpa 973, wnd dir 130 @ 13 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:23:13	21.15	Brown	696.6	26.9	Craig Webb

Comments: [None]

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:44:19	21.07	Green	708.5	25.8	Craig Webb

Comments: [None]

Session: 104

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-09-2021	12:56:32	13:56:31	29222	06:25	967.2	966.9
			30495	07:15	954.1	953.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:04:26	21.95	Blue	690.3	27.0	Craig Webb

Comments:
smokie, temp 36C, hum 50%, hpa 973, wnd dir 120 @ 16 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:49:44	26.70	Blue	622.1	31.9	Craig Webb

Comments: [None]

Session: 105

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-09-2021	13:56:31	14:55:36	29222	06:25	966.9	966.9
			30495	07:15	953.6	953.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:04:31	28.84	Blue	618.4	32.9	Craig Webb

Comments:
smokie, temp 37C, hum 48, hpa 972, wnd dir 156 @ 19 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:19:08	31.15	Green	609.1	33.2	Craig Webb

Comments:
STD 31152F3 keeps alarming ,I have cleanrd dome check leveling and find nothing wrong.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:20:59	31.45	Blue	609.6	33.2	Craig Webb

Comments:
clouds forming to the southeast.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:52:52	36.99	Red	520.1	41.6	Craig Webb

Comments: [None]

Session: 106

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-09-2021	14:55:36	15:49:55	29222	06:25	966.9	966.6
			30495	07:15	953.5	953.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:11:24	40.41	Red	251.1	63.2	Craig Webb

Comments:
clouds in area, temp 37C, hum 49%, hpa 972, wnd dir 130 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:28:53	43.74	Green	550.7	39.0	Craig Webb

Comments:
with clouds in area going to quit at the end of this session.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:47:09	47.27	Blue	530.1	39.7	Craig Webb

Comments: [None]

Session: 107

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	06:54:13	07:54:15	29222	06:35	970.6	969.3
			30495	06:35	956.3	956.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:28:34	70.29	Blue	385.8	45.9	Craig Webb

Comments:
clear but low levels, temp 29C, hum 73%, hpa 976, wnd dir 090 @ 12 mph.

Session: 108

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	07:54:15	08:55:16	29222	06:35	969.3	969.3
			30495	06:35	956.3	955.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:54:32	65.10	Blue	474.3	39.2	Craig Webb

Comments:
clear but signal weak due to smoke, temp 29C, hum 69%, hpa 976, wnd dir 108 @ 17 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:10:28	61.90	Blue	521.7	35.9	Craig Webb

Comments: [None]

Session: 109

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	08:55:16	09:56:18	29222	06:35	969.3	968.4
			30495	06:35	955.5	954.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:06:16	50.79	Blue	648.7	27.6	Craig Webb

Comments:
clear and windy, termp 32C, hum 60, hpa 976, wnd dir 130 @ 24 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:53:16	41.69	Blue	724.1	22.8	Craig Webb

Comments: [None]

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Session: 110

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	09:56:18	10:56:21	29222	06:35	968.4	968.0
			30495	06:35	954.5	954.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:13:39	37.91	Green	743.5	21.5	Craig Webb

Comments:
clear and windy, temp 32C, hum 57%, hpa 976, wnd dir 104@ 26 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:48:38	31.82	Green	805.7	17.0	Craig Webb

Comments: [None]

Session: 111

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	10:56:21	11:56:23	29222	06:35	968.0	967.4
			30495	06:35	954.7	954.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:00:35	29.90	Blue	829.4	15.4	Craig Webb

Comments:
hot and windy, temp 34C, hum 54%, hpa 976, wnd dir 124 @ 18 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:50:46	23.45	Blue	858.9	13.6	Craig Webb

Comments: [None]

Session: 112

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	11:56:23	12:53:24	29222	06:35	967.4	966.9
			30495	06:35	954.0	953.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:12:36	21.86	Green	863.5	13.4	Craig Webb

Comments:
solar noon this run, temp 36C, hum 50%, hpa 976, wnd dir 037 @ 14 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:33:05	21.28	Blue	866.5	13.2	Craig Webb

Comments: [None]

Session: 113

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	12:53:24	13:53:26	29222	06:35	966.9	966.7
			30495	06:35	953.8	953.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:54:37	21.71	Green	861.4	13.5	Craig Webb

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Comments:
field burning S/E of site 4 miles away, temp 36C, hum 48%, hpa 975, wnd dir 135 @ 14mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:33:48	24.95	Blue	865.1	13.1	Craig Webb

Comments: [None]

