Broadband Outdoor Radiometer Calibration Shortwave

BORCAL-SW 2020-01

Generated by

RCC

Radiometer Calibration and Characterization

<u>Calibration Facility</u>

Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Calibration date

05/19/2020

Report Date

June 10, 2020

ARM

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction....3
Control Instrument history plots....4
Results summary....6
Appendix 1 Instrument Details....A1-1
Appendix 2 BORCAL Notes....A2-1
Appendix 3 Session Configuration Audit Report....A3-1
Appendix 4 Operator Logs....A4-1

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

The following instruments instruments were invalidated in this BORCAL:
Invalidate:32991F3 very odd Rs vs. time, possible dirty inside dome
Invalidate:31121E6 large Rs change of 1.47% in 2020 but remained valid since all QC checks were good (Table layout, channel check).
Invalidate and check level : 30802F3 has very large AM/PM Rs assymetry
Invalidate and check level : 32039F3 has very large AM/PM Rs assymetry
Invalidate and check level : 32015F3 has very large AM/PM Rs assymetry

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

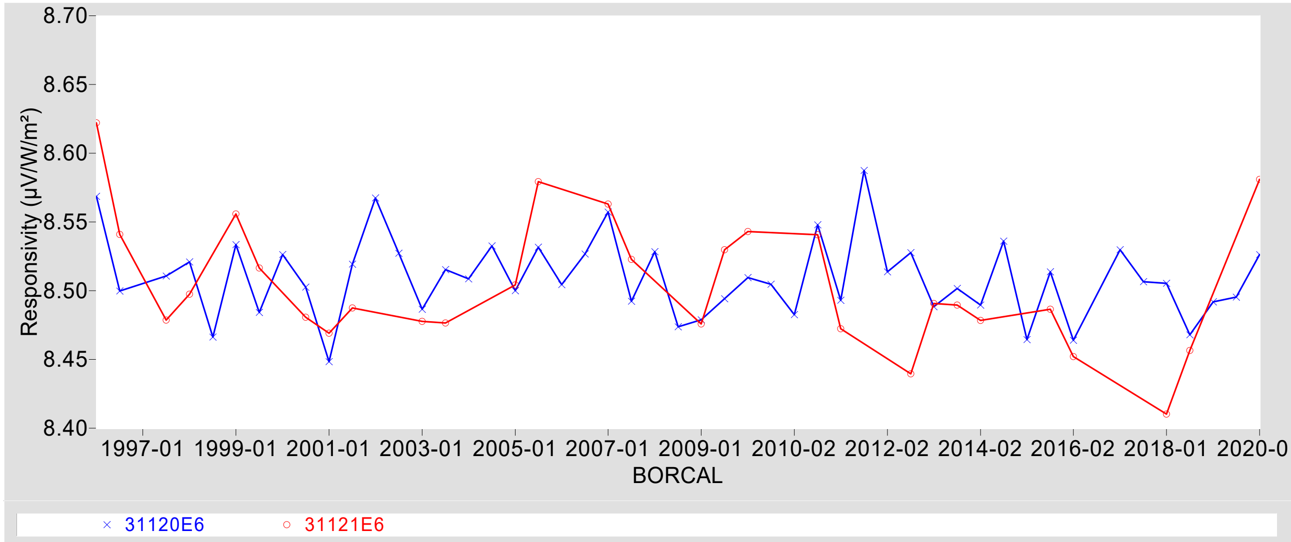


Figure 2. Eppley PSP Control Instrument History

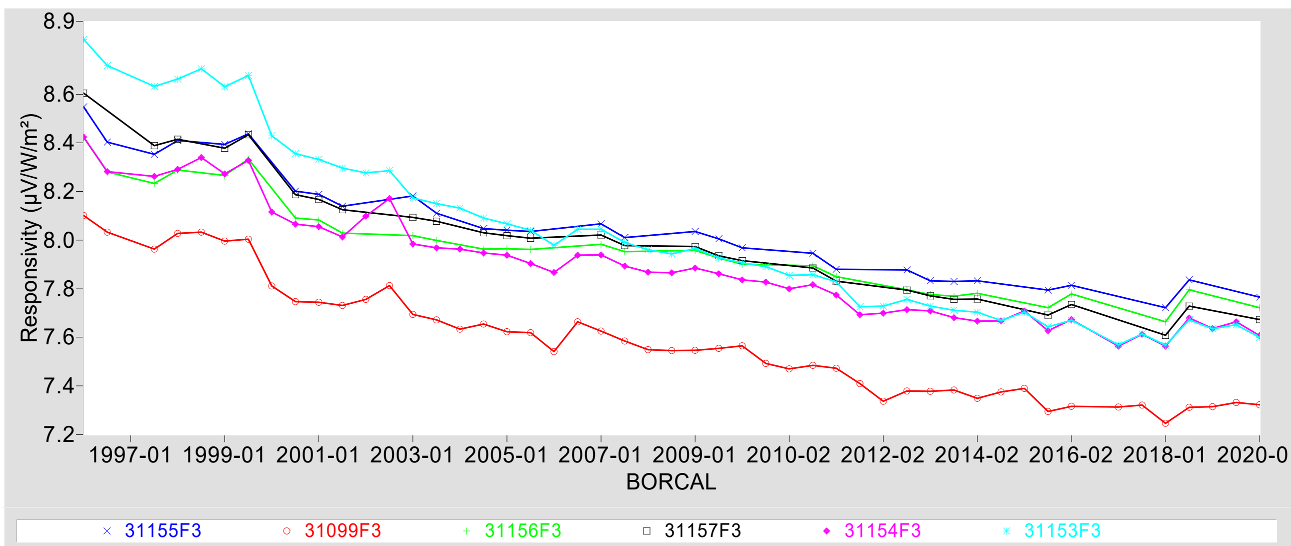
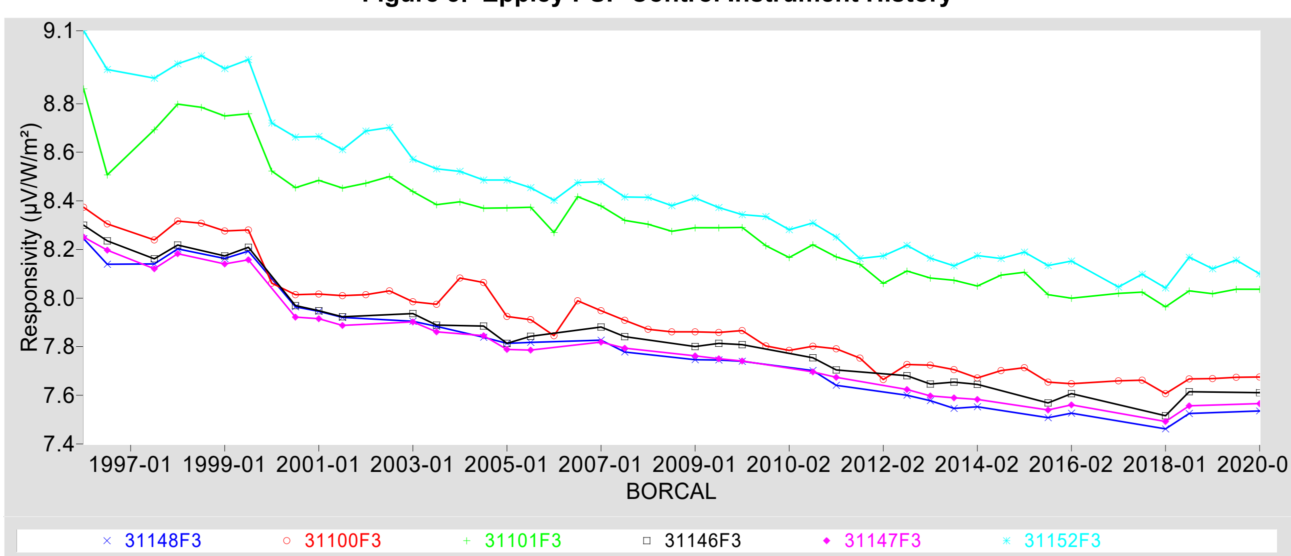
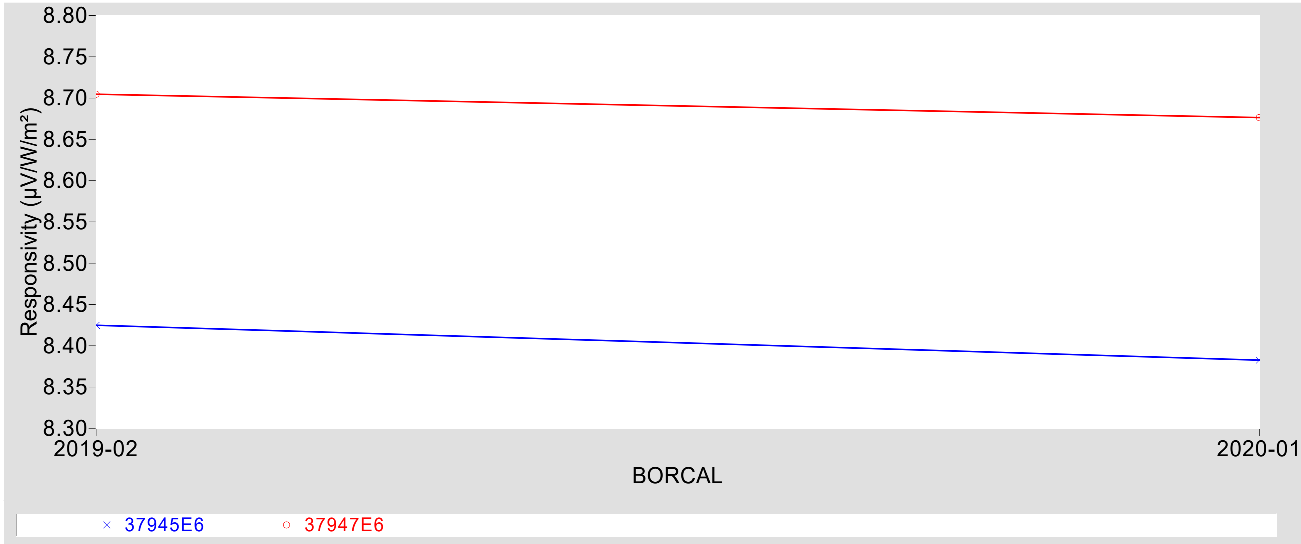


Figure 3. Eppley PSP Control Instrument History



Control Instrument History

Figure 4. Eppley sNIP 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
16256F3	TWP	7.9782	+1.3 / -2.0	0.60000	A1-2
17933F3	TWP	7.6560	+2.3 / -2.6	0.60000	A1-5
17934F3	Nels Laulainen	8.0358	+2.2 / -2.8	0.60000	A1-8
18289F3	Nels Laulainen	8.1721	+1.9 / -2.2	0.60000	A1-11
18350E6	TWP	9.1703	+1.2 / -0.66	0	A1-14
27973F3	TWP	8.3917	+1.6 / -1.2	0.60000	A1-17
29554E6	SGP	8.0931	+1.2 / -0.77	0	A1-20
29608F3	SGP	7.8460	+2.7 / -2.8	0.57100	A1-23
29612F3	SGP	8.2441	+2.3 / -2.5	0.57100	A1-26
29618F3	SGP	9.4184	+2.4 / -2.7	0.67500	A1-29
29738E6	SGP	8.0877	+1.8 / -0.80	0	A1-32
29743E6	SGP	8.1640	+1.3 / -0.66	0	A1-35
29848E6	SGP	8.1757	+1.3 / -0.99	0	A1-38
29856E6	SGP	7.7186	+1.3 / -0.66	0	A1-41
29913F3	TWP	7.6012	+2.4 / -2.4	0.53900	A1-44
29914F3	TWP	8.4389	+1.8 / -3.1	0.65100	A1-47
29916F3	TWP	7.3250	+2.6 / -3.4	0.54700	A1-50
29937E6	TWP	7.8934	+1.3 / -0.64	0	A1-53
29939E6	SGP	8.2850	+1.4 / -0.72	0	A1-56
30614F3	SGP	8.4931	+2.6 / -3.6	0.63119	A1-59
30620F3	SGP	8.8297	+2.6 / -3.0	0.66913	A1-62
30663F3	SGP	8.7602	+2.4 / -2.7	0.59430	A1-65
30666F3	SGP	7.9510	+3.0 / -4.1	0.69195	A1-68
30667F3	SGP	8.5440	+2.8 / -3.8	0.62861	A1-71
30673F3	SGP	7.6370	+1.7 / -1.9	0.57412	A1-74
30674F3	SGP	9.0356	+2.2 / -2.8	0.61487	A1-77
30720E6	SGP	8.1562	+1.4 / -0.76	0	A1-80
30722E6	SGP	8.6119	+1.5 / -0.72	0	A1-83
30797F3	SGP	8.7698	+2.1 / -2.0	0.61400	A1-86
30811F3	SGP	8.0344	+2.1 / -2.7	0.55500	A1-89
30825F3	SGP	8.1595	+2.6 / -3.1	0.63800	A1-92
30890F3	SGP	7.6027	+2.3 / -3.0	0.59445	A1-95
30895F3	SGP	8.4363	+1.9 / -2.0	0.54800	A1-98
30897F3	SGP	7.9920	+2.1 / -2.6	0.59840	A1-101
30899F3	SGP	7.5449	+2.6 / -3.1	0.52200	A1-104
30902F3	SGP	8.3237	+2.1 / -2.7	0.55035	A1-107
30929F3	SGP	7.6185	+2.6 / -3.7	0.63036	A1-110
30938F3	SGP	7.4287	+2.4 / -3.3	0.55200	A1-113
30939F3	SGP	7.6836	+2.4 / -2.9	0.58311	A1-116
30946F3	SGP	7.5812	+2.5 / -3.6	0.66251	A1-119
30951F3	SGP	8.5207	+1.8 / -2.0	0.64270	A1-122
30954F3	SGP	8.6226	+2.3 / -2.9	0.63330	A1-125
30958F3	SGP	9.0796	+2.2 / -2.2	0.61540	A1-128
31097F3	SGP	8.2374	+2.4 / -2.7	0.48715	A1-131
31099F3	Calibration System	7.3223	+2.5 / -3.3	0.57866	A1-134
31100F3	Calibration System	7.6748	+2.3 / -2.4	0.64729	A1-137
31101F3	Calibration System	8.0362	+2.7 / -3.2	0.64834	A1-140
31120E6	Calibration System	8.5263	+1.5 / -0.97	0	A1-143
31121E6	Calibration System	8.5808	+1.6 / -0.64	0	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
31146F3	Calibration System	7.6111	+2.1 / -2.5	0.54900	A1-149
31147F3	Calibration System	7.5666	+2.2 / -3.0	0.55100	A1-152
31148F3	Calibration System	7.5352	+2.3 / -2.6	0.53300	A1-155
31152F3	Calibration System	8.0999	+2.5 / -2.8	0.63390	A1-158
31153F3	Calibration System	7.5993	+3.8 / -4.9	0.64286	A1-161
31154F3	Calibration System	7.6075	+2.6 / -3.0	0.56158	A1-164
31155F3	Calibration System	7.7656	+2.2 / -2.3	0.52400	A1-167
31156F3	Calibration System	7.7221	+2.2 / -2.4	0.53200	A1-170
31157F3	Calibration System	7.6733	+2.4 / -3.3	0.49000	A1-173
31278F3	TWP	8.0899	+2.2 / -2.4	0.56100	A1-176
31281F3	TWP	7.5669	+2.4 / -4.2	0.54100	A1-179
31284F3	TWP	7.6769	+2.4 / -3.1	0.54600	A1-182
31291F3	TWP	8.0529	+2.6 / -3.2	0.61842	A1-185
31293F3	TWP	7.8012	+2.3 / -2.9	0.62546	A1-188
31388E6	SGP	7.8755	+1.4 / -0.73	0	A1-191
31631F3	SGP	8.5008	+2.2 / -3.6	0.65987	A1-194
31827E6	TWP	8.4463	+1.8 / -1.1	0	A1-197
31866E6	TWP	8.1649	+1.5 / -1.1	0	A1-200
32016F3	NSA	8.6085	+1.6 / -2.2	0.64054	A1-203
32017F3	NSA	8.8885	+1.7 / -2.0	0.59100	A1-206
32018F3	NSA	8.5795	+2.1 / -2.9	0.60555	A1-209
32882	TWP	8.4562	+3.0 / -1.7	0	A1-212
32989F3	TWP	8.1046	+2.1 / -2.3	0.60000	A1-215
33239	SGP	9.7117	+2.2 / -1.5	0	A1-218
33242	SGP	9.0998	+4.9 / -2.0	0	A1-221
33247	SGP	9.1891	+1.6 / -1.6	0	A1-224
33259	NSA	8.7616	+3.9 / -2.0	0	A1-227
33261	SGP	8.7718	+1.6 / -1.3	0	A1-230
33271	TWP	8.7446	+1.6 / -1.2	0	A1-233
33274	SGP	8.8365	+6.0 / -2.0	0	A1-236
33277	SGP	9.3384	+1.7 / -1.3	0	A1-239
33279	SGP	8.6844	+3.4 / -1.5	0	A1-242
33374	TWP	7.5516	+5.4 / -2.2	0	A1-245
33375	NSA	8.6957	+2.0 / -2.4	0	A1-248
33551E6	TWP	8.0040	+1.3 / -0.83	0	A1-251
33784	SGP	9.7873	+3.1 / -1.6	0	A1-254
33785	SGP	9.3675	+2.1 / -1.4	0	A1-257
33860E6	AMF	7.8462	+1.4 / -0.66	0	A1-260
34066	AMF	8.6179	+2.1 / -1.9	0	A1-263
34135E6	AMF	7.8442	+1.3 / -0.60	0	A1-266
34281	TWP	9.8110	+1.3 / -1.5	0	A1-269
34504E6	SGP	8.0897	+1.5 / -0.85	0	A1-272
34505E6	SGP	7.9432	+1.2 / -0.59	0	A1-275
34506E6	SGP	7.6232	+1.9 / -1.3	0	A1-278
34580	SGP	9.9346	+3.3 / -1.7	0	A1-281
35751	AMF#2	9.5486	+3.6 / -2.0	0	A1-284
35804E6	AMF#2	7.8901	+0.99 / -0.79	0	A1-287
35864	SGP	8.3484	+3.1 / -1.9	0	A1-290
37285E6	AMF	8.4180	+1.4 / -1.0	0	A1-293

[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
37303F3	AMF	8.4353	+2.2 / -2.1	0.60000	A1-296
37304F3	NSA	8.9639	+1.6 / -1.5	0.60000	A1-299
37314F3	NSA	9.0123	+1.5 / -1.6	0.60000	A1-302
37317F3	AMF	8.7005	+2.1 / -1.7	0.60000	A1-305
37359E6	NSA	8.3151	+1.4 / -0.68	0	A1-308
37361E6	NSA	8.6088	+1.1 / -0.82	0	A1-311
37945E6	SGP	8.3825	+0.84 / -0.70	0	A1-314
37947E6	SGP	8.6763	+0.86 / -0.63	0	A1-317
37959E6	SGP	7.9021	+0.94 / -0.90	0	A1-320
37961E6	SGP	8.4874	+0.95 / -0.62	0	A1-323
38909F3	SGP	8.3511	+1.5 / -1.6	0.22000	A1-326
38910F3	SGP	7.8680	+1.6 / -1.5	0.22000	A1-329

[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 A1-332.