Session: 114

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	13:53:26	14:53:28	29222	06:35	966.7	966.3
			30495	06:35	953.5	953.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:54:48	27.66	Blue	864.7	13.2	Craig Webb

Comments:
clear hot and windy, temp 36C, hum 46%, hpa 975, wnd dir142 @ 20 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:46:50	36.14	Green	837.4	14.3	Craig Webb

Comments: [None]

Session: 115

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	14:53:28	15:54:31	29222	06:35	966.3	966.3
			30495	06:35	953.3	953.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:55:14	37.65	Blue	826.3	14.8	Craig Webb

Comments:
a few small cirrus forming to the n/w, temp 37C, hum 43%, hpa 974, wnd dir 120 @ 27 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:28:57	43.94	Blue	807.7	15.7	Craig Webb

Comments: [None]

Session: 116

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	15:54:31	16:55:33	29222	06:35	966.3	966.1
			30495	06:35	953.3	952.9

Observations: [None]

Session: 117

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	16:55:33	17:55:35	29222	06:35	966.1	966.2
			30495	06:35	952.9	953.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:49:10	71.79	Blue	518.7	32.6	Craig Webb

Comments: [None]

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Session: 118

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-10-2021	17:55:35	18:11:06	29222	06:35	966.2	966.5
			30495	06:35	953.1	952.7

Observations: [None]

Session: 119

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	07:35:31	08:35:32	29222	06:25	970.2	969.3
			30495	06:25	956.8	955.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:56:11	66.55	Blue	697.7	20.1	Craig Webb

Comments:
a few small clouds in area, temp 29C, hum 68%, hpa 976, wnd dir 150 @ 16 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:29:44	59.88	Blue	763.1	16.7	Craig Webb

Comments: [None]

Session: 120

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	08:35:32	09:35:35	29222	06:25	969.3	968.5
			30495	06:25	955.9	955.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:50:00	55.88	Green	801.9	14.7	Craig Webb

Comments:
some clouds to the north and west, temp 31C, hum 53%, hpa 976, wnd dir 165 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:17:11	50.63	Blue	839.2	13.1	Craig Webb

Comments: [None]

Session: 121

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	09:35:35	10:35:36	29222	06:25	968.5	967.5
			30495	06:25	955.0	954.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:39:12	46.45	Blue	845.1	12.9	Craig Webb

Comments:
some clouds to the north and west, temp 34C, hum 40%, hpa 976, wnd dir 140 @ 17 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:23:31	38.57	Blue	868.5	12.1	Craig Webb

Comments: [None]

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Session: 122

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	10:35:36	11:02:39	29222	06:25	967.5	967.2
			30495	06:25	954.5	953.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:49:58	34.33	Blue	891.2	11.0	Craig Webb

Comments:
some cloudsi the area, temp 35C, hum 35%, hpa 976, wnd dir 145 @ 13 mph.

Session: 123

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	11:02:39	12:00:42	29222	06:25	967.2	966.8
			30495	06:25	953.9	953.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:10:06	31.46	Blue	908.3	10.2	Craig Webb

Comments:
some clouds in area, temp 36C, hum 33%, hpa 976, wnd dir 106 @ 14 mph.

Session: 124

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	12:00:42	13:04:44	29222	06:25	966.8	966.4
			30495	06:25	953.6	953.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:21:44	25.54	Red	612.5	29.4	Craig Webb

Comments:
clouds moving into the area, temp 37C, hum 29%, hpa 976, wnd dir 109 @ n17 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:49:20	25.71	Brown	933.5	10.3	Craig Webb

Comments: [None]

Session: 125

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	13:04:44	14:04:45	29222	06:25	966.4	967.5
			30495	06:25	953.2	954.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:13:24	27.06	Blue	935.0	12.7	Craig Webb

Comments:
some clouds in area, temp 37C, hum 30%, hpa 976, wnd dir 136 @ 14 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:14:11	27.12	Blue	930.9	13.2	Craig Webb

Comments: [None]

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Session: 126

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	14:04:45	15:04:45	29222	06:25	967.5	966.0
			30495	06:25	954.1	952.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:21:43	35.38	Green	783.7	12.5	Craig Webb

Comments:
clouds seem to be clearing out, temp 38C, hum 30%, hpa 974, wnd dir 095 @ 20 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:45:42	39.32	Green	744.4	14.1	Craig Webb

Comments: [None]

Session: 127

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	15:04:45	16:01:47	29222	06:25	966.0	965.7
			30495	06:25	952.9	953.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:37:10	48.65	Blue	851.8	12.9	Craig Webb

Comments:
clearing temp 37C, hum 27%, hpa 973, wnd dir 144 @ 20 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:58:00	52.64	Blue	841.1	12.9	Craig Webb

Comments: [None]

Session: 128

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	16:01:47	17:01:49	29222	06:25	965.7	966.1
			30495	06:25	953.0	952.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:19:42	56.87	Green	808.8	14.6	Craig Webb

Comments:
temp 37C, hum 28%, hpa 973, wnd dir 136 @ 14 mph

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:42:18	61.35	Blue	764.0	16.3	Craig Webb

Comments: [None]

Session: 129

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-23-2021	17:01:49	17:59:22	29222	06:25	966.1	965.9
			30495	06:25	952.7	952.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:23:38	69.60	Blue	681.9	20.3	Craig Webb

```
Comments:
temp 36C, hum 29%, hpa 973, wnd dir 126 @ 10 mph.
------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
17:51:58        75.28         Blue            571.9              26.0      Craig Webb
------------------------------------------------------------------------------------
Comments: [None]
============================================================================================================
Session: 130
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-24-2021     06:42:41       07:34:07       29222          06:15            971.5          970.9
                                             30495          06:15            957.4          956.9
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
07:07:08        76.51         Blue            581.4              29.0      Craig Webb
------------------------------------------------------------------------------------
Comments:
some small clouds in area, temp 26C, hum 72%, hpa 975, wnd dir 090 @ 4 mph
------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
07:28:09        72.31         Blue            582.0              30.2      Craig Webb
------------------------------------------------------------------------------------
Comments: [None]
============================================================================================================
Session: 131
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-24-2021     08:55:24       09:58:26       29222          06:15            969.5          968.3
                                             30495          06:15            955.9          955.1
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
09:30:10        48.31         Blue            868.9              11.2      Craig Webb
------------------------------------------------------------------------------------
Comments:
clouds cleared so started up again. temp 33c, hum 47%, hpa 975 wnd dir 078@ 15 mph.
------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
09:53:13        44.05         Blue            871.4              10.9      Craig Webb
------------------------------------------------------------------------------------
Comments: [None]
============================================================================================================
Session: 132
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-24-2021     09:58:26       10:59:28       29222          06:15            968.3          967.5
                                             30495          06:15            955.1          954.0
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
10:34:59        36.88         Blue            890.2              10.4      Craig Webb
------------------------------------------------------------------------------------
Comments:
temp 36C, hum 38%, hpa 975, wnd dir 150 @ 16 mph.
============================================================================================================
Session: 133
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
08-24-2021     10:59:28       11:59:30       29222          06:15            967.5          966.7
                                             30495          06:15            954.0          953.5
--------------------------------------------------------------------------------------------------
```

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:12:54	31.35	Brown	915.4	9.5	Craig Webb

Comments:
some light clouds in area, temp 36C, hum 35%, hpa 975, wnd dir 152 @ 24 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:40:03	28.32	Blue	925.5	9.0	Craig Webb

Comments: [None]

Session: 134

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-24-2021	11:59:30	12:59:30	29222	06:15	966.7	966.2
			30495	06:15	953.5	952.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:02:18	26.63	Green	930.4	8.7	Craig Webb

Comments:
clouds to the east, temp 37C, hum 32%, hpa 974, wnd dir 145 @ 21 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:36:05	25.78	Red	932.0	8.7	Craig Webb

Comments: [None]

Session: 135

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-24-2021	12:59:30	14:01:34	29222	06:15	966.2	966.2
			30495	06:15	952.8	952.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:34:02	29.32	Blue	909.3	9.6	Craig Webb

Comments: [None]

Session: 136

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-24-2021	14:01:34	15:03:34	29222	06:15	966.2	965.5
			30495	06:15	952.9	952.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:02:38	32.87	Blue	897.6	10.3	Craig Webb

Comments:
clear and windy, temp 38C, hum 33%, hpa 974, wnd dir 121 @ 27 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:44:07	39.35	Green	866.1	11.7	Craig Webb

Comments: [None]

Session: 137

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-24-2021	15:03:34	16:00:35	29222	06:15	965.5	966.0
			30495	06:15	952.5	952.4

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:32:16	47.99	Blue	845.6	12.6	Craig Webb

Comments:
clouds to the south west, temp 38C, hum 32%, hpa 974, wnd dir 132 @ 20 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:54:55	52.30	Blue	824.8	13.3	Craig Webb

Comments: [None]

Session: 138

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-24-2021	16:00:35	17:00:38	29222	06:15	966.0	965.7
			30495	06:15	952.4	952.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:15:08	56.23	Blue	803.3	14.4	Craig Webb