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:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	16256F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

16256F3 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

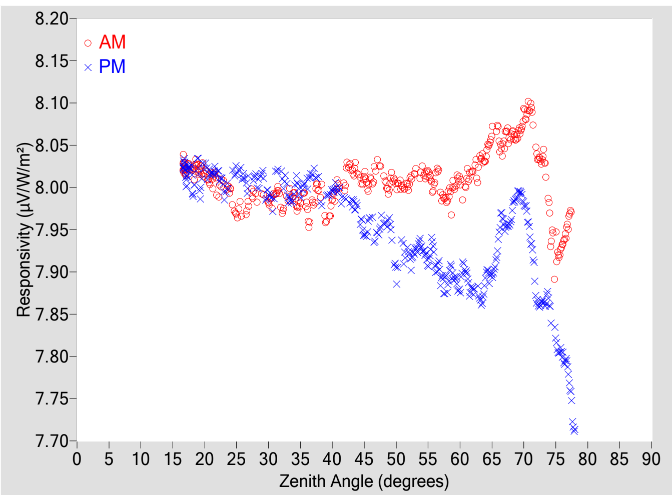


Figure 2. Responsivity vs Local Standard Time

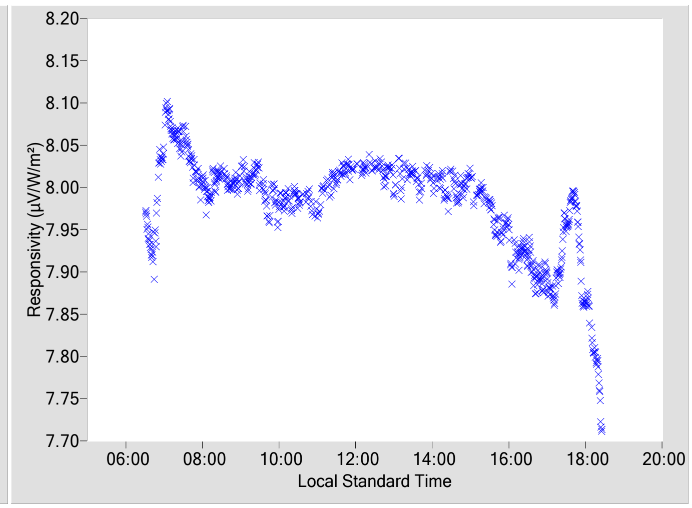


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0087	0.34	97.32	7.9643	0.34	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0105	0.34	95.41	7.9576	0.35	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0039	0.35	93.92	7.9017	0.35	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0035	0.35	92.38	7.9223	0.36	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0181	0.36	90.89	7.9297	0.37	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0057	0.37	89.33	7.9137	0.37	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9879	0.38	87.85	7.8880	0.39	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0081	0.39	86.46	7.8853	0.40	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0187	0.40	85.11	7.8794	0.42	275.05
18	8.0219	0.30	155.12	8.0063	0.30	204.90	64	8.0348	0.41	83.65	7.8906	0.44	276.44
20	8.0172	0.30	142.73	8.0266	0.30	216.66	66	8.0617	0.43	82.27	7.9362	0.46	277.84
22	7.9985	0.30	134.57	8.0183	0.30	225.42	68	8.0624	0.45	80.86	7.9663	0.49	279.26
24	7.9980	0.31	128.70	N/A	N/A	N/A	70	8.0833	N/A	79.51	7.9806	0.52	280.61
26	7.9660	0.31	124.08	8.0118	0.31	236.55	72	8.0385	N/A	78.07	7.8700	N/A	281.97
28	7.9877	0.31	119.22	8.0103	0.31	240.60	74	7.9672	N/A	76.74	7.8609	N/A	283.37
30	7.9828	0.31	115.74	7.9939	0.31	244.17	76	7.9316	N/A	75.33	7.8024	N/A	284.77
32	7.9728	0.31	112.54	8.0149	0.31	247.51	78	N/A	N/A	N/A	7.7138	N/A	286.10
34	7.9915	0.32	109.93	7.9929	0.32	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9734	0.32	107.32	8.0046	0.32	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9938	0.32	105.16	7.9979	0.32	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9871	0.33	102.89	7.9964	0.33	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0113	0.33	100.87	7.9870	0.33	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0160	0.33	99.04	7.9801	0.33	260.87	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

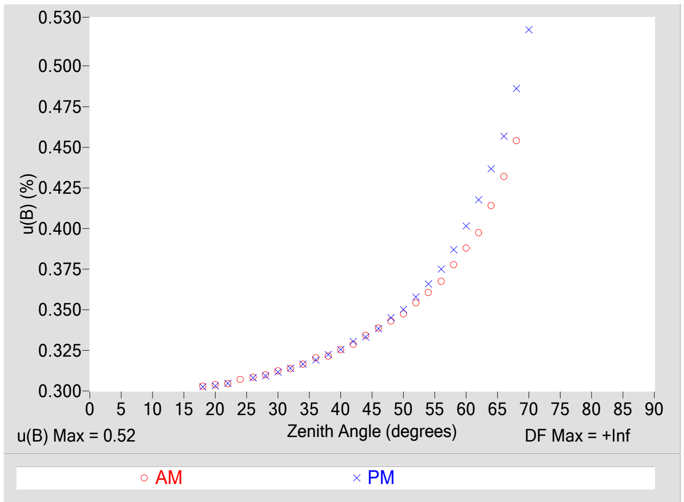


Figure 4. Residuals from Spline Interpolation

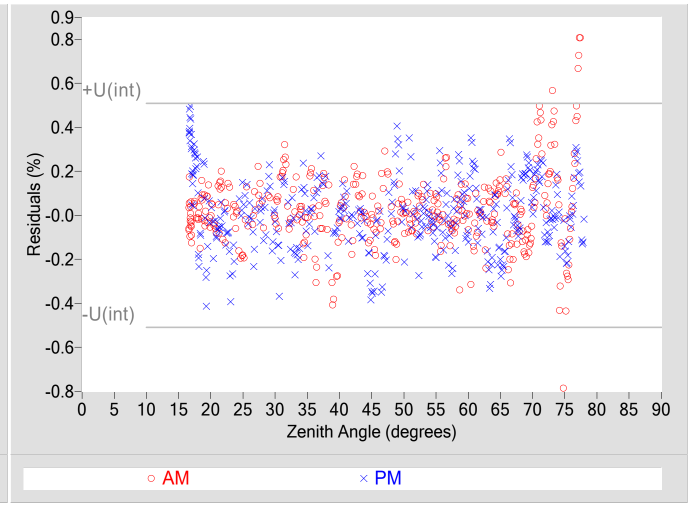


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.52
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	18712
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

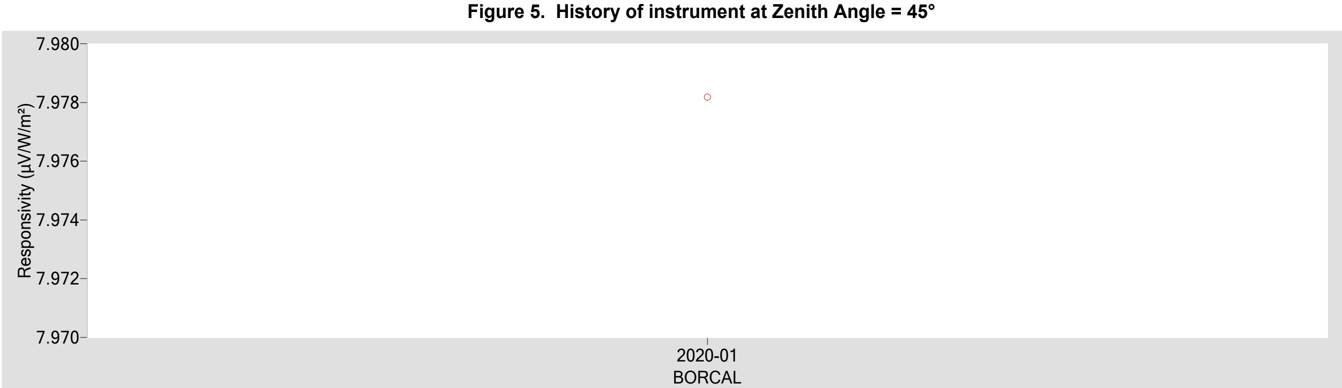
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9782	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.79
Offset Uncertainty, U(off) (%)	+0.50 / -1.2
Expanded Uncertainty, U (%)	+1.3 / -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:**	17933F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

17933F3 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

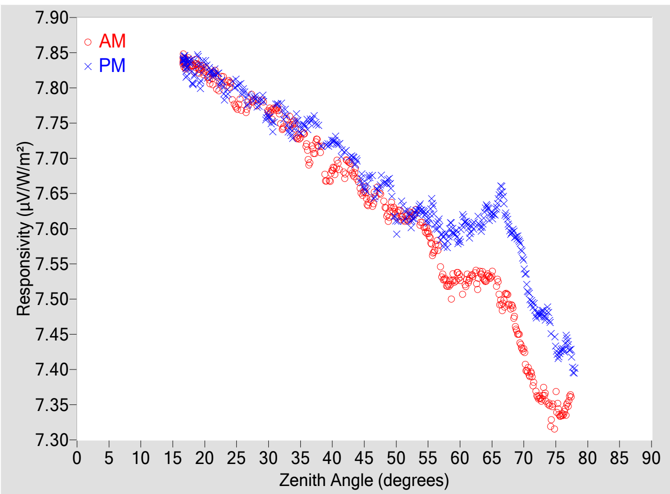


Figure 2. Responsivity vs Local Standard Time

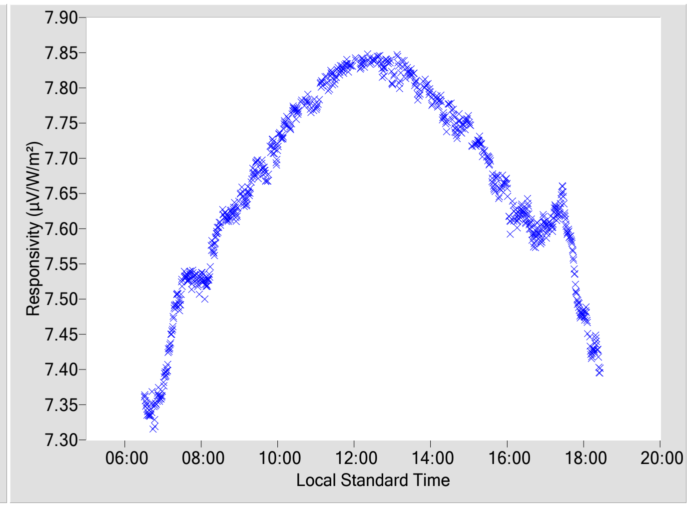


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.6407	0.34	97.32	7.6747	0.34	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6345	0.35	95.41	7.6652	0.35	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6221	0.35	93.92	7.6077	0.35	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6161	0.36	92.38	7.6199	0.36	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6077	0.36	90.89	7.6271	0.37	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5698	0.37	89.33	7.6131	0.38	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5206	0.38	87.85	7.5860	0.39	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5304	0.39	86.46	7.5900	0.41	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5333	0.40	85.11	7.6030	0.42	275.05
18	7.8315	0.30	155.12	7.8195	0.30	204.90	64	7.5277	0.42	83.65	7.6270	0.44	276.44
20	7.8241	0.30	142.73	7.8359	0.30	216.66	66	7.5140	0.44	82.27	7.6418	0.46	277.84
22	7.8047	0.31	134.57	7.8199	0.31	225.42	68	7.4897	0.46	80.86	7.5952	0.49	279.26
24	7.8063	0.31	128.70	N/A	N/A	N/A	70	7.4232	N/A	79.51	7.5480	0.53	280.61
26	7.7683	0.31	124.08	7.7944	0.31	236.55	72	7.3626	N/A	78.07	7.4785	N/A	281.97
28	7.7787	0.31	119.22	7.7832	0.31	240.60	74	7.3425	N/A	76.74	7.4714	N/A	283.37
30	7.7670	0.31	115.74	7.7606	0.31	244.17	76	7.3352	N/A	75.33	7.4282	N/A	284.77
32	7.7440	0.31	112.54	7.7735	0.32	247.51	78	N/A	N/A	N/A	7.3974	N/A	286.10
34	7.7488	0.32	109.93	7.7409	0.32	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7116	0.32	107.32	7.7483	0.32	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7144	0.32	105.16	7.7323	0.32	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6836	0.33	102.89	7.7245	0.33	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6849	0.33	100.87	7.7100	0.33	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6683	0.34	99.04	7.6977	0.34	260.87	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

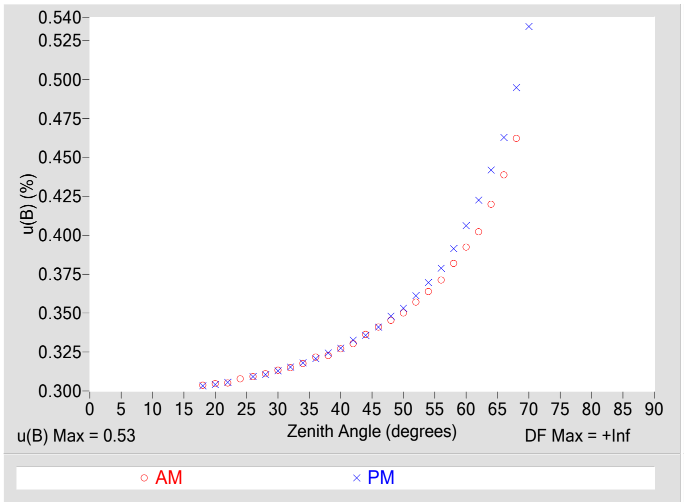


Figure 4. Residuals from Spline Interpolation

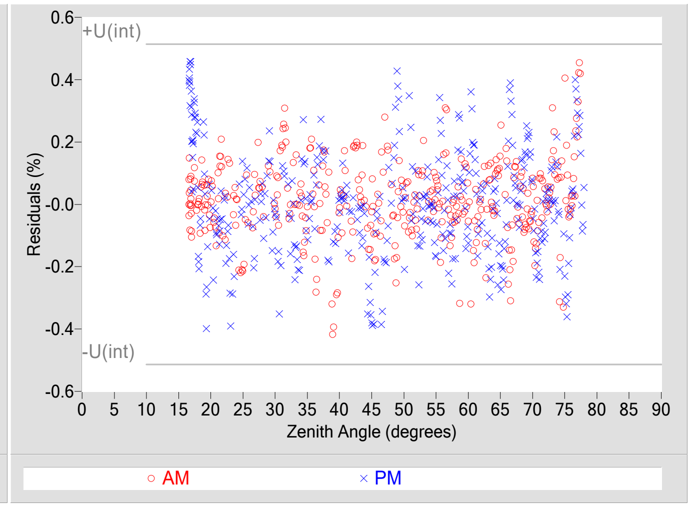


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.53
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	19463
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

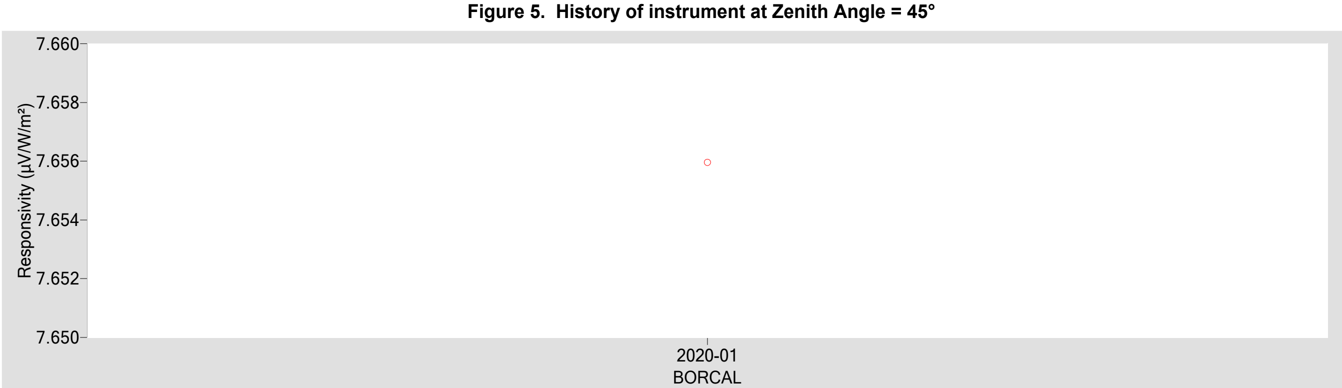
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6560	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.80
Offset Uncertainty, U(off) (%)	+1.5 / -1.8
Expanded Uncertainty, U (%)	+2.3 / -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:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	17934F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Nels Laulainen	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

17934F3 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

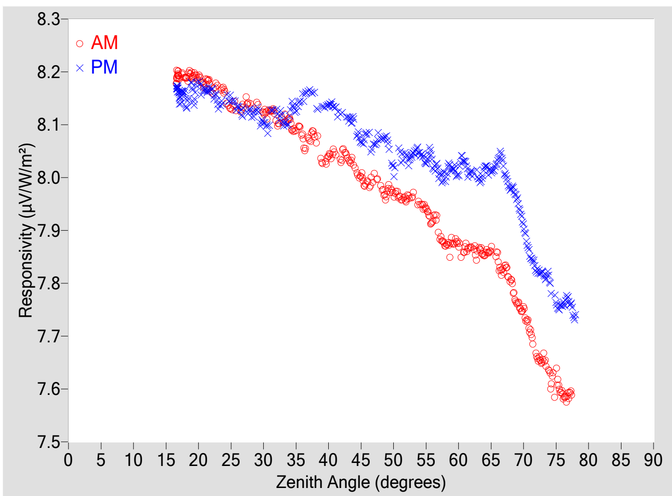


Figure 2. Responsivity vs Local Standard Time

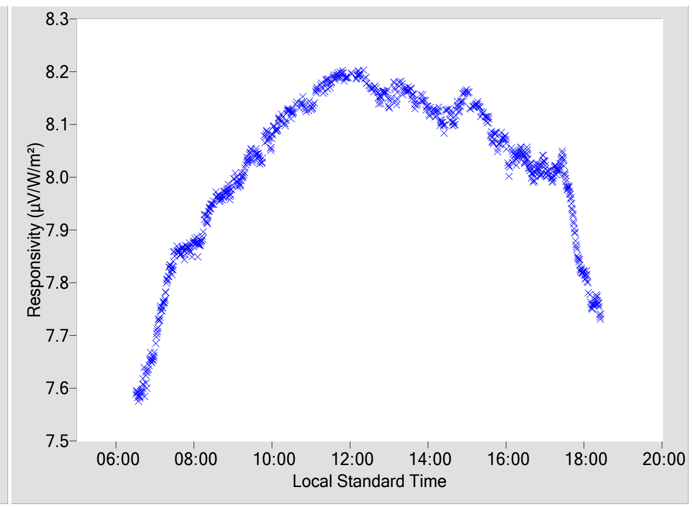


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9910	0.34	97.32	8.0840	0.34	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9806	0.34	95.41	8.0733	0.34	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9703	0.35	93.92	8.0164	0.35	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9601	0.35	92.38	8.0415	0.36	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9510	0.36	90.89	8.0469	0.36	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9187	0.37	89.33	8.0267	0.37	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8728	0.38	87.85	8.0044	0.39	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8748	0.39	86.46	8.0129	0.40	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8678	0.40	85.11	8.0090	0.42	275.05
18	8.1891	0.30	155.12	8.1458	0.30	204.90	64	7.8541	0.42	83.65	8.0159	0.43	276.44
20	8.1892	0.30	142.73	8.1782	0.30	216.66	66	7.8465	0.43	82.27	8.0317	0.45	277.84
22	8.1670	0.30	134.57	8.1663	0.30	225.42	68	7.8056	0.46	80.86	7.9799	0.49	279.26
24	8.1651	0.31	128.70	N/A	N/A	N/A	70	7.7474	N/A	79.51	7.9064	0.52	280.61
26	8.1265	0.31	124.08	8.1323	0.31	236.55	72	7.6600	N/A	78.07	7.8250	N/A	281.97
28	8.1356	0.31	119.22	8.1244	0.31	240.60	74	7.6251	N/A	76.74	7.8040	N/A	283.37
30	8.1236	0.31	115.74	8.1060	0.31	244.17	76	7.5895	N/A	75.33	7.7600	N/A	284.77
32	8.1026	0.31	112.54	8.1245	0.31	247.51	78	N/A	N/A	N/A	7.7354	N/A	286.10
34	8.1090	0.32	109.93	8.1150	0.32	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0729	0.32	107.32	8.1515	0.32	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0747	0.32	105.16	8.1461	0.32	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0413	0.33	102.89	8.1379	0.32	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0408	0.33	100.87	8.1216	0.33	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0209	0.33	99.04	8.1129	0.33	260.87	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

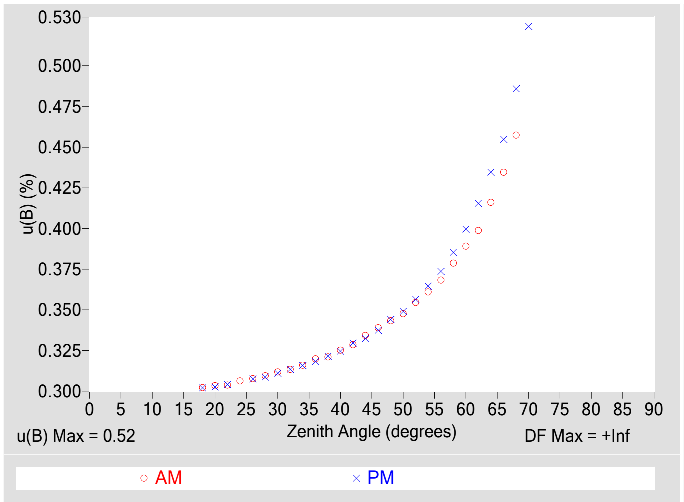


Figure 4. Residuals from Spline Interpolation

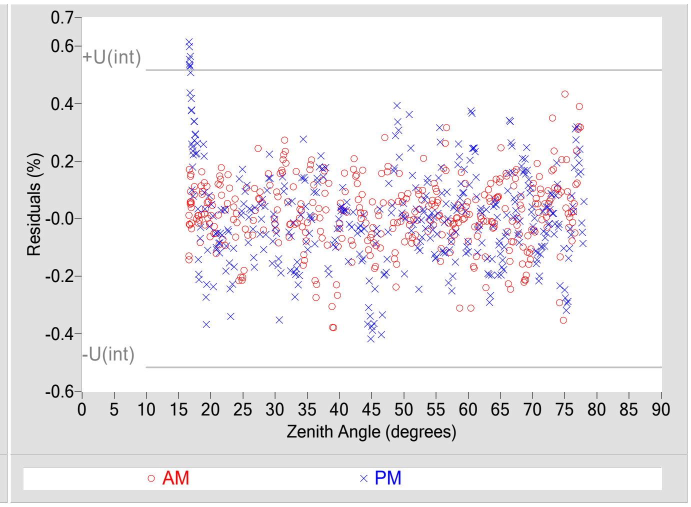


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.52
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	17951
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

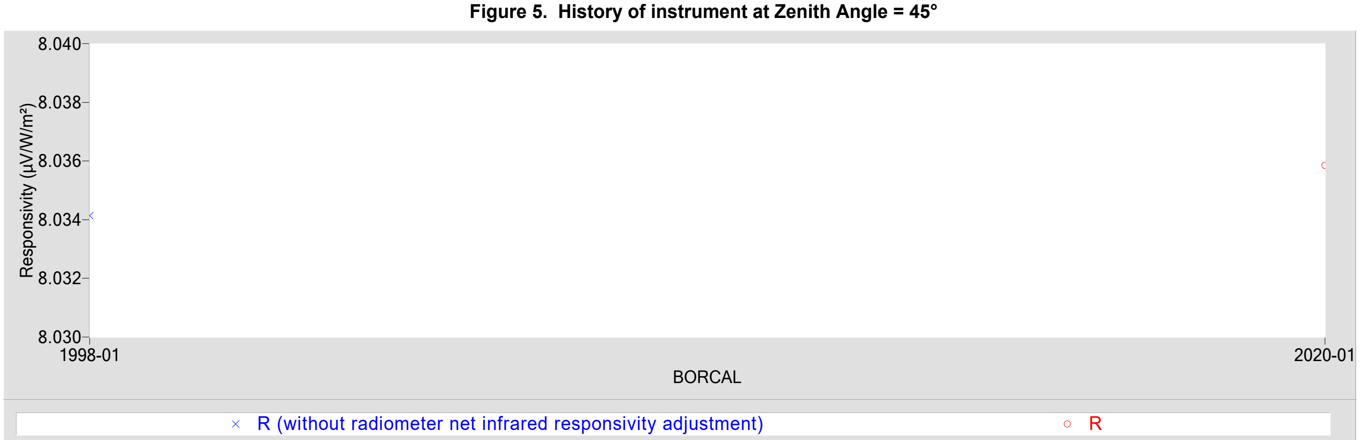
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0358	0.60000

† Rnet determination date: 05/18/2019

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.4 / -2.0
Expanded Uncertainty, U (%)	+2.2 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	18289F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Nels Laulainen	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

18289F3 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

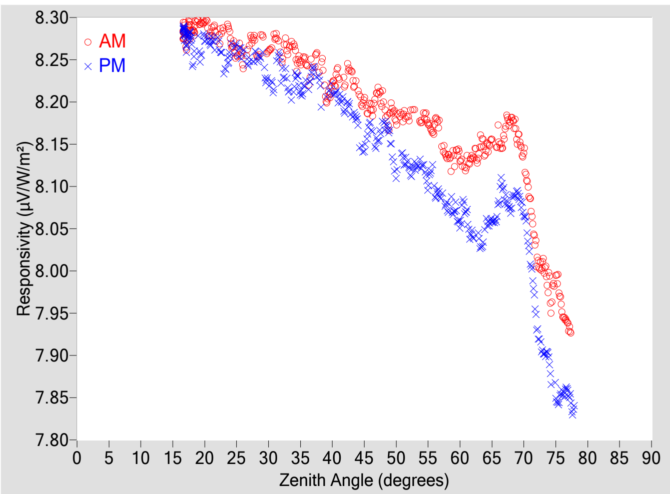


Figure 2. Responsivity vs Local Standard Time

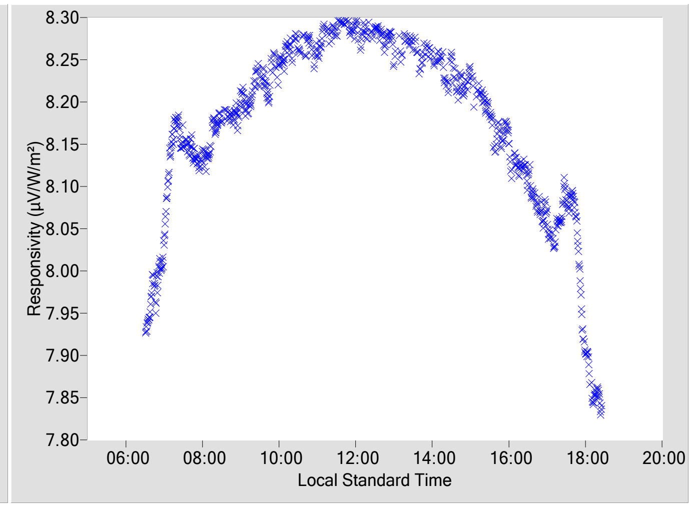


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1921	0.34	97.21	8.1707	0.34	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1996	0.34	95.57	8.1730	0.34	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1812	0.35	93.94	8.1159	0.35	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1836	0.36	92.28	8.1218	0.35	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1792	0.36	90.79	8.1258	0.36	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1722	0.37	89.31	8.0915	0.37	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1361	0.38	87.87	8.0761	0.38	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1356	0.39	86.45	8.0567	0.40	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1341	0.40	85.05	8.0422	0.41	275.03
18	8.2835	0.30	155.28	8.2630	0.30	204.78	64	8.1429	0.42	83.68	8.0549	0.43	276.52
20	8.2951	0.30	143.13	8.2756	0.30	216.96	66	8.1537	0.44	82.29	8.0810	0.45	277.87
22	8.2757	0.30	134.43	8.2702	0.30	226.01	68	8.1788	0.46	80.87	8.0757	0.48	279.24
24	8.2755	0.31	128.43	8.2575	0.30	231.38	70	8.1346	N/A	79.53	8.0687	0.52	280.59
26	8.2490	0.31	123.79	8.2564	0.31	236.45	72	8.0200	N/A	78.13	7.9368	N/A	281.99
28	8.2652	0.31	119.39	8.2560	0.31	240.78	74	7.9756	N/A	76.72	7.8869	N/A	283.39
30	8.2605	0.31	115.74	8.2236	0.31	244.17	76	7.9543	N/A	75.36	7.8553	N/A	284.80
32	8.2523	0.31	112.59	8.2385	0.31	247.37	78	N/A	N/A	N/A	7.8383	N/A	286.09
34	8.2651	0.31	109.93	8.2231	0.31	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2460	0.32	107.50	8.2203	0.32	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2349	0.32	105.12	8.2174	0.32	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2204	0.32	102.93	8.2131	0.32	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2223	0.33	101.02	8.1914	0.33	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2157	0.33	99.04	8.1702	0.33	261.05	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

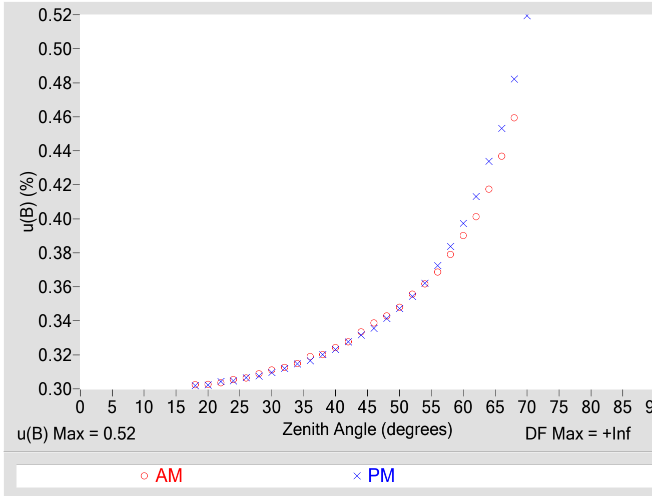


Figure 4. Residuals from Spline Interpolation

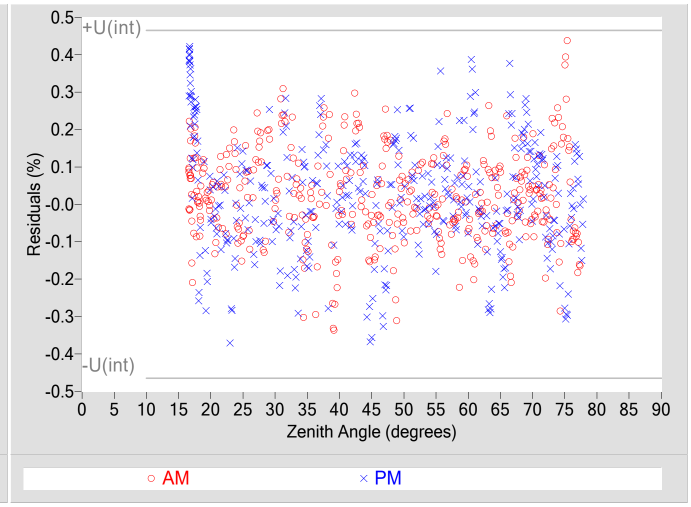


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.52
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	25672
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

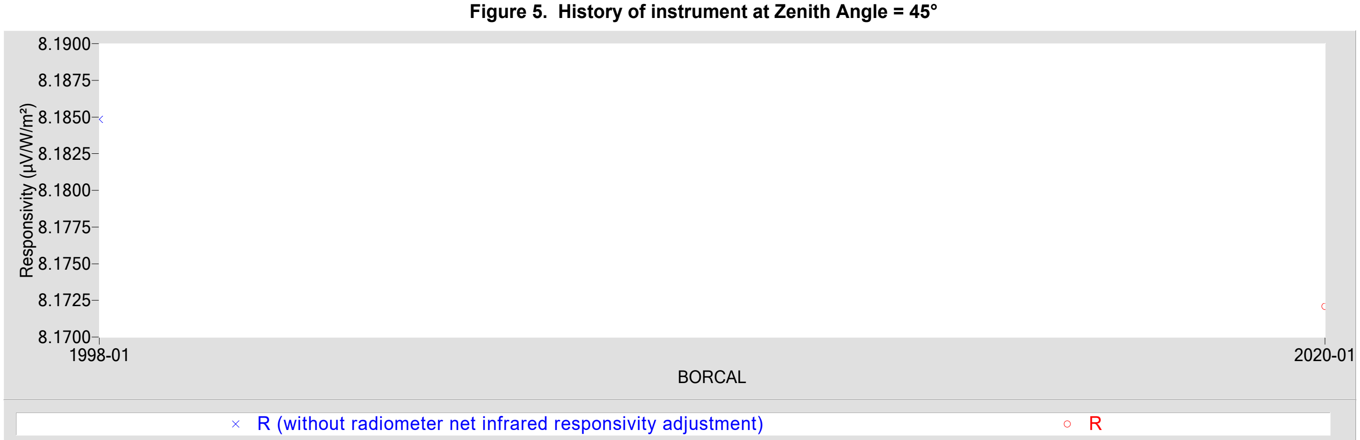
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.1721	0.60000

† Rnet determination date: 05/18/2019

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.1 / -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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	18350E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

18350E6 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

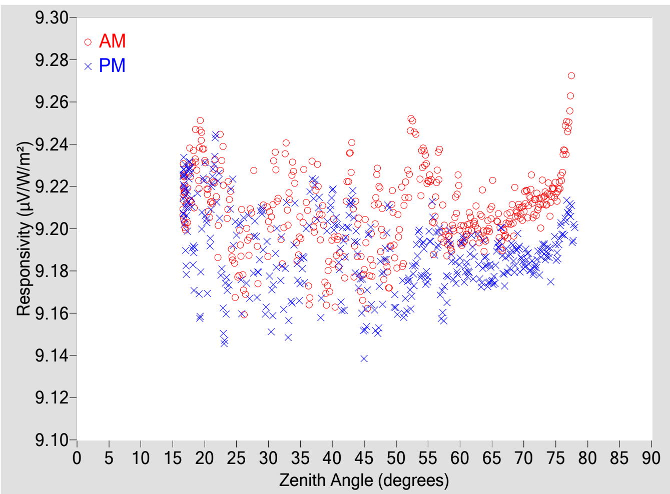


Figure 2. Responsivity vs Local Standard Time

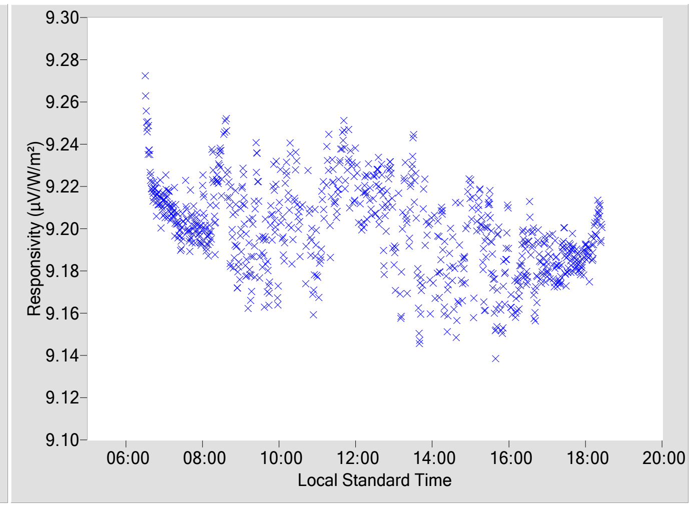


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.1845	0.29	97.21	9.1875	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1940	0.29	95.60	9.1797	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1914	0.29	93.87	9.1636	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2286	0.29	92.31	9.1720	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2286	0.29	90.82	9.1853	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2028	0.30	89.36	9.1970	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1933	0.30	87.88	9.1786	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2013	0.30	86.41	9.1889	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1996	0.30	84.99	9.1878	0.29	275.07
18	9.2230	0.28	155.81	9.2042	0.28	204.70	64	9.1953	0.30	83.64	9.1845	0.30	276.46
20	9.2311	0.28	142.42	9.2177	0.28	217.26	66	9.2021	0.30	82.25	9.1918	0.30	277.83
22	9.2010	0.28	134.63	9.2265	0.28	225.36	68	9.2062	0.30	80.93	9.1888	0.30	279.24
24	9.2062	0.29	128.41	9.2006	0.28	231.51	70	9.2104	N/A	79.50	9.1841	0.30	280.63
26	9.1793	0.29	123.50	9.1802	0.28	236.26	72	9.2116	N/A	78.13	9.1848	N/A	281.99
28	9.1917	0.29	118.97	9.1886	0.28	240.74	74	9.2145	N/A	76.76	9.1851	N/A	283.39
30	9.2021	0.29	115.89	9.1857	0.28	244.17	76	9.2295	N/A	75.31	9.1998	N/A	284.71
32	9.1891	0.29	112.62	9.1846	0.28	247.39	78	N/A	N/A	N/A	9.2013	N/A	286.14
34	9.2267	0.29	110.00	9.2022	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1980	0.29	107.27	9.2000	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.2072	0.29	105.09	9.1874	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1946	0.29	102.80	9.2124	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1930	0.29	100.91	9.1878	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1980	0.29	99.02	9.1862	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

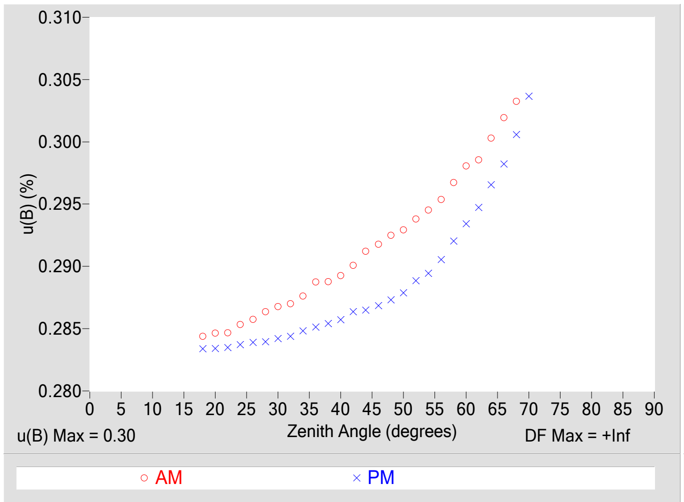


Figure 4. Residuals from Spline Interpolation

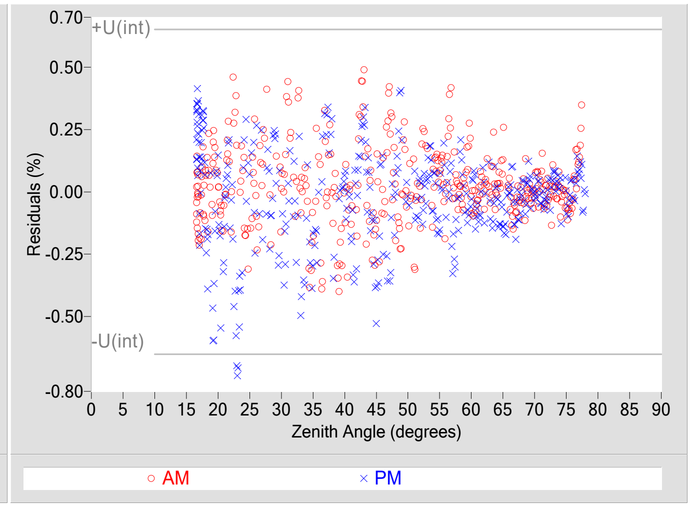


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.45
Effective degrees of freedom, DF(c)	2525
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.87
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

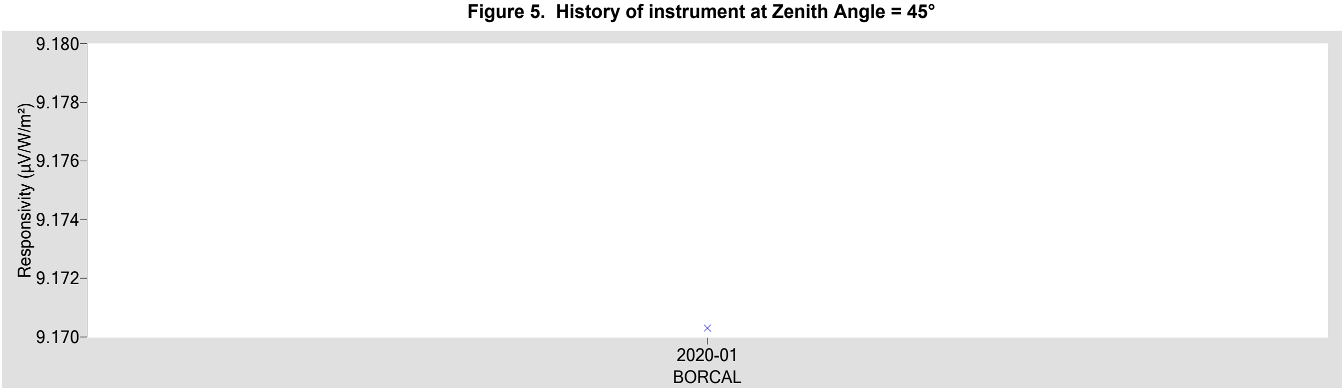
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.1703	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.64 / -0.073
Expanded Uncertainty, U (%)	+1.2 / -0.66
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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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:

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

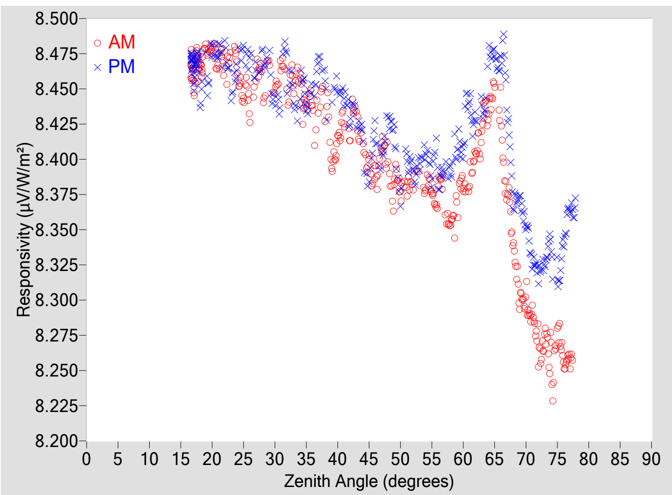


Figure 2. Responsivity vs Local Standard Time

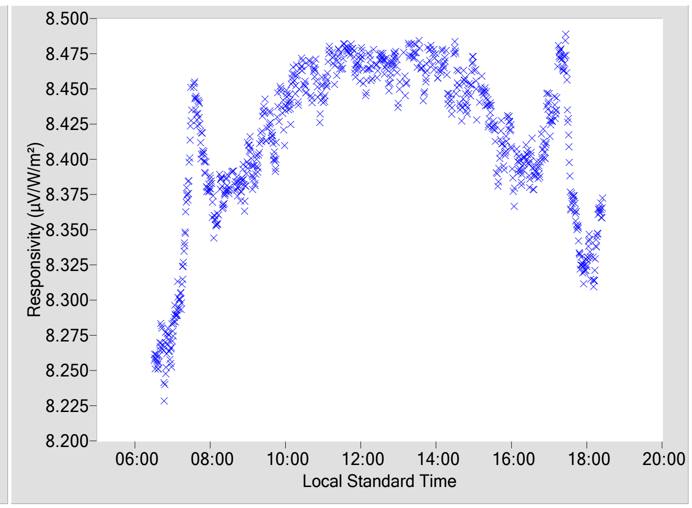


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3886	0.34	97.21	8.4174	0.33	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3984	0.34	95.57	8.4274	0.34	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3788	0.35	93.94	8.3745	0.34	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3841	0.35	92.28	8.3920	0.35	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3801	0.36	90.79	8.4047	0.36	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3775	0.37	89.31	8.3837	0.37	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3549	0.38	87.87	8.3930	0.38	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3829	0.39	86.45	8.4078	0.39	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4037	0.40	85.05	8.4288	0.41	275.03
18	8.4649	0.30	155.28	8.4574	0.30	204.78	64	8.4319	0.41	83.68	8.4733	0.43	276.52
20	8.4792	0.30	143.13	8.4776	0.30	216.96	66	8.4302	0.43	82.29	8.4724	0.45	277.87
22	8.4631	0.30	134.43	8.4774	0.30	226.01	68	8.3378	0.46	80.87	8.3703	0.48	279.24
24	8.4627	0.30	128.43	8.4668	0.30	231.38	70	8.2987	N/A	79.53	8.3542	0.51	280.59
26	8.4368	0.31	123.79	8.4703	0.31	236.45	72	8.2678	N/A	78.13	8.3199	N/A	281.99
28	8.4535	0.31	119.39	8.4740	0.31	240.78	74	8.2526	N/A	76.72	8.3339	N/A	283.39
30	8.4509	0.31	115.74	8.4425	0.31	244.17	76	8.2578	N/A	75.36	8.3424	N/A	284.80
32	8.4430	0.31	112.59	8.4626	0.31	247.37	78	N/A	N/A	N/A	8.3690	N/A	286.09
34	8.4567	0.31	109.93	8.4492	0.31	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4400	0.32	107.50	8.4494	0.32	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4268	0.32	105.12	8.4493	0.32	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4133	0.32	102.93	8.4507	0.32	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4162	0.33	101.02	8.4287	0.33	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4116	0.33	99.04	8.4122	0.33	261.05	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

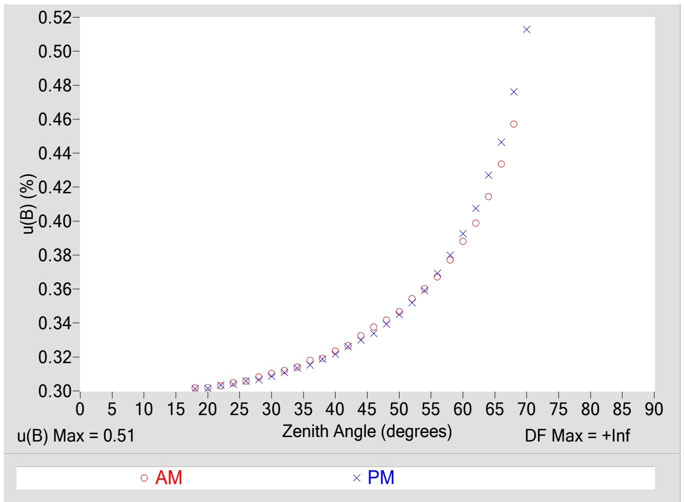


Figure 4. Residuals from Spline Interpolation

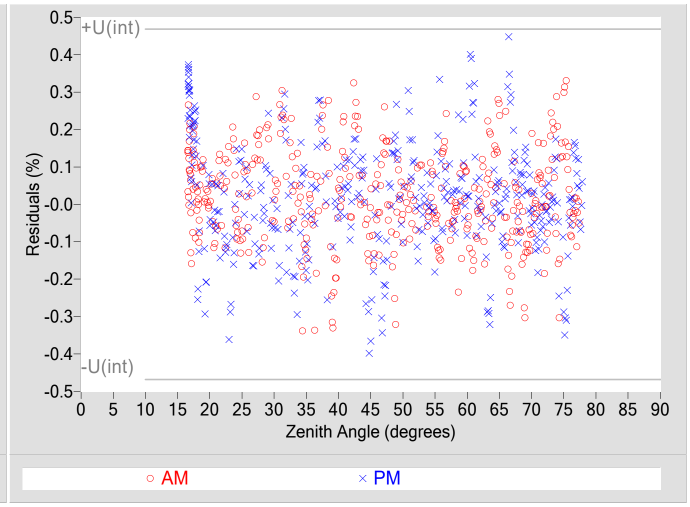


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.51
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.56
Effective degrees of freedom, DF(c)	24024
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