Comments:
clouds to the west and south, temp 38C, hum 33%, hpa 973, wnd dir 156 @ 24 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:35:36	60.26	Blue	760.5	16.1	Craig Webb

Comments: [None]

Session: 139

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-24-2021	17:00:38	17:47:33	29222	06:15	965.7	965.9
			30495	06:15	952.2	952.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:01:21	65.40	Blue	718.3	18.4	Craig Webb

Comments:
clouuds to the siuth and west, temp 37C, hum 36%, hpa 973, wnd dir 160 @ 21 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:42:48	73.69	Blue	589.4	25.3	Craig Webb

Comments:
will be quiting in a few minutes, it will be sunny angain tomorrow and I will come in and run, but I will be gone thursday and friday.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:44:32	74.05	Blue	577.1	25.6	Craig Webb

Comments: [None]

Session: 140

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	06:32:04	07:35:06	29222	06:15	971.1	970.1
			30495	06:15	956.6	956.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:55:39	78.93	Blue	477.2	32.8	Craig Webb

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Comments:
clouds to the west and soutrh, temp 25C, hum 83%, hpa 978, wnd dir 110 @ 3 mph.

Session: 141

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	07:35:06	08:35:09	29222	06:15	970.1	969.4
			30495	06:15	956.6	955.2

Observations: [None]

Session: 142

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	08:35:09	09:38:11	29222	06:15	969.4	968.3
			30495	06:15	955.2	954.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:28:33	48.78	Brown	802.9	15.6	Craig Webb

Comments:
some small clouds in area, temp 34C, hum 49%, hpa 979, wnd dir 136 @ 6 mph.

Session: 143

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	09:38:11	10:38:14	29222	06:15	968.3	967.4
			30495	06:15	954.8	954.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:18:18	39.84	Blue	867.8	12.4	Craig Webb

Comments:
some light clouds, temp 36C, hum 43%, hpa 079, wnd dir 163 @ 10 m[h.

Session: 144

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	10:38:14	11:38:16	29222	06:15	967.4	966.2
			30495	06:15	954.2	953.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:48:26	35.01	Green	876.8	15.2	Craig Webb

Comments:
clouds moving into the area, temp 37C, hum 41%, hpa 979, wnd dir 183 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:31:52	29.42	Green	886.2	11.6	Craig Webb

Comments: [None]

Session: 145

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	11:38:16	12:07:15	29222	06:15	966.2	966.2
			30495	06:15	953.4	953.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:53:33	27.51	Green	885.2	11.4	Craig Webb

BORCAL 2021-03 Operator Session Log

Comments:
some clouds in the area, temp 38C, hum 37%, hpa 978, wnd dir 114 @ 3 mph.

Session: 146

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	12:07:15	13:07:17	29222	06:15	966.2	965.9
			30495	06:15	953.2	952.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:18:40	26.28	Blue	893.7	10.8	Craig Webb

Comments:
solar noon comming up, temp 38C, hum 37%, hpa 978, wnd dir 114 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:59:42	26.86	Green	890.0	10.7	Craig Webb

Comments: [None]

Session: 147

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	13:07:17	14:06:18	29222	06:15	965.9	965.6
			30495	06:15	952.7	952.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:26:07	28.85	Blue	891.7	10.7	Craig Webb

Comments:
some clouds in the area, temp 39C, hum 33%, hpa 978, wnd dir 140 @ 7 mph.

Session: 148

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	14:06:18	15:06:19	29222	06:15	965.6	965.4
			30495	06:15	952.7	952.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:08:33	34.04	Blue	865.3	11.6	Craig Webb

Comments:
some clouds in area, temp 39C, hum 32%, hpa 977, wnd dir 117 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:32:39	37.75	Blue	864.9	11.6	Craig Webb

Comments: [None]

Session: 149

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	15:06:19	16:07:21	29222	06:15	965.4	965.3
			30495	06:15	952.4	952.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:06:40	43.58	Blue	844.4	12.7	Craig Webb

Comments:
clouds clearing out, temp 38C, hum 34%, hpa 977, wnd dir 136 @ 16 mph.

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Session: 150

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	16:07:21	17:08:24	29222	06:15	965.3	965.3
			30495	06:15	952.0	952.1

Observations: [None]

Session: 151

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
08-25-2021	17:08:24	17:54:24	29222	06:15	965.3	965.7
			30495	06:15	952.1	952.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:46:45	74.74	Blue	534.0	28.8	Craig Webb

Comments:
closing down temp-37C, hum 40%, mhpa 976, wnd dir 150 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:51:03	75.60	Blue	528.8	29.4	Craig Webb

Comments:
cquiting for the night.