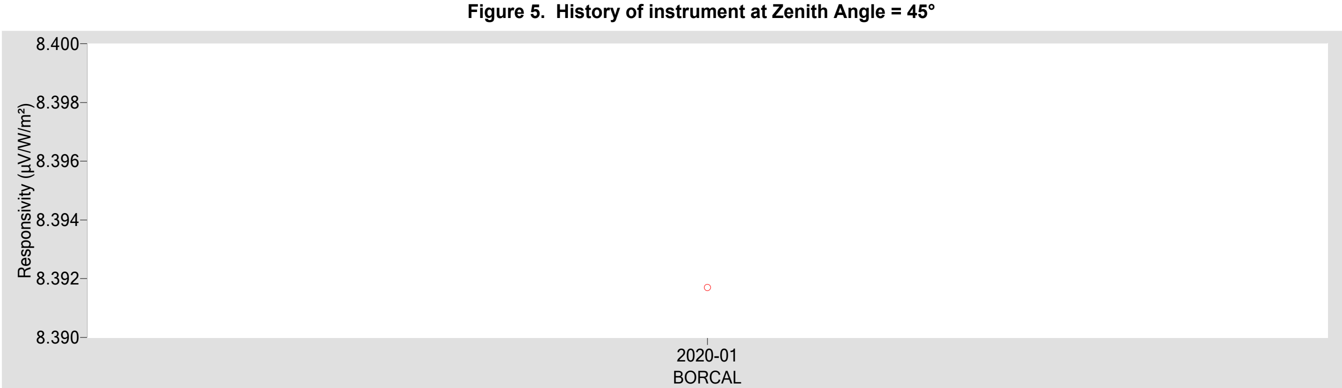
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3917	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.77
Offset Uncertainty, U(off) (%)	+0.85 / -0.44
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: 29554E6

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

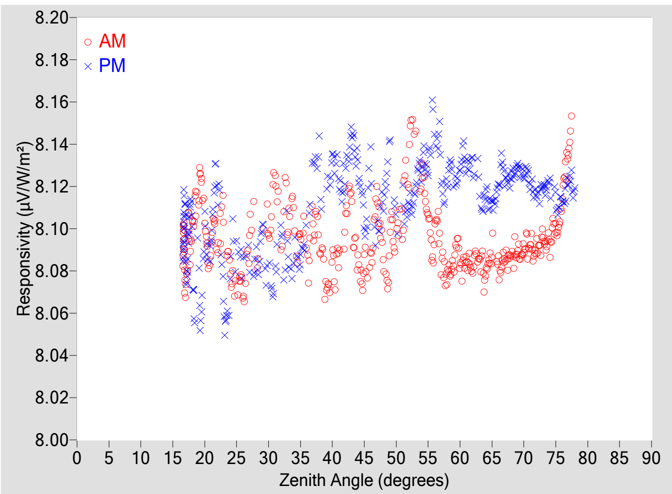


Figure 2. Responsivity vs Local Standard Time

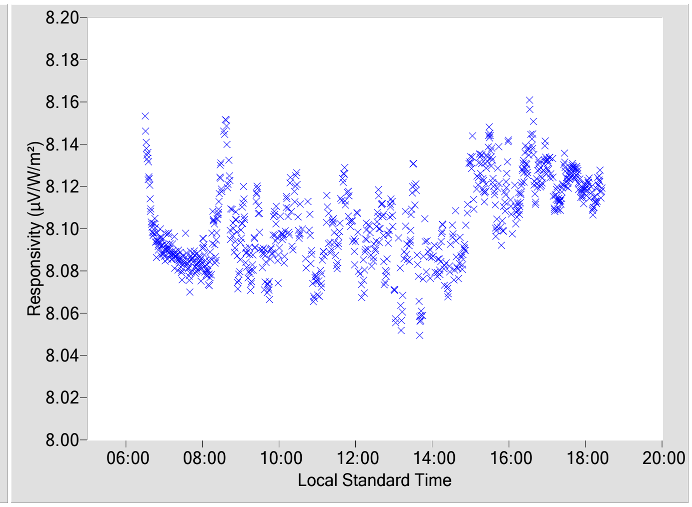


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0857	0.29	97.21	8.1296	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0861	0.29	95.60	8.1153	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0973	0.29	93.87	8.1050	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1323	0.29	92.31	8.1117	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1244	0.29	90.82	8.1284	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0938	0.30	89.36	8.1468	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0781	0.30	87.88	8.1230	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0829	0.30	86.41	8.1296	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0820	0.30	84.99	8.1293	0.29	275.07
18	8.0957	0.28	155.81	8.0947	0.28	204.70	64	8.0771	0.30	83.64	8.1171	0.30	276.46
20	8.1030	0.28	142.42	8.0944	0.28	217.26	66	8.0822	0.30	82.25	8.1199	0.30	277.83
22	8.0908	0.28	134.63	8.1209	0.28	225.36	68	8.0874	0.30	80.93	8.1245	0.30	279.24
24	8.0798	0.29	128.41	8.0740	0.28	231.51	70	8.0900	N/A	79.50	8.1262	0.30	280.63
26	8.0694	0.29	123.50	8.0843	0.28	236.26	72	8.0903	N/A	78.13	8.1167	N/A	281.99
28	8.0813	0.29	118.97	8.0844	0.28	240.74	74	8.0934	N/A	76.76	8.1205	N/A	283.39
30	8.1004	0.29	115.89	8.0832	0.28	244.17	76	8.1152	N/A	75.31	8.1139	N/A	284.71
32	8.0908	0.29	112.62	8.0985	0.28	247.39	78	N/A	N/A	N/A	8.1186	N/A	286.14
34	8.1080	0.29	110.00	8.0898	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0843	0.29	107.27	8.1017	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0912	0.29	105.09	8.1253	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0840	0.29	102.80	8.1320	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1017	0.29	100.91	8.1266	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0836	0.29	99.02	8.1292	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

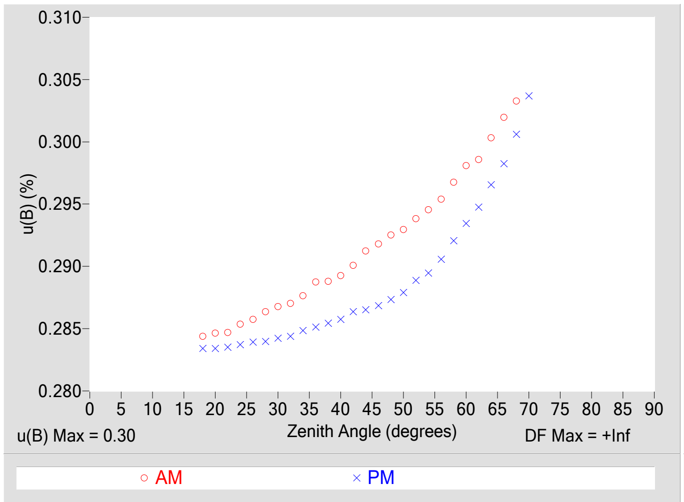


Figure 4. Residuals from Spline Interpolation

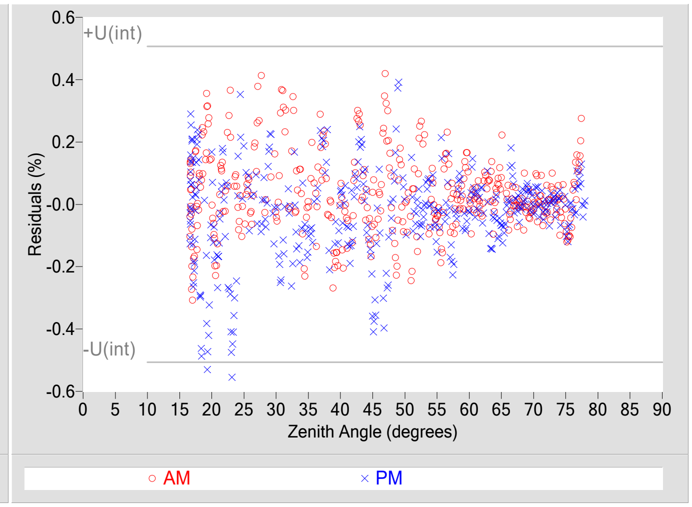


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	4298
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

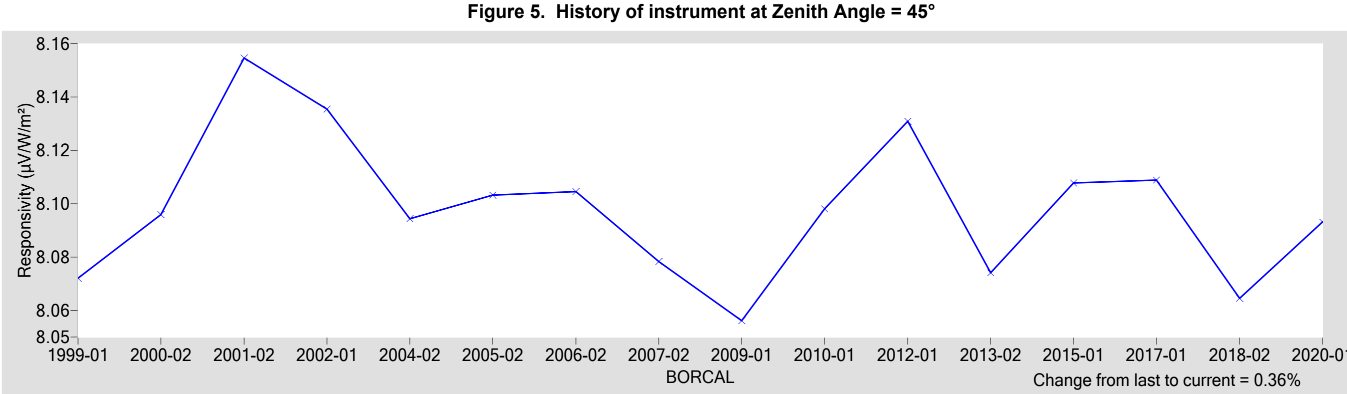
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0931	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.66 / -0.19
Expanded Uncertainty, U (%)	+1.2 / -0.77
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	29608F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

29608F3 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

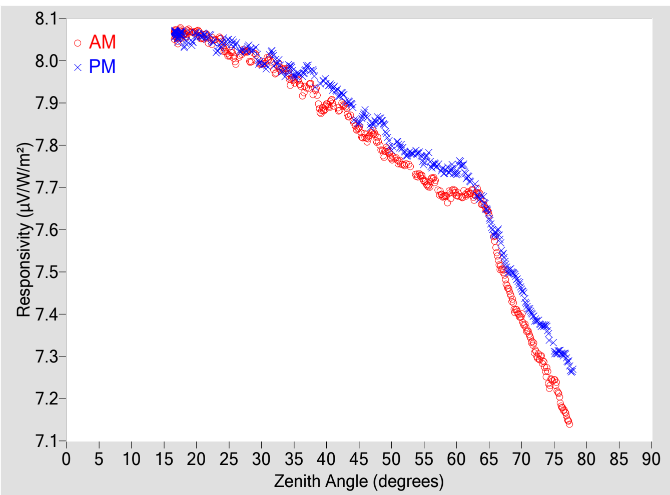


Figure 2. Responsivity vs Local Standard Time

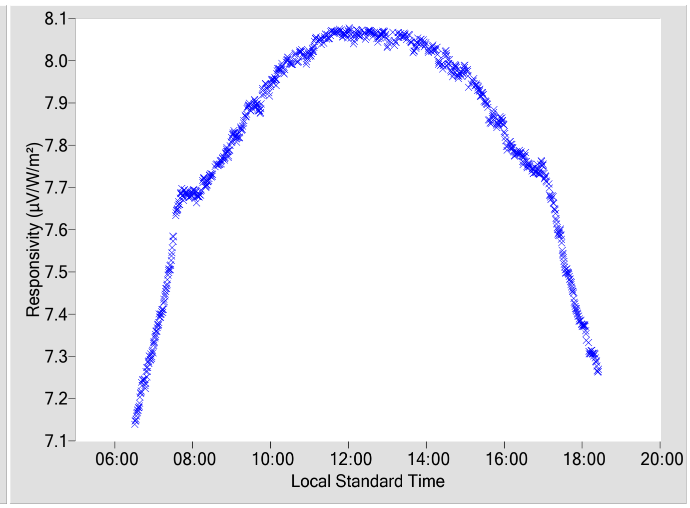


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.8193	0.32	97.21	7.8735	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8082	0.32	95.57	7.8614	0.31	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7722	0.33	93.94	7.7942	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7538	0.33	92.28	7.7848	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7288	0.34	90.79	7.7827	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7128	0.35	89.31	7.7524	0.34	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6800	0.35	87.87	7.7393	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6859	0.36	86.45	7.7336	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6859	0.37	85.05	7.7203	0.36	275.03
18	8.0619	0.29	155.28	8.0501	0.29	204.78	64	7.6645	0.38	83.68	7.6741	0.38	276.52
20	8.0688	0.29	143.13	8.0620	0.29	216.96	66	7.5688	0.40	82.29	7.5911	0.39	277.87
22	8.0456	0.29	134.43	8.0567	0.29	226.01	68	7.4583	0.42	80.87	7.5013	0.42	279.24
24	8.0379	0.29	128.43	8.0435	0.29	231.38	70	7.3919	N/A	79.53	7.4612	0.44	280.59
26	8.0016	0.30	123.79	8.0372	0.29	236.45	72	7.3188	N/A	78.13	7.3893	N/A	281.99
28	8.0095	0.30	119.39	8.0326	0.29	240.78	74	7.2498	N/A	76.72	7.3595	N/A	283.39
30	7.9934	0.30	115.74	7.9937	0.29	244.17	76	7.1934	N/A	75.36	7.3092	N/A	284.80
32	7.9731	0.30	112.59	8.0026	0.30	247.37	78	N/A	N/A	N/A	7.2673	N/A	286.09
34	7.9763	0.30	109.93	7.9799	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9459	0.31	107.50	7.9660	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9201	0.31	105.12	7.9637	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8935	0.31	102.93	7.9480	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8840	0.31	101.02	7.9182	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8607	0.32	99.04	7.8861	0.31	261.05	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

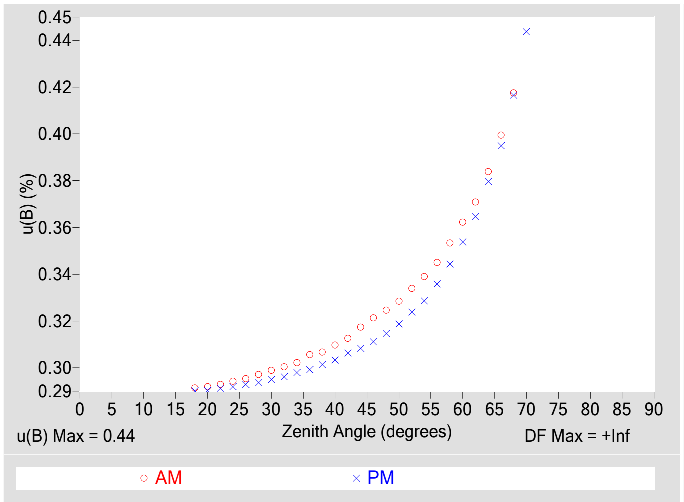


Figure 4. Residuals from Spline Interpolation

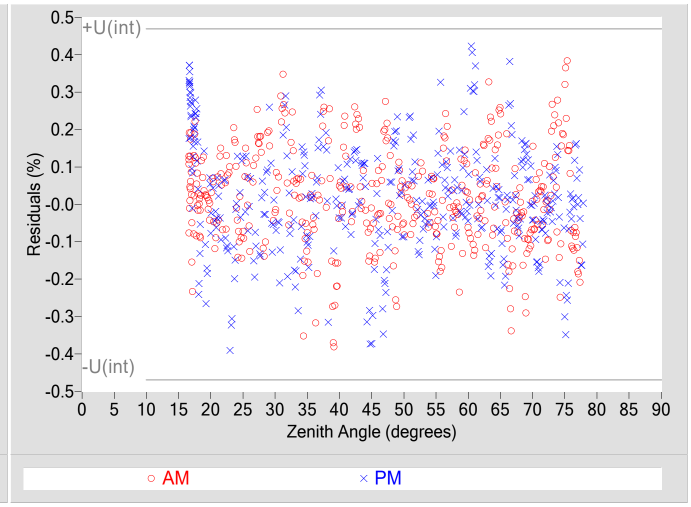


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	15016
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

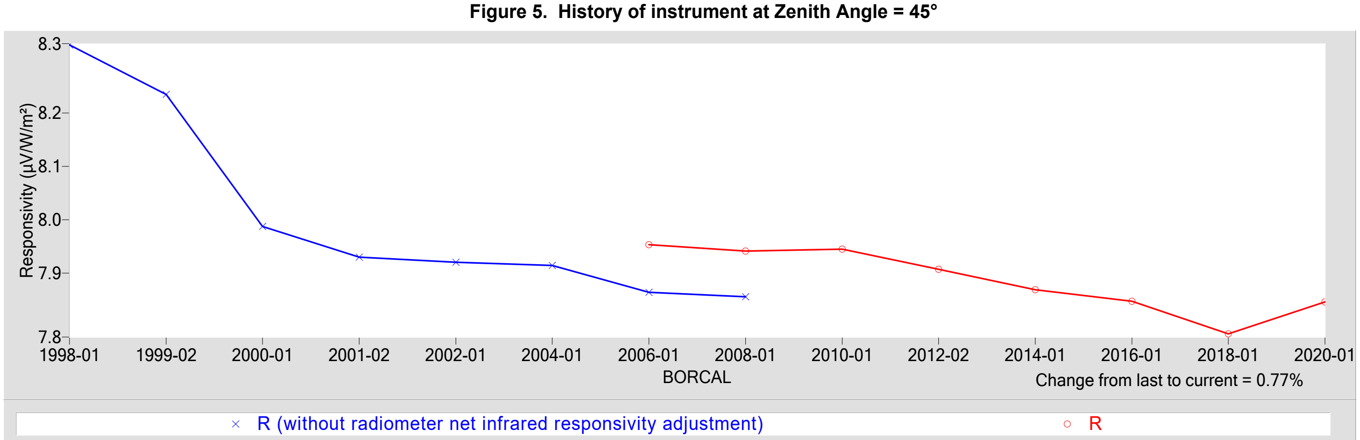
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8460	0.57100

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+2.0 / -2.1
Expanded Uncertainty, U (%)	+2.7 / -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:**	29612F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

29612F3 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

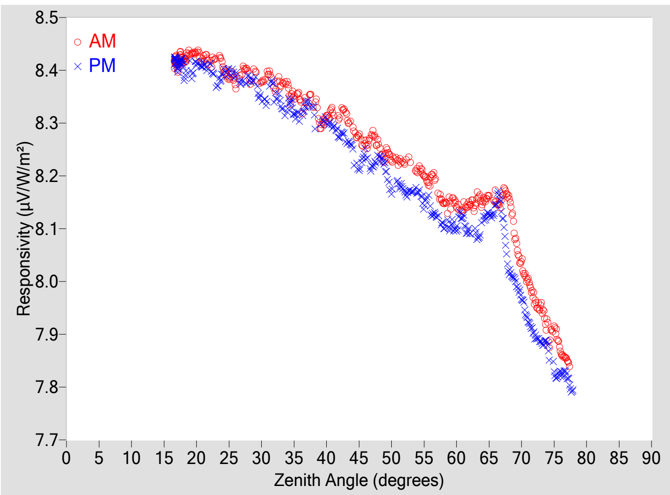


Figure 2. Responsivity vs Local Standard Time

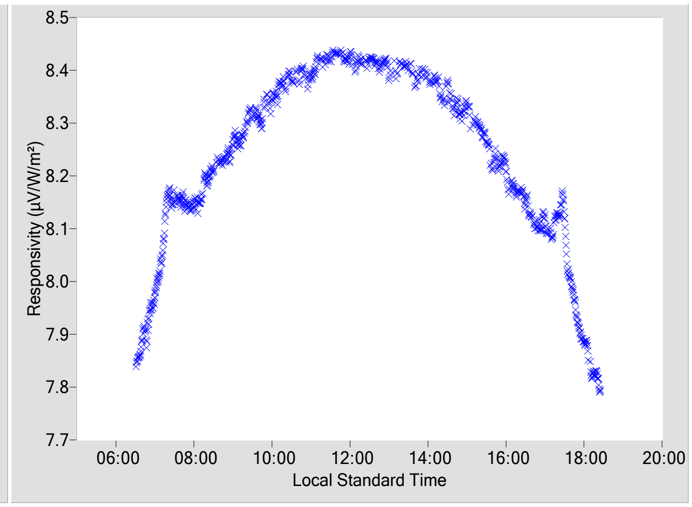


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2609	0.32	97.21	8.2400	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2600	0.32	95.57	8.2344	0.31	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2326	0.33	93.94	8.1716	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2259	0.33	92.28	8.1702	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2116	0.34	90.79	8.1713	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1940	0.34	89.31	8.1311	0.33	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1498	0.35	87.87	8.1060	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1460	0.36	86.45	8.0993	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1452	0.37	85.05	8.0945	0.36	275.03
18	8.4196	0.29	155.28	8.4022	0.29	204.78	64	8.1496	0.38	83.68	8.1170	0.38	276.52
20	8.4344	0.29	143.13	8.4138	0.29	216.96	66	8.1550	0.40	82.29	8.1464	0.39	277.87
22	8.4147	0.29	134.43	8.4076	0.29	226.01	68	8.1587	0.41	80.87	8.0222	0.41	279.24
24	8.4079	0.29	128.43	8.3924	0.29	231.38	70	8.0339	N/A	79.53	7.9705	0.44	280.59
26	8.3763	0.29	123.79	8.3897	0.29	236.45	72	7.9662	N/A	78.13	7.8975	N/A	281.99
28	8.3892	0.30	119.39	8.3866	0.29	240.78	74	7.9040	N/A	76.72	7.8743	N/A	283.39
30	8.3782	0.30	115.74	8.3471	0.29	244.17	76	7.8706	N/A	75.36	7.8263	N/A	284.80
32	8.3636	0.30	112.59	8.3586	0.30	247.37	78	N/A	N/A	N/A	7.7934	N/A	286.09
34	8.3726	0.30	109.93	8.3331	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3466	0.31	107.50	8.3091	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3300	0.31	105.12	8.3168	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3114	0.31	102.93	8.3030	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3099	0.31	101.02	8.2753	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2935	0.32	99.04	8.2468	0.31	261.05	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

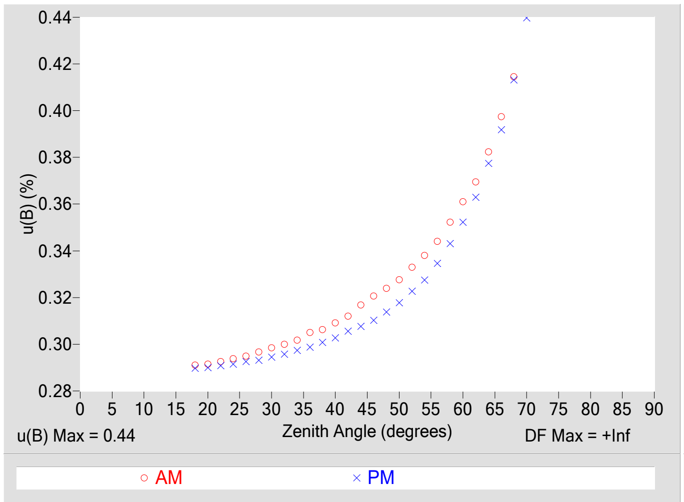


Figure 4. Residuals from Spline Interpolation

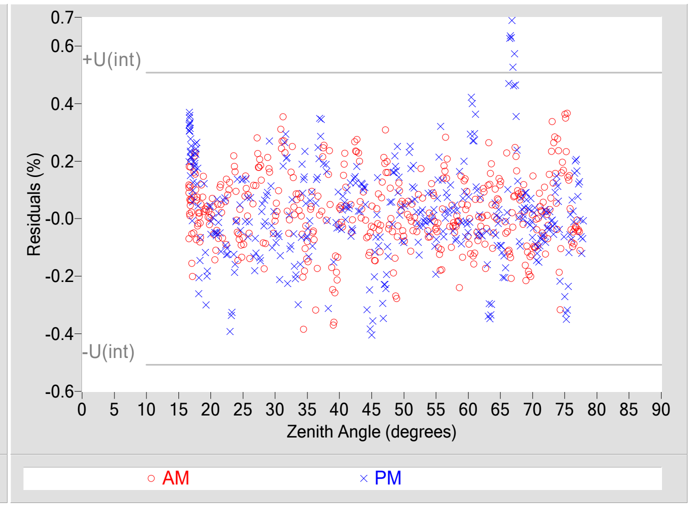


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	11427
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

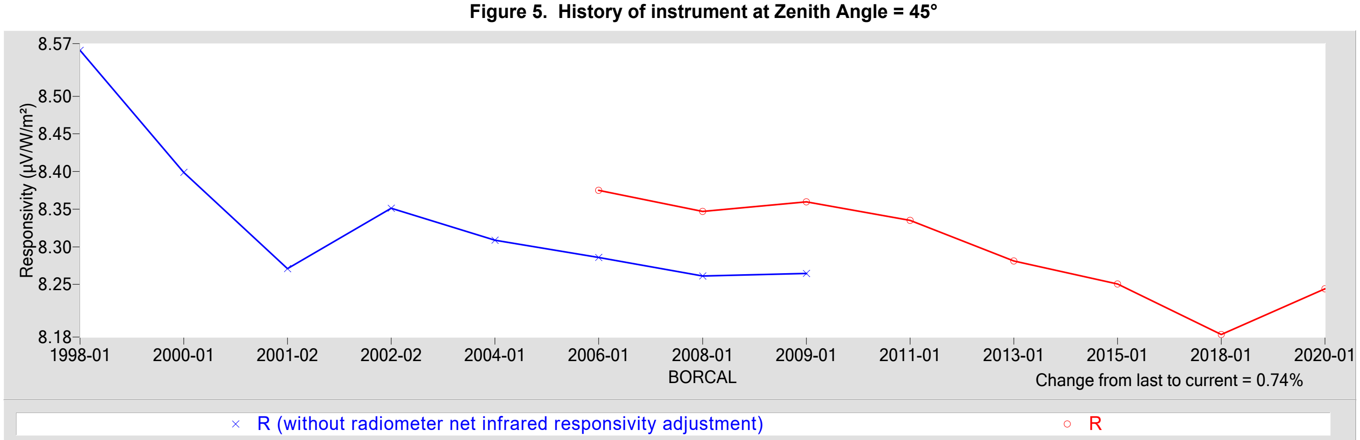
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.2441	0.57100

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.6 / -1.8
Expanded Uncertainty, U (%)	+2.3 / -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:**	29618F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

29618F3 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 - σ * Tc^4*
where, *Win* = incoming infrared (W/m²), *σ* = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

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

Figure 1. Responsivity vs Zenith Angle

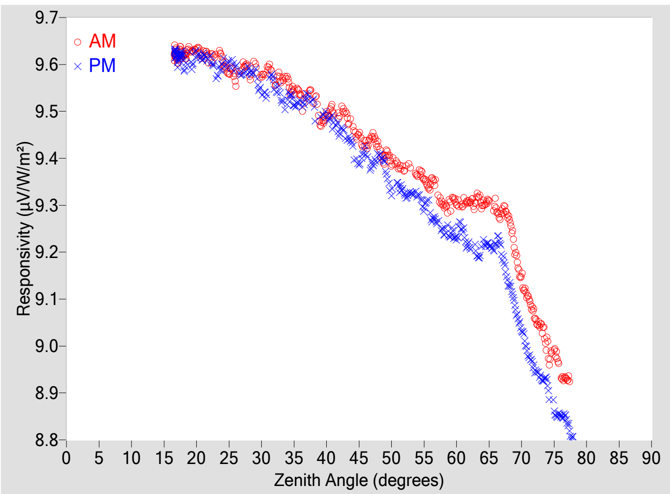


Figure 2. Responsivity vs Local Standard Time

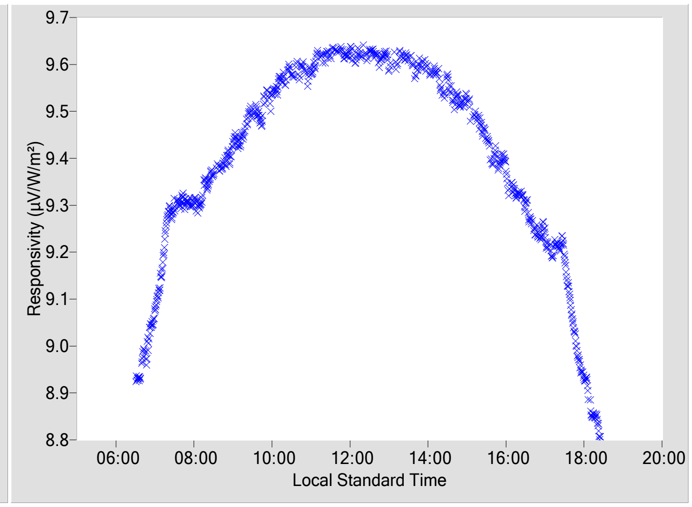


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.4301	0.32	97.21	9.4136	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4261	0.32	95.57	9.4043	0.31	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3943	0.33	93.94	9.3292	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3773	0.33	92.28	9.3239	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3664	0.34	90.79	9.3225	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3461	0.34	89.31	9.2724	0.34	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3013	0.35	87.87	9.2450	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3067	0.36	86.45	9.2307	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3066	0.37	85.05	9.2136	0.36	275.03
18	9.6186	0.29	155.28	9.6063	0.29	204.78	64	9.3016	0.38	83.68	9.2189	0.38	276.52
20	9.6332	0.29	143.13	9.6219	0.29	216.96	66	9.2960	0.40	82.29	9.2179	0.39	277.87
22	9.6131	0.29	134.43	9.6133	0.29	226.01	68	9.2725	0.42	80.87	9.1328	0.41	279.24
24	9.6069	0.29	128.43	9.6008	0.29	231.38	70	9.1441	N/A	79.53	9.0363	0.44	280.59
26	9.5682	0.30	123.79	9.5928	0.29	236.45	72	9.0656	N/A	78.13	8.9500	N/A	281.99
28	9.5851	0.30	119.39	9.5902	0.29	240.78	74	8.9904	N/A	76.72	8.9136	N/A	283.39
30	9.5763	0.30	115.74	9.5425	0.29	244.17	76	8.9413	N/A	75.33	8.8521	N/A	284.80
32	9.5598	0.30	112.59	9.5563	0.30	247.37	78	N/A	N/A	N/A	8.8066	N/A	286.09
34	9.5689	0.30	109.93	9.5281	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.5380	0.31	107.50	9.5165	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.5175	0.31	105.12	9.5094	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.4920	0.31	102.93	9.4891	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.4904	0.31	101.02	9.4554	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.4700	0.32	99.04	9.4231	0.31	261.05	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

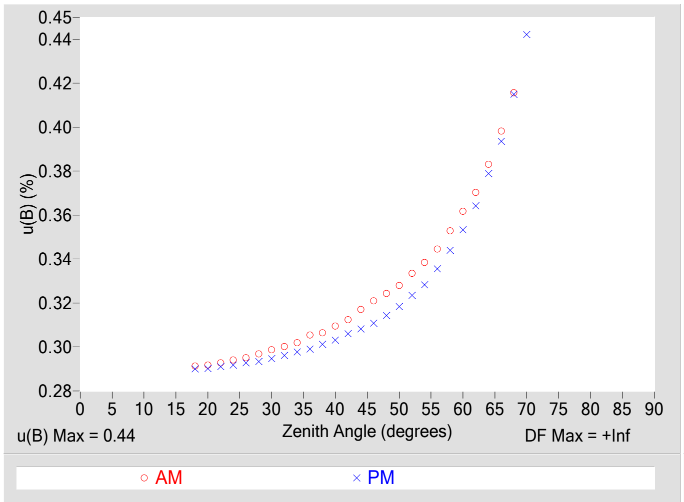


Figure 4. Residuals from Spline Interpolation

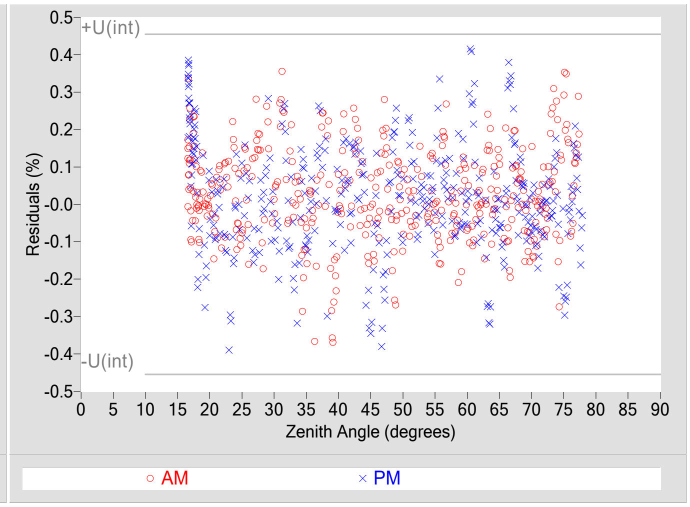


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	16322
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

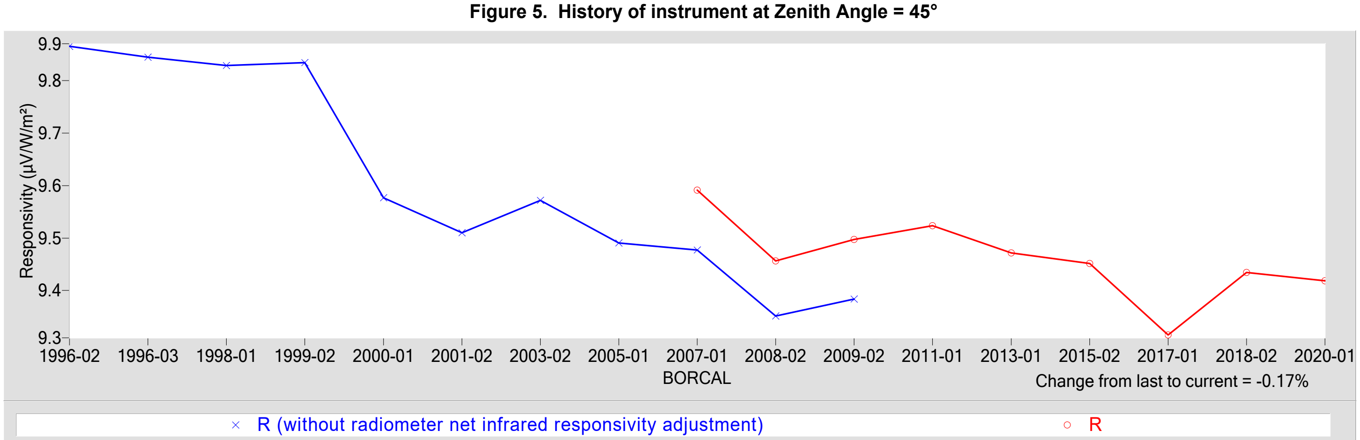
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.4184	0.67500

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -2.0
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

[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: 29738E6

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

29738E6 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

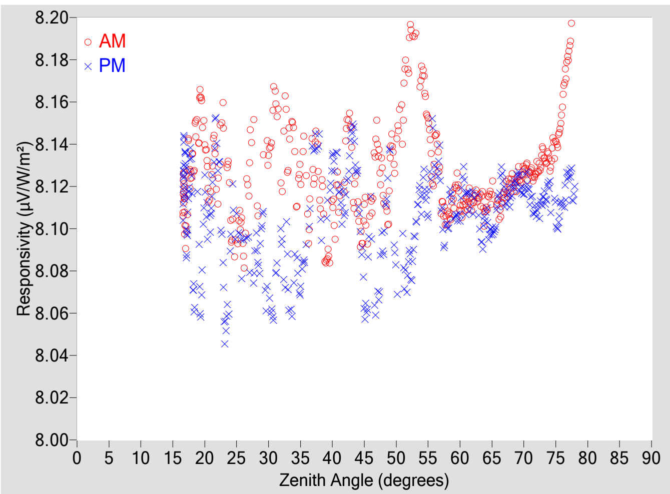


Figure 2. Responsivity vs Local Standard Time

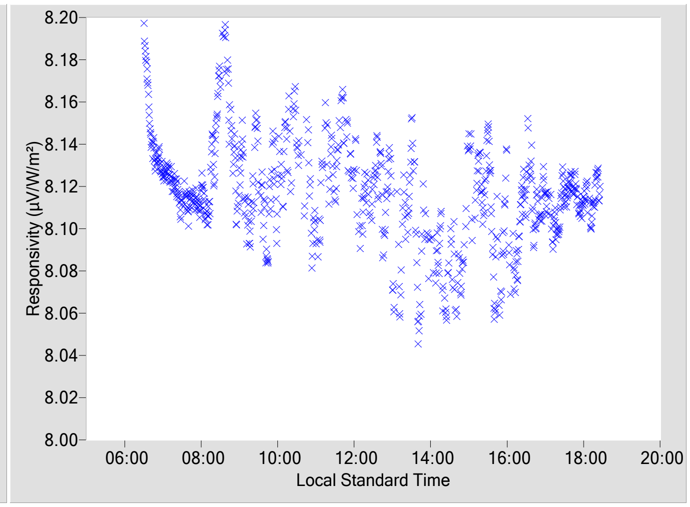


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1103	0.29	97.21	8.1023	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1189	0.29	95.60	8.0973	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1392	0.29	93.87	8.0801	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1840	0.29	92.31	8.0832	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1723	0.29	90.82	8.1155	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1321	0.30	89.36	8.1345	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1057	0.30	87.88	8.1013	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1103	0.30	86.41	8.1112	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1123	0.30	84.99	8.1138	0.29	275.07
18	8.1274	0.28	155.81	8.1080	0.28	204.70	64	8.1073	0.30	83.64	8.1068	0.30	276.46
20	8.1414	0.28	142.42	8.1120	0.28	217.26	66	8.1104	0.30	82.25	8.1132	0.30	277.83
22	8.1181	0.28	134.63	8.1381	0.28	225.36	68	8.1226	0.30	80.93	8.1164	0.30	279.24
24	8.1092	0.29	128.41	8.0822	0.28	231.51	70	8.1275	N/A	79.50	8.1195	0.30	280.63
26	8.0916	0.29	123.50	8.0886	0.28	236.26	72	8.1270	N/A	78.13	8.1083	N/A	281.99
28	8.1107	0.29	118.97	8.0881	0.28	240.74	74	8.1323	N/A	76.76	8.1178	N/A	283.39
30	8.1361	0.29	115.89	8.0700	0.28	244.17	76	8.1586	N/A	75.31	8.1120	N/A	284.71
32	8.1196	0.29	112.62	8.0959	0.28	247.39	78	N/A	N/A	N/A	8.1183	N/A	286.14
34	8.1449	0.29	110.00	8.0812	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1084	0.29	107.27	8.0925	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1167	0.29	105.09	8.1207	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1097	0.29	102.80	8.1302	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1321	0.29	100.91	8.1141	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1078	0.29	99.02	8.1197	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

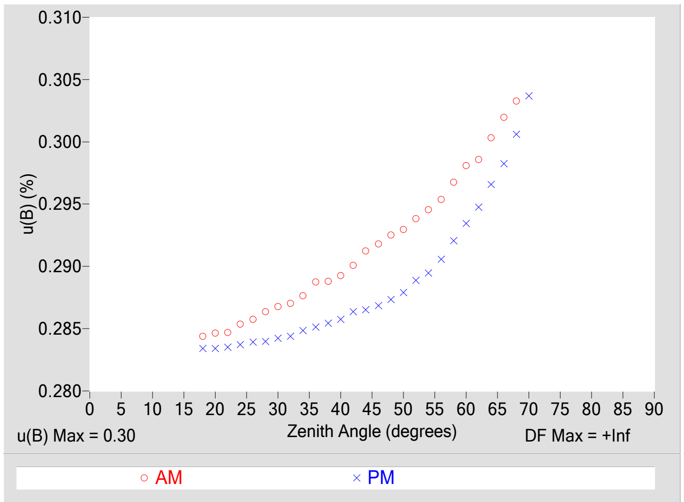


Figure 4. Residuals from Spline Interpolation

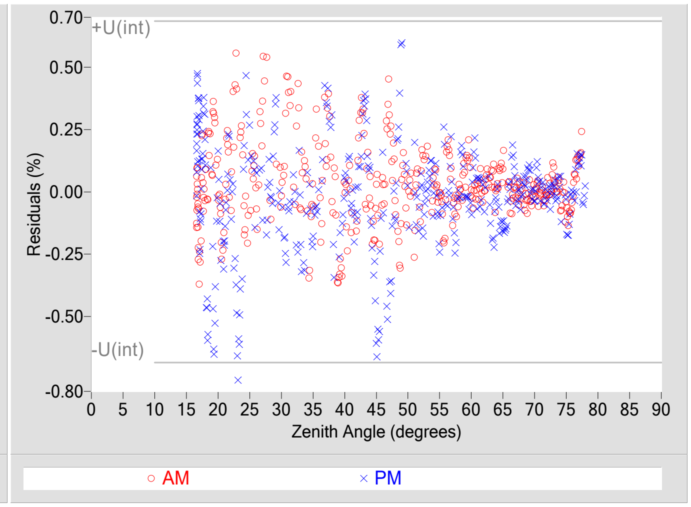


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.46
Effective degrees of freedom, DF(c)	2310
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.90
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

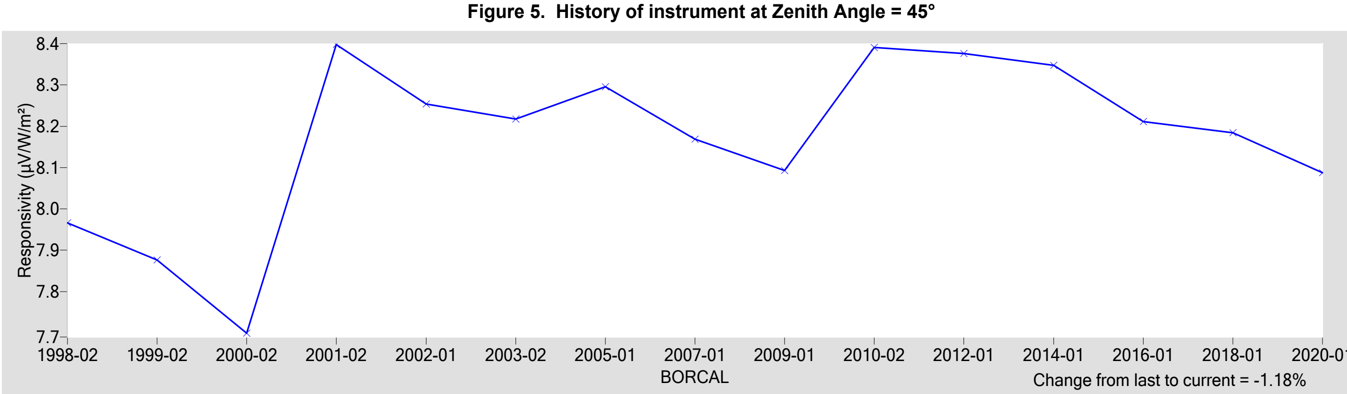
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0877	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+1.2 / -0.22
Expanded Uncertainty, U (%)	+1.8 / -0.80
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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:

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

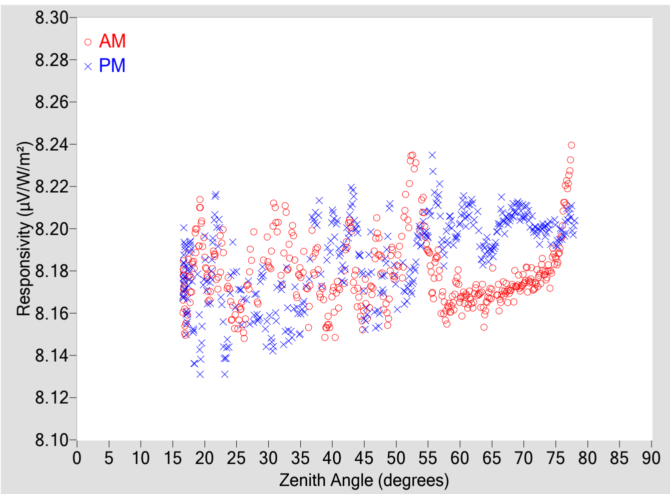


Figure 2. Responsivity vs Local Standard Time

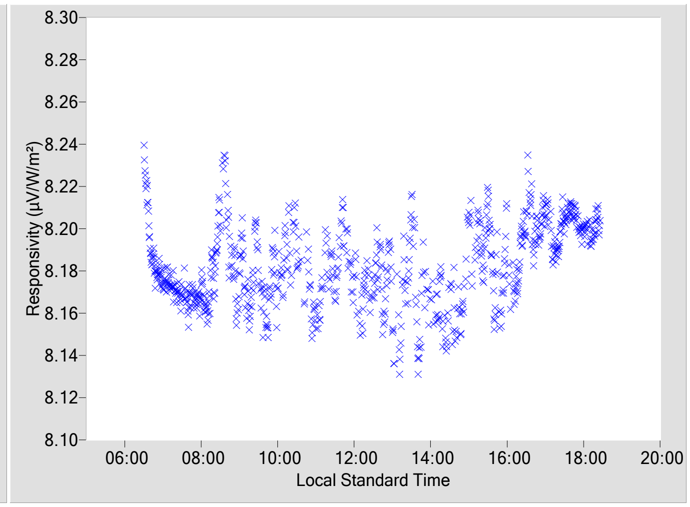


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1691	0.29	97.21	8.1885	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1696	0.29	95.60	8.1763	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1825	0.29	93.87	8.1712	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2145	0.29	92.31	8.1749	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2074	0.29	90.82	8.1961	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1766	0.30	89.36	8.2188	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1604	0.30	87.88	8.1968	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1664	0.30	86.41	8.2053	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1653	0.30	84.99	8.2080	0.29	275.07
18	8.1763	0.28	155.81	8.1736	0.28	204.70	64	8.1609	0.30	83.64	8.1922	0.30	276.46
20	8.1862	0.28	142.42	8.1803	0.28	217.26	66	8.1677	0.30	82.25	8.2006	0.30	277.83
22	8.1747	0.28	134.63	8.2032	0.28	225.36	68	8.1711	0.30	80.93	8.2074	0.30	279.24
24	8.1655	0.29	128.41	8.1637	0.28	231.51	70	8.1751	N/A	79.50	8.2077	0.30	280.63
26	8.1547	0.29	123.50	8.1641	0.28	236.26	72	8.1750	N/A	78.13	8.1990	N/A	281.99
28	8.1653	0.29	118.97	8.1626	0.28	240.74	74	8.1789	N/A	76.76	8.1994	N/A	283.39
30	8.1861	0.29	115.89	8.1575	0.28	244.17	76	8.2028	N/A	75.31	8.1979	N/A	284.71
32	8.1756	0.29	112.62	8.1730	0.28	247.39	78	N/A	N/A	N/A	8.2027	N/A	286.14
34	8.1945	0.29	110.00	8.1673	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1655	0.29	107.27	8.1728	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1724	0.29	105.09	8.1928	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1678	0.29	102.80	8.2036	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1845	0.29	100.91	8.1878	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1675	0.29	99.02	8.1950	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

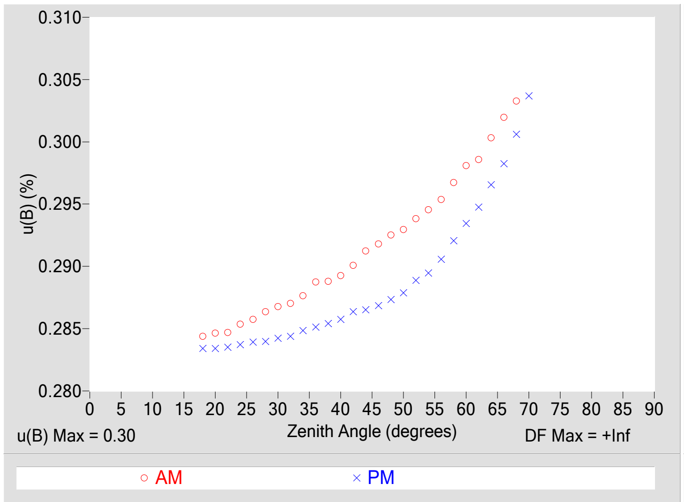


Figure 4. Residuals from Spline Interpolation

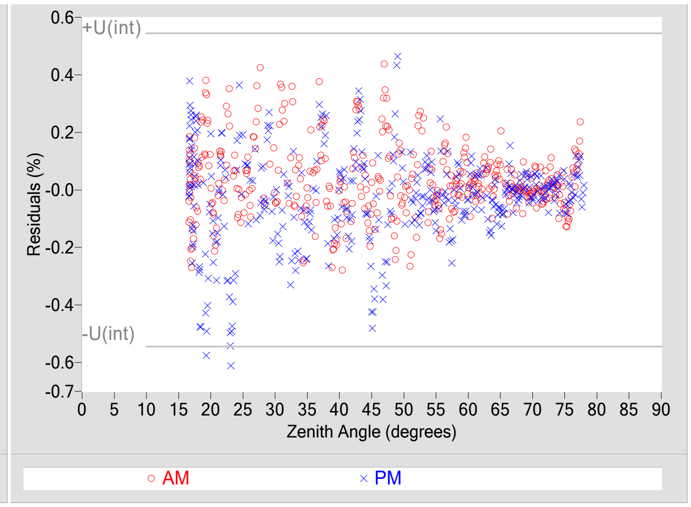


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	3637
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.80
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

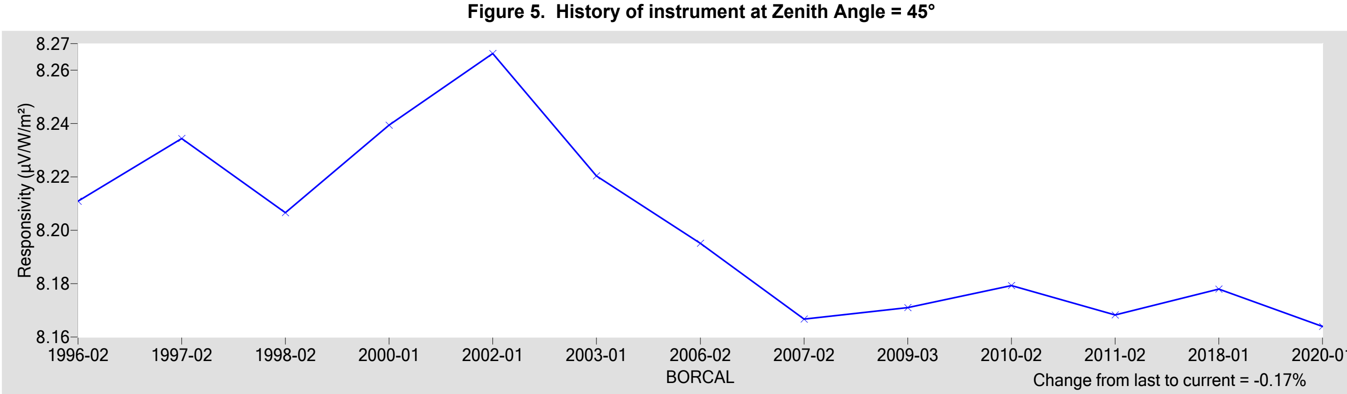
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.1640	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.67 / -0.079
Expanded Uncertainty, U (%)	+1.3 / -0.66
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:**	29848E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

29848E6 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 - 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

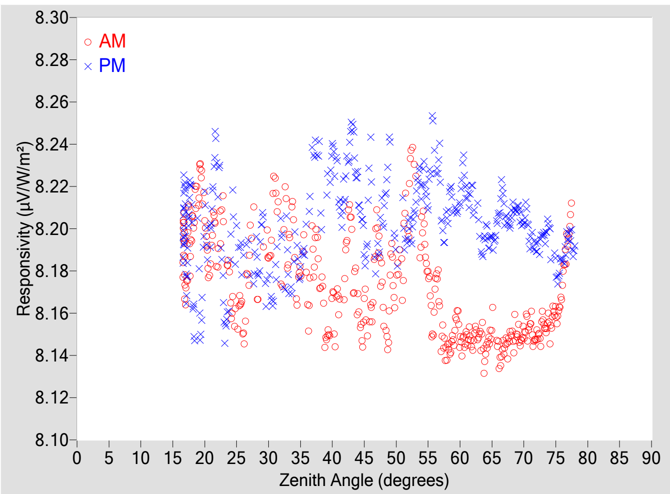


Figure 2. Responsivity vs Local Standard Time

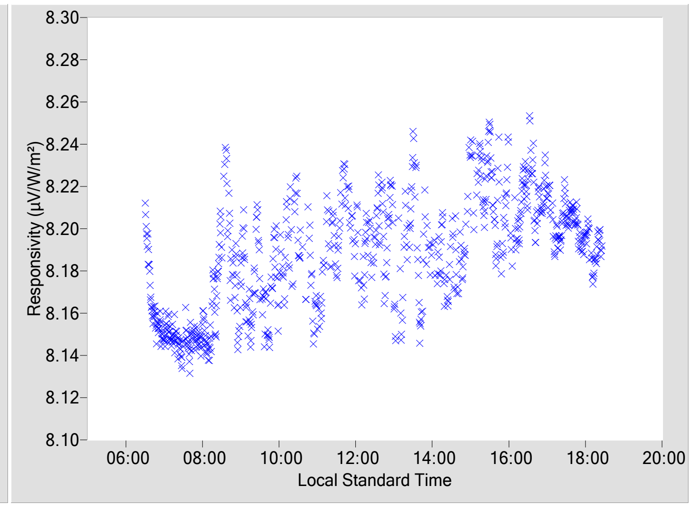


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1596	0.29	97.21	8.2314	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1638	0.29	95.60	8.2090	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1748	0.29	93.87	8.1893	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2125	0.29	92.31	8.1998	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1979	0.29	90.82	8.2209	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1616	0.30	89.36	8.2381	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1424	0.30	87.88	8.2061	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1467	0.30	86.41	8.2163	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1460	0.30	84.99	8.2141	0.29	275.07
18	8.1951	0.28	155.81	8.1956	0.28	204.70	64	8.1395	0.30	83.64	8.1986	0.30	276.46
20	8.2044	0.28	142.42	8.2017	0.28	217.26	66	8.1421	0.30	82.25	8.2054	0.30	277.83
22	8.1849	0.28	134.63	8.2295	0.28	225.36	68	8.1497	0.30	80.93	8.2057	0.30	279.24
24	8.1693	0.29	128.41	8.1812	0.28	231.51	70	8.1505	N/A	79.50	8.2053	0.30	280.63
26	8.1530	0.29	123.50	8.1863	0.28	236.26	72	8.1487	N/A	78.13	8.1913	N/A	281.99
28	8.1665	0.29	118.97	8.1858	0.28	240.74	74	8.1542	N/A	76.76	8.1971	N/A	283.39
30	8.1897	0.29	115.89	8.1770	0.28	244.17	76	8.1740	N/A	75.31	8.1854	N/A	284.71
32	8.1732	0.29	112.62	8.1994	0.28	247.39	78	N/A	N/A	N/A	8.1908	N/A	286.14
34	8.2012	0.29	110.00	8.1914	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1650	0.29	107.27	8.2021	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1765	0.29	105.09	8.2207	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1642	0.29	102.80	8.2356	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1816	0.29	100.91	8.2218	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1630	0.29	99.02	8.2195	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

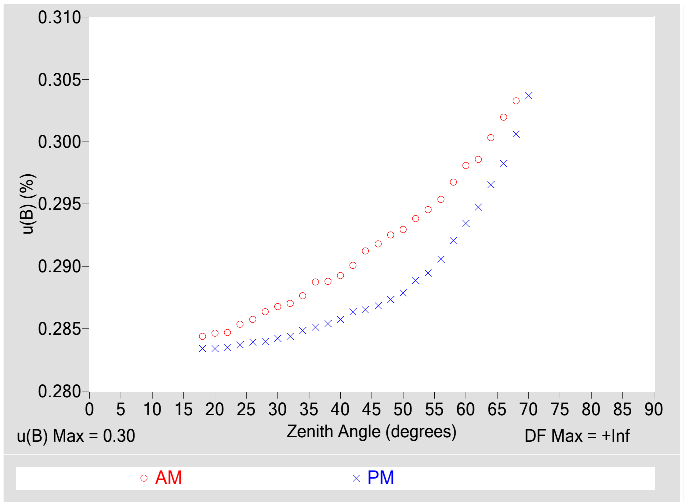


Figure 4. Residuals from Spline Interpolation

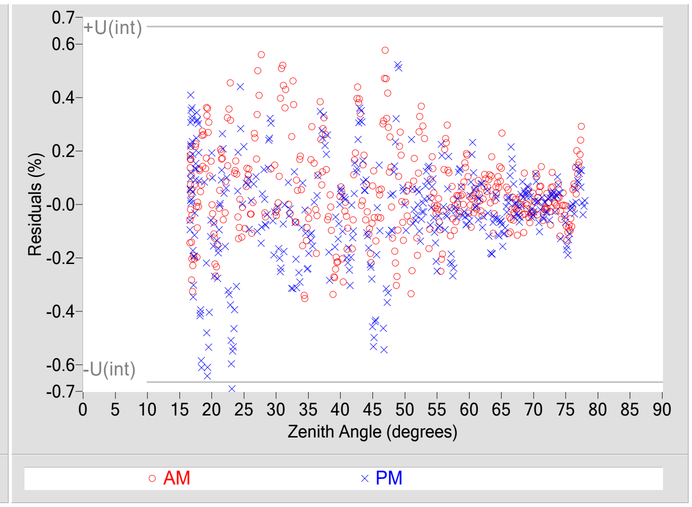


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.33
Combined Standard Uncertainty, u(c) (%)	±0.45
Effective degrees of freedom, DF(c)	2429
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.88
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

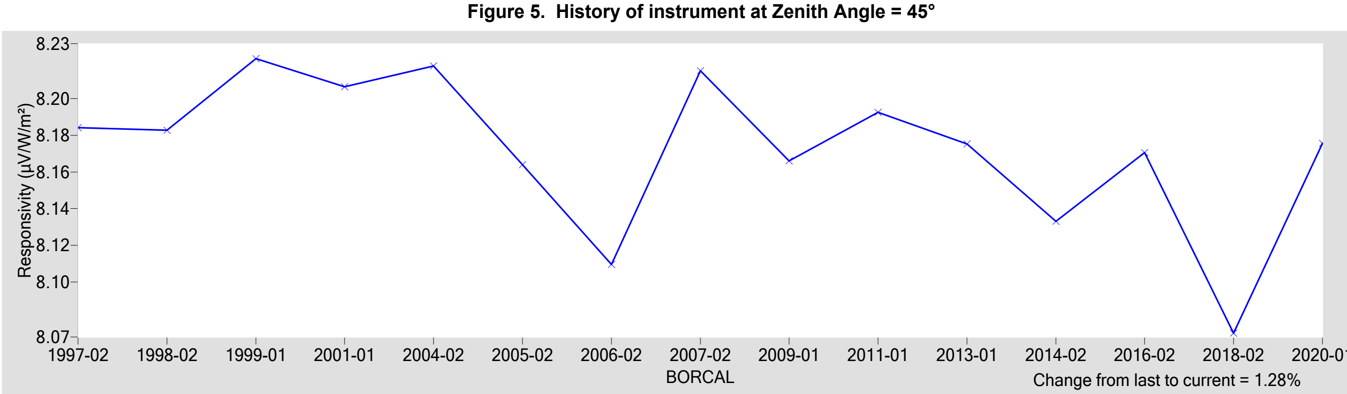
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1757	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.76 / -0.41
Expanded Uncertainty, U (%)	+1.3 / -0.99
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: 5/19/2020

Due Date: 5/19/2021

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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:

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

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

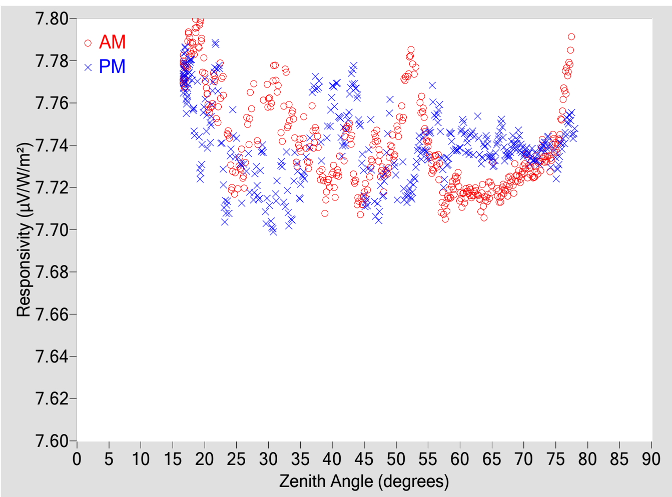


Figure 2. Responsivity vs Local Standard Time

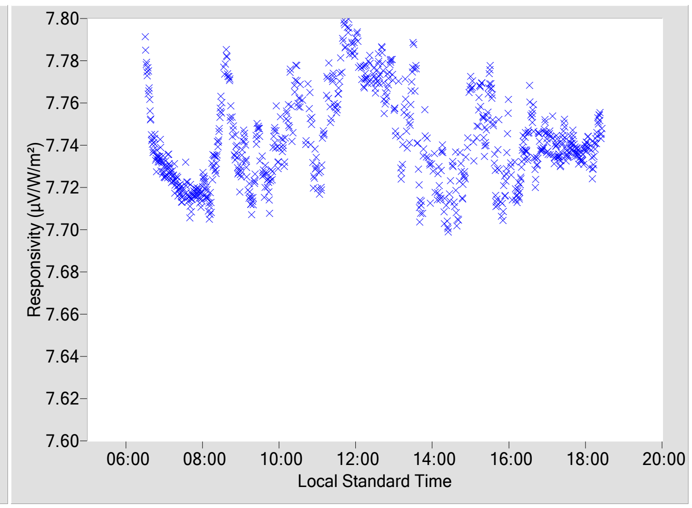


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.7300	0.29	97.21	7.7394	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7246	0.29	95.60	7.7214	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7439	0.29	93.87	7.7233	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7776	0.29	92.31	7.7184	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7584	0.29	90.82	7.7378	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7322	0.30	89.36	7.7560	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7129	0.30	87.88	7.7323	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7154	0.30	86.41	7.7429	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7164	0.30	84.99	7.7429	0.29	275.07
18	7.7857	0.28	155.81	7.7695	0.28	204.70	64	7.7128	0.30	83.64	7.7417	0.30	276.46
20	7.7732	0.28	142.42	7.7587	0.28	217.26	66	7.7164	0.30	82.25	7.7430	0.30	277.83
22	7.7538	0.28	134.63	7.7768	0.28	225.36	68	7.7231	0.30	80.93	7.7392	0.30	279.24
24	7.7319	0.29	128.41	7.7269	0.28	231.51	70	7.7289	N/A	79.50	7.7368	0.30	280.63
26	7.7269	0.29	123.50	7.7247	0.28	236.26	72	7.7292	N/A	78.13	7.7336	N/A	281.99
28	7.7422	0.29	118.97	7.7222	0.28	240.74	74	7.7337	N/A	76.76	7.7383	N/A	283.39
30	7.7628	0.29	115.89	7.7131	0.28	244.17	76	7.7578	N/A	75.31	7.7408	N/A	284.71
32	7.7439	0.29	112.62	7.7308	0.28	247.39	78	N/A	N/A	N/A	7.7467	N/A	286.14
34	7.7507	0.29	110.00	7.7297	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7332	0.29	107.27	7.7344	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7300	0.29	105.09	7.7530	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7259	0.29	102.80	7.7647	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7432	0.29	100.91	7.7462	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7135	0.29	99.02	7.7590	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

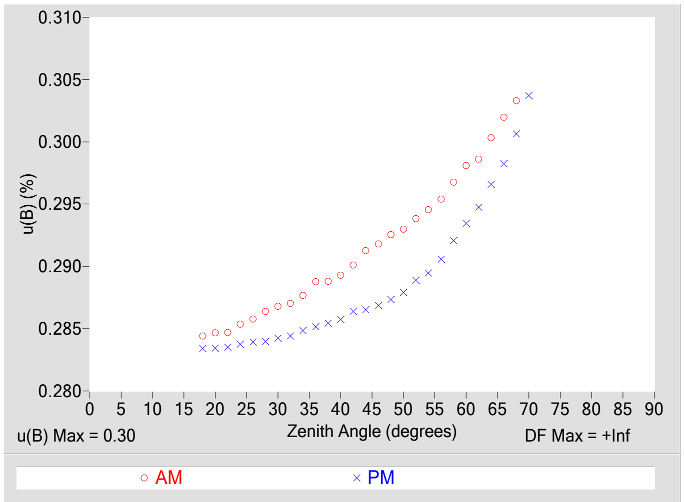


Figure 4. Residuals from Spline Interpolation

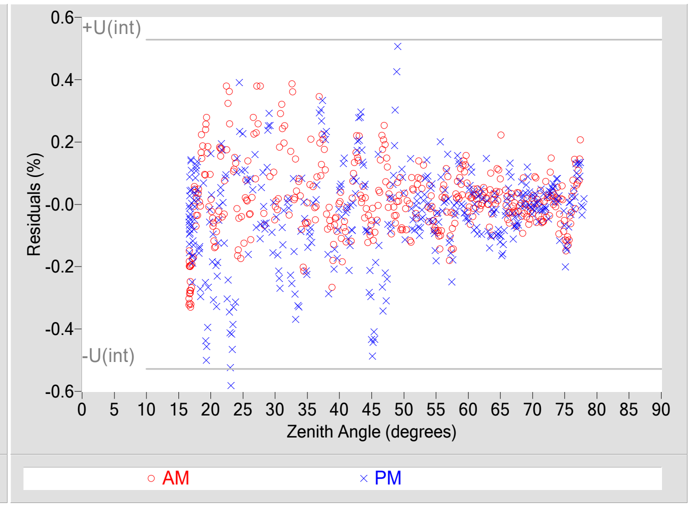


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	3901
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.79
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

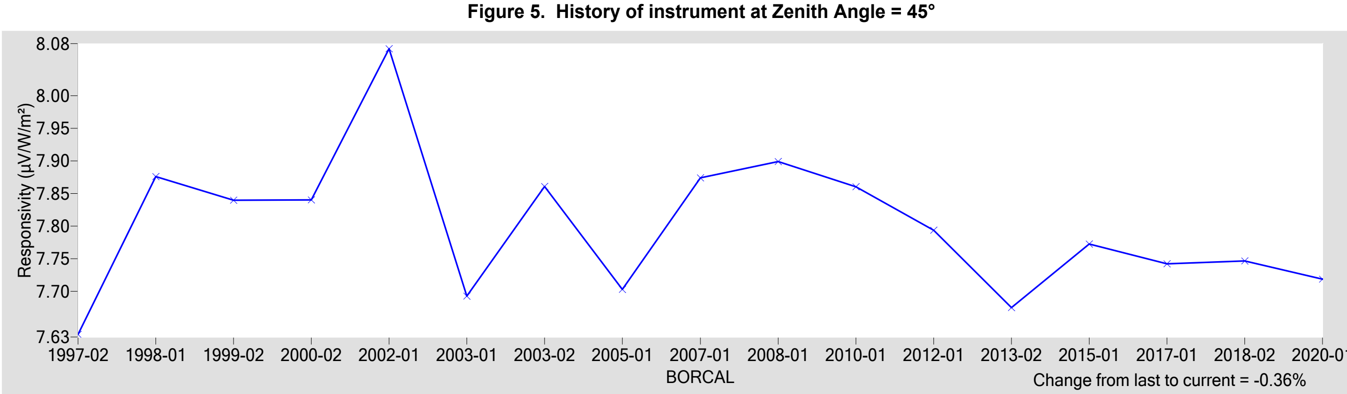
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.7186	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.76 / -0.074
Expanded Uncertainty, U (%)	+1.3 / -0.66
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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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:

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

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

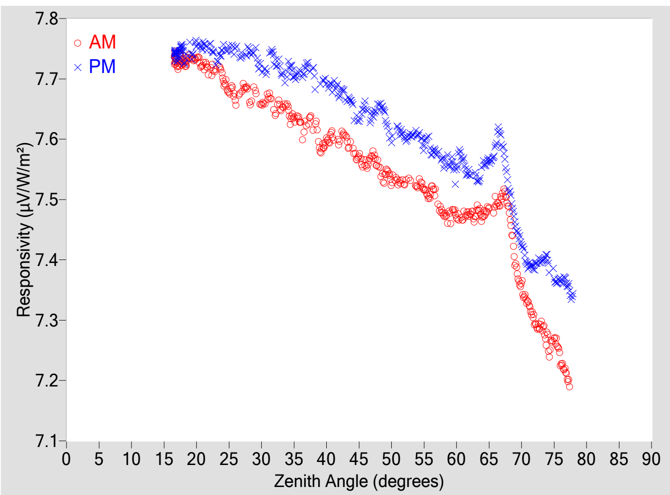


Figure 2. Responsivity vs Local Standard Time

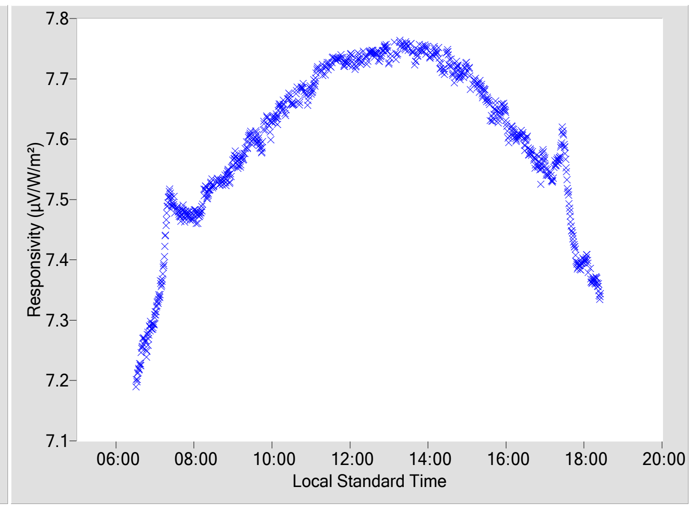


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5591	0.32	97.21	7.6540	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5574	0.32	95.57	7.6547	0.31	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5337	0.33	93.94	7.6003	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5276	0.33	92.28	7.6029	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5244	0.34	90.79	7.6089	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5121	0.34	89.31	7.5775	0.34	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4769	0.35	87.87	7.5627	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4741	0.36	86.45	7.5466	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4754	0.37	85.05	7.5427	0.36	275.03
18	7.7265	0.29	155.28	7.7411	0.29	204.78	64	7.4727	0.38	83.68	7.5580	0.38	276.52
20	7.7341	0.29	143.13	7.7579	0.29	216.96	66	7.4901	0.40	82.29	7.5909	0.39	277.87
22	7.7124	0.29	134.43	7.7544	0.29	226.01	68	7.4832	0.42	80.87	7.5193	0.41	279.24
24	7.7021	0.29	128.43	7.7477	0.29	231.38	70	7.3565	N/A	79.53	7.4275	0.44	280.59
26	7.6669	0.30	123.79	7.7484	0.29	236.45	72	7.2988	N/A	78.13	7.3894	N/A	281.99
28	7.6721	0.30	119.39	7.7489	0.29	240.78	74	7.2606	N/A	76.72	7.3979	N/A	283.39
30	7.6584	0.30	115.74	7.7179	0.29	244.17	76	7.2356	N/A	75.36	7.3665	N/A	284.80
32	7.6435	0.30	112.59	7.7322	0.30	247.37	78	N/A	N/A	N/A	7.3416	N/A	286.09
34	7.6540	0.30	109.93	7.7154	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6304	0.31	107.50	7.7088	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6149	0.31	105.12	7.7057	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5968	0.31	102.93	7.6920	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5955	0.31	101.02	7.6747	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5856	0.32	99.04	7.6532	0.31	261.05	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

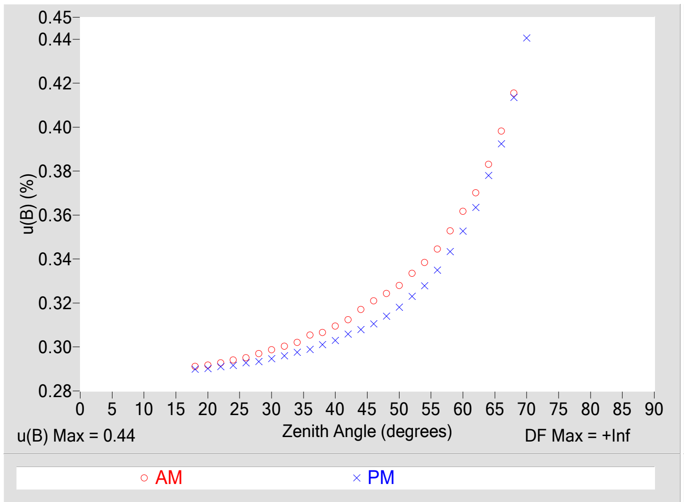


Figure 4. Residuals from Spline Interpolation

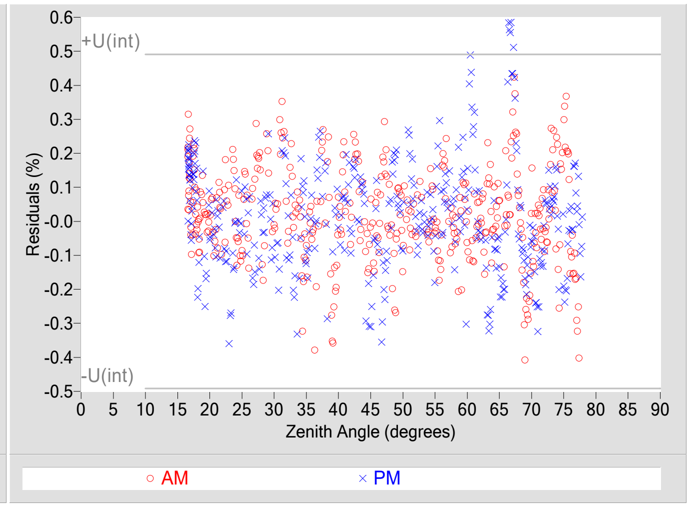


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	12725
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

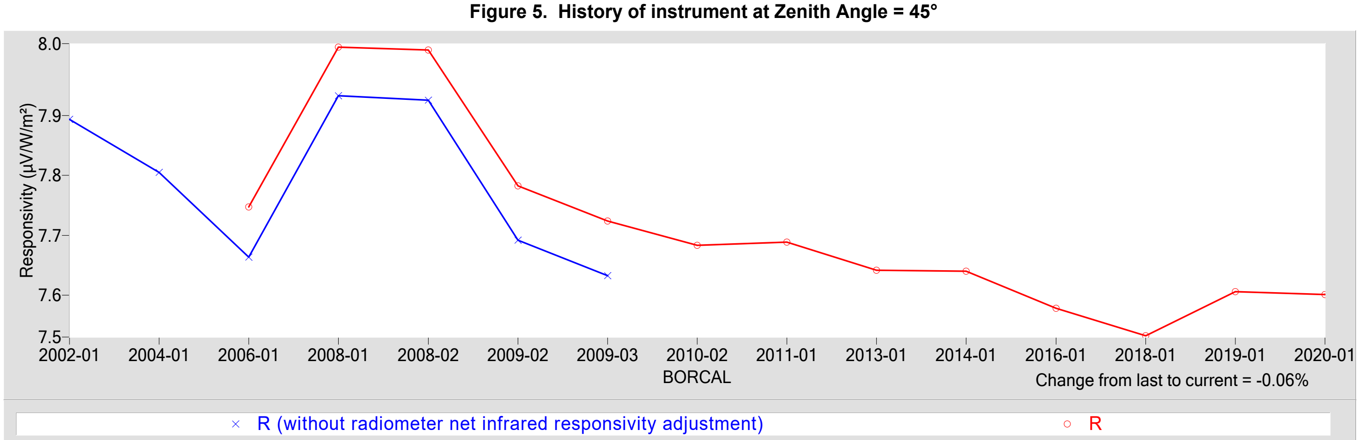
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6012	0.53900

† Rnet determination date: 03/31/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -1.7
Expanded Uncertainty, U (%)	+2.4 / -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:**	29914F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

29914F3 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

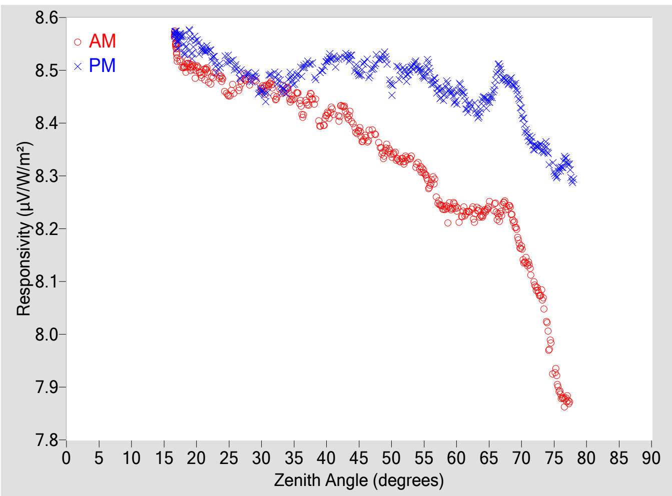


Figure 2. Responsivity vs Local Standard Time

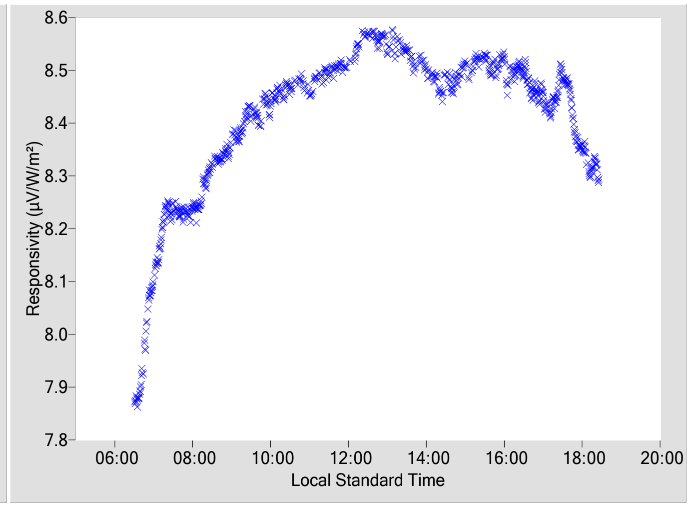


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3726	0.32	97.32	8.5173	0.31	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3582	0.33	95.41	8.5204	0.32	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3414	0.33	93.92	8.4681	0.32	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3293	0.33	92.38	8.4992	0.33	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3215	0.34	90.89	8.5068	0.33	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2846	0.35	89.33	8.4873	0.34	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2390	0.35	87.85	8.4559	0.35	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2383	0.36	86.46	8.4479	0.36	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2325	0.37	85.11	8.4310	0.37	275.05
18	8.5057	0.29	155.12	8.5462	0.29	204.90	64	8.2257	0.38	83.65	8.4415	0.38	276.44
20	8.5007	0.29	142.73	8.5591	0.29	216.66	66	8.2357	0.40	82.27	8.4812	0.40	277.84
22	8.4840	0.29	134.57	8.5379	0.29	225.42	68	8.2415	0.42	80.86	8.4779	0.42	279.26
24	8.4843	0.29	128.70	N/A	N/A	N/A	70	8.1591	N/A	79.51	8.4203	0.44	280.61
26	8.4565	0.30	124.08	8.5048	0.29	236.55	72	8.0914	N/A	78.07	8.3544	N/A	281.97
28	8.4781	0.30	119.22	8.4897	0.29	240.60	74	8.0056	N/A	76.74	8.3456	N/A	283.37
30	8.4656	0.30	115.74	8.4625	0.30	244.17	76	7.8857	N/A	75.33	8.3147	N/A	284.77
32	8.4471	0.30	112.54	8.4913	0.30	247.51	78	N/A	N/A	N/A	8.2906	N/A	286.10
34	8.4635	0.30	109.93	8.4698	0.30	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4322	0.31	107.32	8.4973	0.30	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4422	0.31	105.16	8.5003	0.30	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4153	0.31	102.89	8.5176	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4191	0.31	100.87	8.5232	0.31	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4007	0.32	99.04	8.5284	0.31	260.87	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

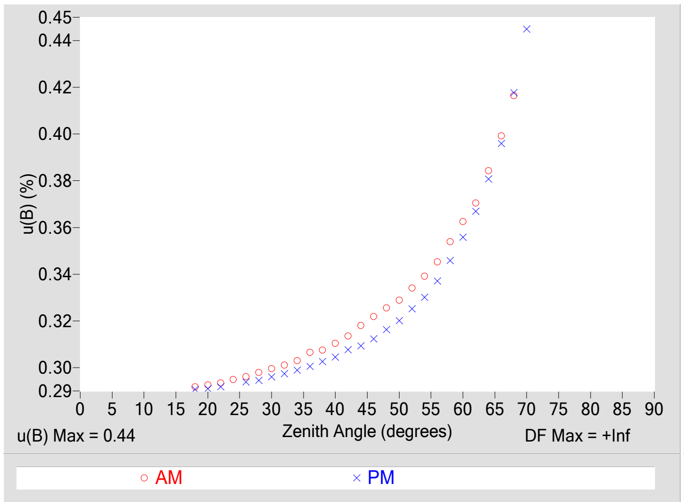


Figure 4. Residuals from Spline Interpolation

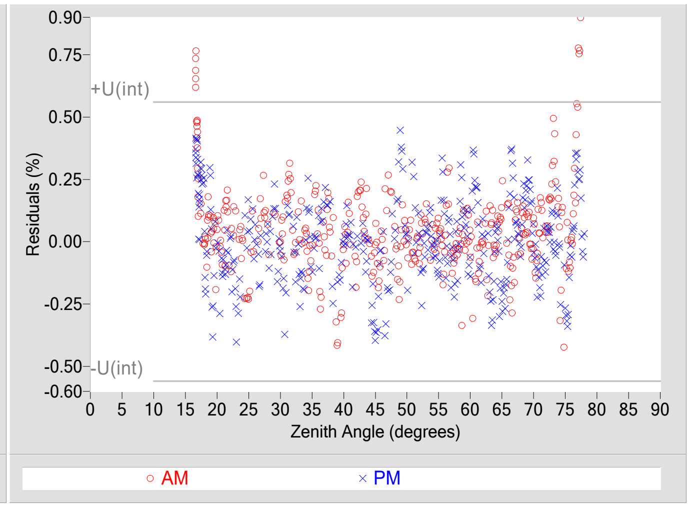


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	8549
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

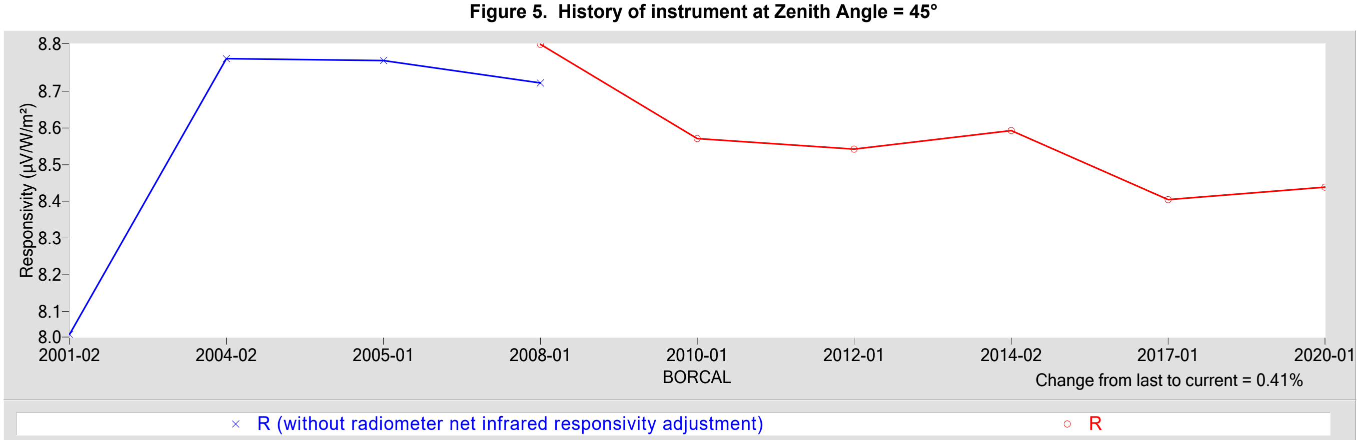
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4389	0.65100

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.1 / -2.4
Expanded Uncertainty, U (%)	+1.8 / -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:**	29916F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

29916F3 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

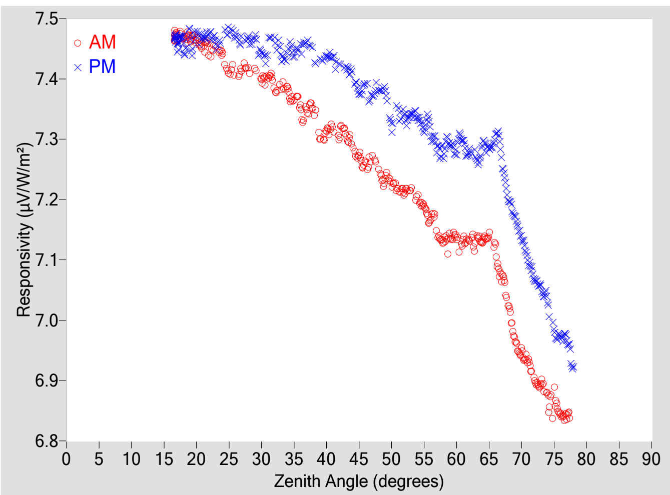


Figure 2. Responsivity vs Local Standard Time

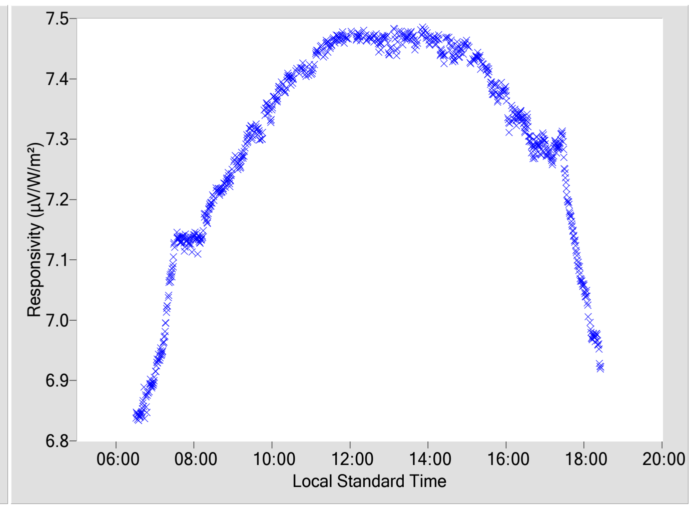


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.2603	0.32	97.32	7.3917	0.31	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2466	0.33	95.41	7.3809	0.32	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2277	0.33	93.92	7.3242	0.32	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2131	0.33	92.38	7.3407	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2038	0.34	90.89	7.3370	0.33	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1671	0.34	89.33	7.3113	0.34	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1316	0.35	87.85	7.2812	0.35	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1375	0.36	86.46	7.2852	0.35	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1324	0.37	85.11	7.2773	0.37	275.05
18	7.4679	0.29	155.12	7.4540	0.29	204.90	64	7.1303	0.38	83.65	7.2886	0.38	276.44
20	7.4644	0.29	142.73	7.4763	0.29	216.66	66	7.1140	0.40	82.27	7.3041	0.39	277.84
22	7.4458	0.29	134.57	7.4757	0.29	225.42	68	7.0235	0.42	80.86	7.1991	0.42	279.26
24	7.4433	0.29	128.70	N/A	N/A	N/A	70	6.9452	N/A	79.51	7.1351	0.44	280.61
26	7.4061	0.30	124.08	7.4707	0.29	236.55	72	6.8985	N/A	78.07	7.0684	N/A	281.97
28	7.4134	0.30	119.22	7.4654	0.29	240.60	74	6.8707	N/A	76.74	7.0295	N/A	283.37
30	7.3994	0.30	115.74	7.4452	0.30	244.17	76	6.8438	N/A	75.33	6.9742	N/A	284.77
32	7.3800	0.30	112.54	7.4638	0.30	247.51	78	N/A	N/A	N/A	6.9217	N/A	286.10
34	7.3837	0.30	109.93	7.4404	0.30	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3475	0.31	107.32	7.4496	0.30	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3473	0.31	105.16	7.4397	0.30	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3144	0.31	102.89	7.4374	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3104	0.31	100.87	7.4245	0.31	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2891	0.32	99.04	7.4141	0.31	260.87	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

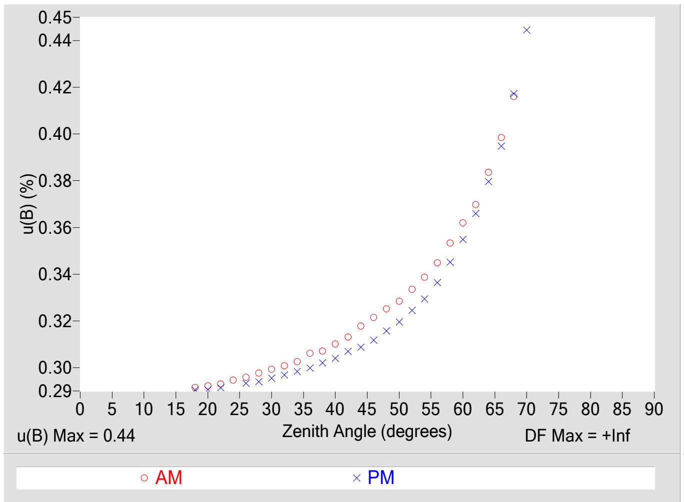


Figure 4. Residuals from Spline Interpolation

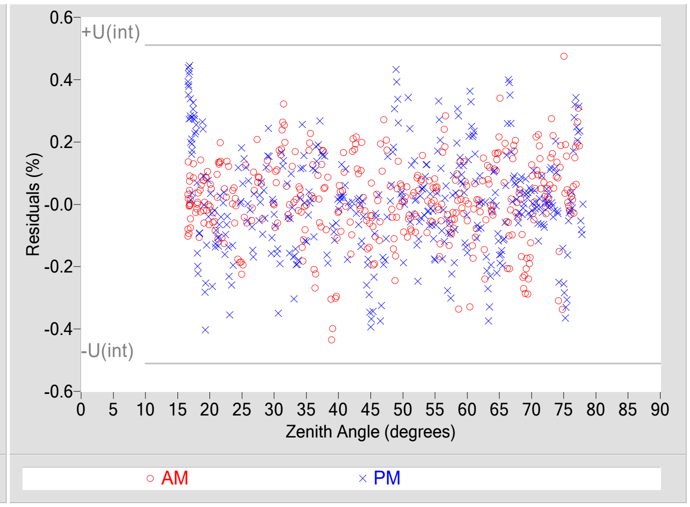


Table 3. Uncertainty using Spline Interpolation ‡

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)	11163
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

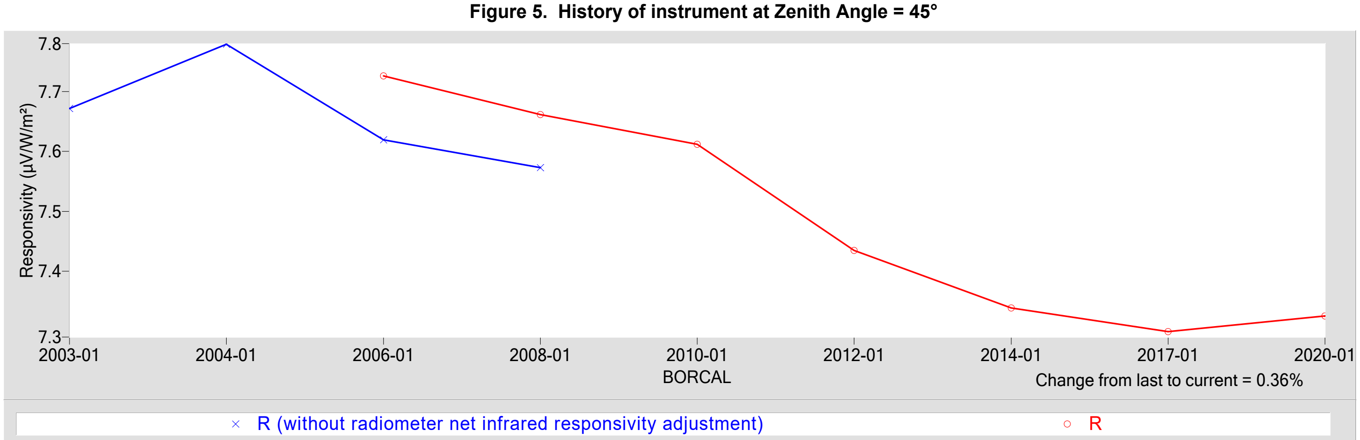
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.3250	0.54700

† Rnet determination date: 04/03/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.9 / -2.6
Expanded Uncertainty, U (%)	+2.6 / -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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29937E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

29937E6 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

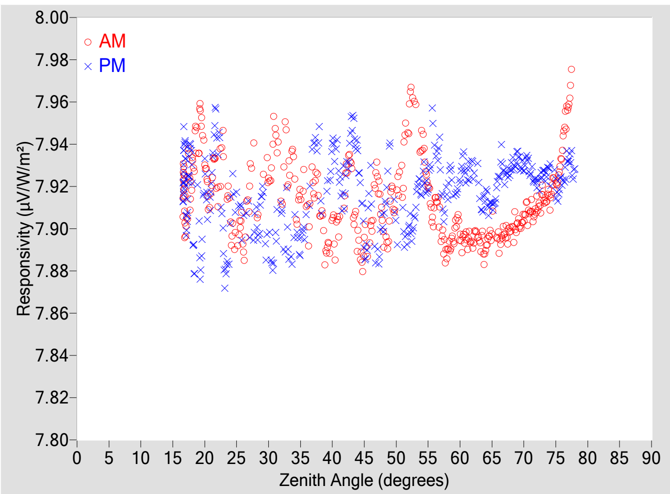


Figure 2. Responsivity vs Local Standard Time

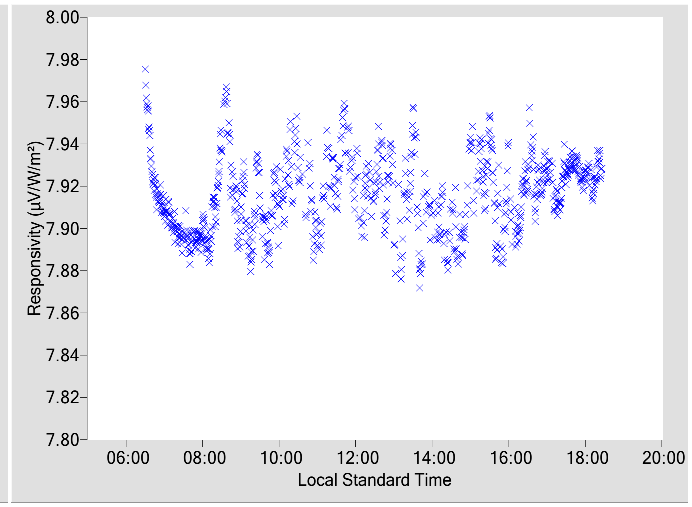


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8993	0.29	97.21	7.9194	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8980	0.29	95.60	7.9053	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9172	0.29	93.87	7.9014	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9536	0.29	92.31	7.9010	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9403	0.29	90.82	7.9199	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9091	0.30	89.36	7.9413	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8892	0.30	87.88	7.9179	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8957	0.30	86.41	7.9255	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8942	0.30	84.99	7.9285	0.29	275.07
18	7.9226	0.28	155.81	7.9180	0.28	204.70	64	7.8891	0.30	83.64	7.9162	0.30	276.46
20	7.9323	0.28	142.42	7.9211	0.28	217.26	66	7.8946	0.30	82.25	7.9231	0.30	277.83
22	7.9164	0.28	134.63	7.9451	0.28	225.36	68	7.8997	0.30	80.93	7.9292	0.30	279.24
24	7.9053	0.29	128.41	7.9002	0.28	231.51	70	7.9053	N/A	79.50	7.9301	0.30	280.63
26	7.8936	0.29	123.50	7.9038	0.28	236.26	72	7.9097	N/A	78.13	7.9220	N/A	281.99
28	7.9051	0.29	118.97	7.9022	0.28	240.74	74	7.9148	N/A	76.76	7.9272	N/A	283.39
30	7.9255	0.29	115.89	7.8979	0.28	244.17	76	7.9387	N/A	75.31	7.9230	N/A	284.71
32	7.9124	0.29	112.62	7.9095	0.28	247.39	78	N/A	N/A	N/A	7.9282	N/A	286.14
34	7.9317	0.29	110.00	7.9012	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9045	0.29	107.27	7.9067	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9093	0.29	105.09	7.9274	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9021	0.29	102.80	7.9374	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9206	0.29	100.91	7.9225	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8943	0.29	99.02	7.9339	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

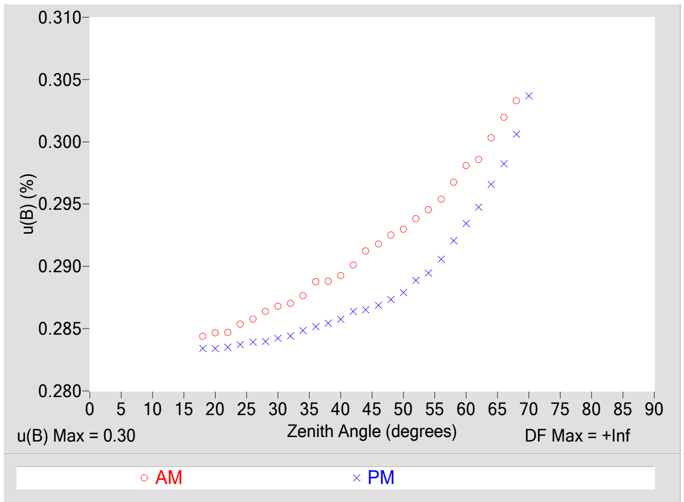


Figure 4. Residuals from Spline Interpolation

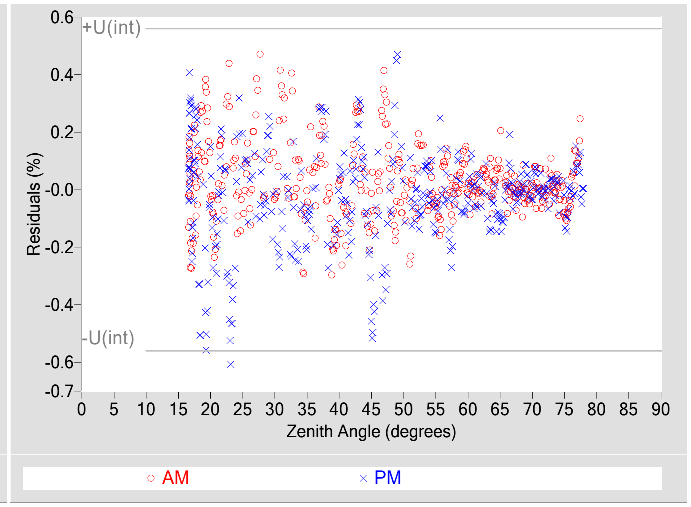


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	3420
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.81
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

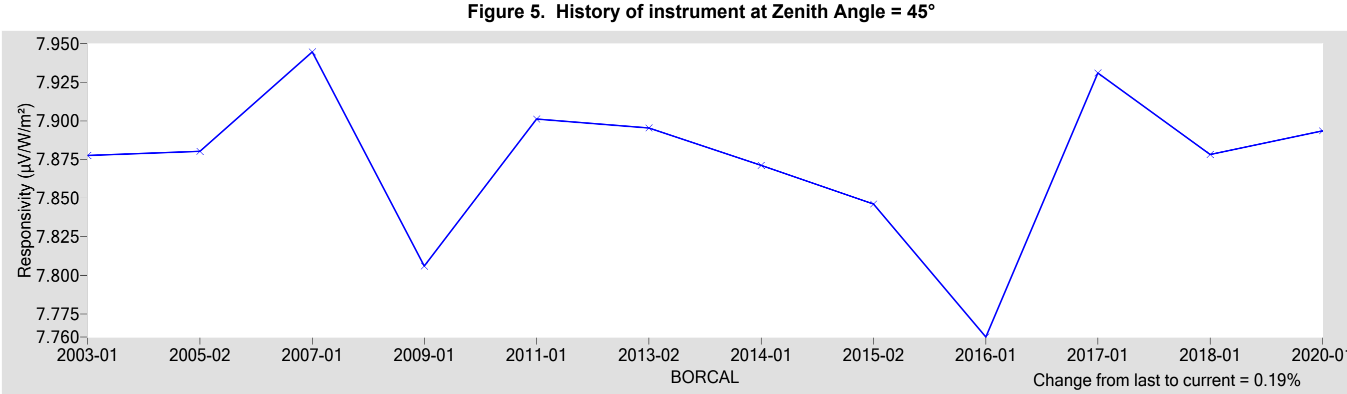
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8934	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.76 / -0.053
Expanded Uncertainty, U (%)	+1.3 / -0.64
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:**	29939E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

29939E6 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

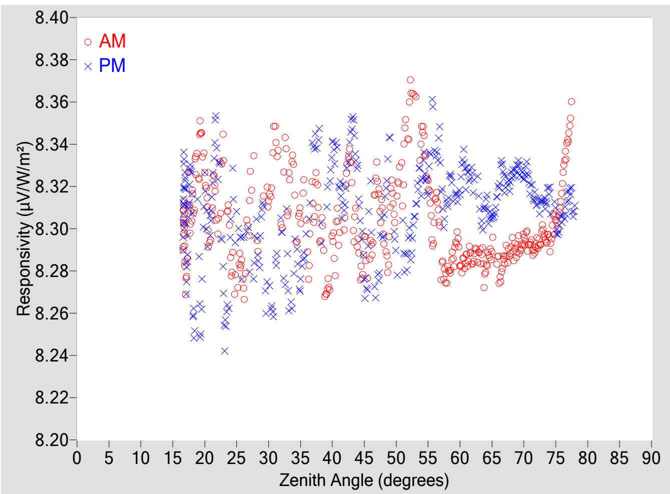


Figure 2. Responsivity vs Local Standard Time

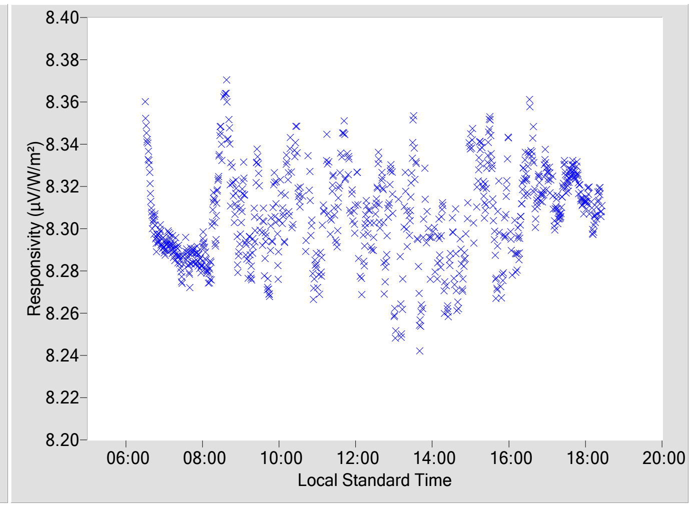


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2900	0.29	97.21	8.3096	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3000	0.29	95.60	8.3039	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3134	0.29	93.87	8.2876	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3538	0.29	92.31	8.2932	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3429	0.29	90.82	8.3237	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3032	0.30	89.36	8.3431	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2788	0.30	87.88	8.3127	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2835	0.30	86.41	8.3222	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2848	0.30	84.99	8.3239	0.29	275.07
18	8.3077	0.28	155.81	8.2986	0.28	204.70	64	8.2790	0.30	83.64	8.3124	0.30	276.46
20	8.3255	0.28	142.42	8.3111	0.28	217.26	66	8.2816	0.30	82.25	8.3182	0.30	277.83
22	8.3021	0.28	134.63	8.3366	0.28	225.36	68	8.2906	0.30	80.93	8.3237	0.30	279.24
24	8.2912	0.29	128.41	8.2876	0.28	231.51	70	8.2944	N/A	79.50	8.3258	0.30	280.63
26	8.2749	0.29	123.50	8.2893	0.28	236.26	72	8.2915	N/A	78.13	8.3127	N/A	281.99
28	8.2944	0.29	118.97	8.2936	0.28	240.74	74	8.2945	N/A	76.76	8.3156	N/A	283.39
30	8.3149	0.29	115.89	8.2740	0.28	244.17	76	8.3216	N/A	75.31	8.3054	N/A	284.71
32	8.3012	0.29	112.62	8.3006	0.28	247.39	78	N/A	N/A	N/A	8.3095	N/A	286.14
34	8.3271	0.29	110.00	8.2869	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2897	0.29	107.27	8.2975	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2993	0.29	105.09	8.3213	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2936	0.29	102.80	8.3363	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3128	0.29	100.91	8.3178	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2917	0.29	99.02	8.3231	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

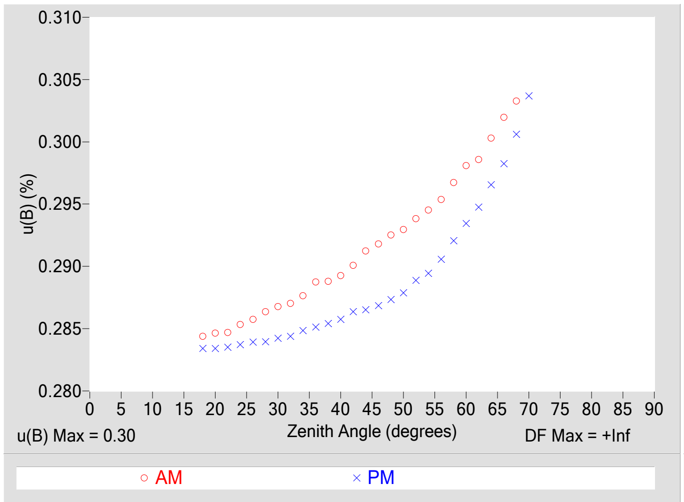


Figure 4. Residuals from Spline Interpolation

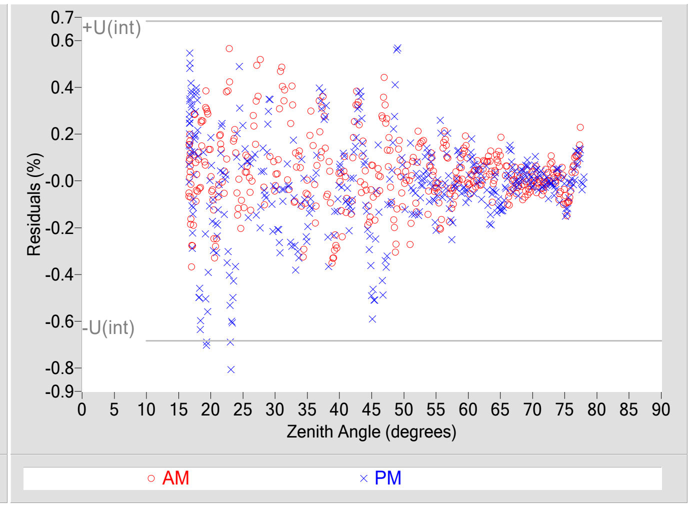


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.46
Effective degrees of freedom, DF(c)	2315
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.90
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

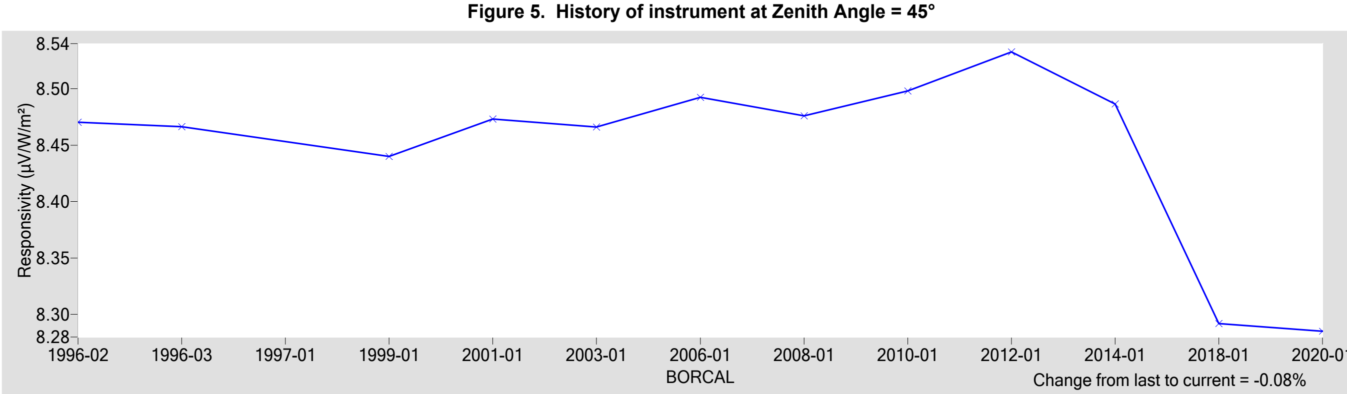
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.2850	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.83 / -0.13
Expanded Uncertainty, U (%)	+1.4 / -0.72
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: 30614F3
Calibration Date: 5/19/2020
Due Date: 5/19/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30614F3 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

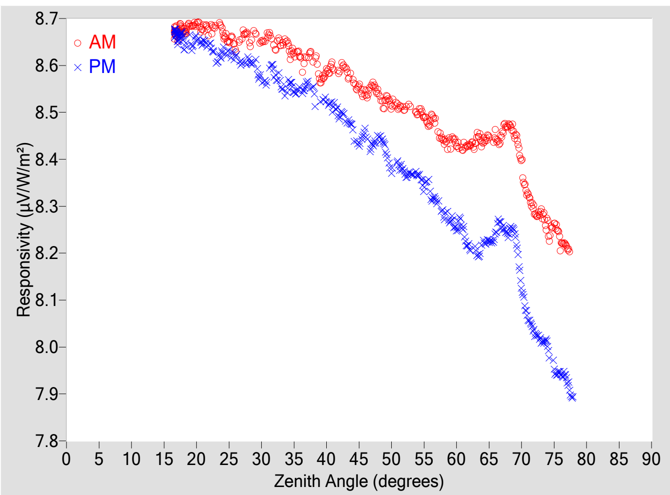


Figure 2. Responsivity vs Local Standard Time

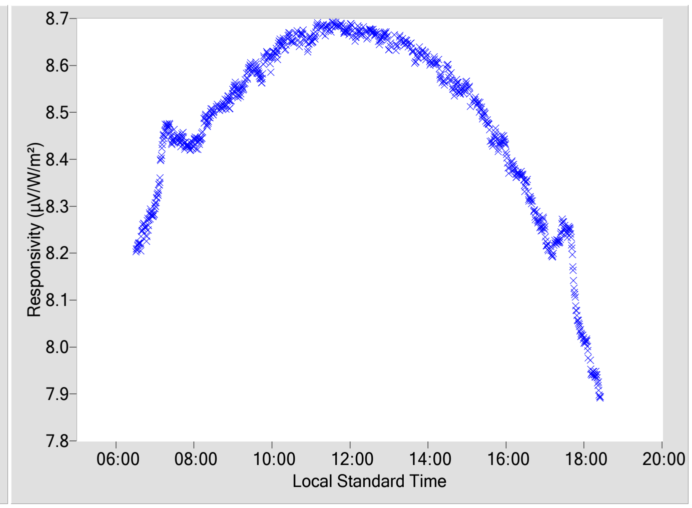


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5398	0.32	97.21	8.4534	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5410	0.32	95.57	8.4457	0.32	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5180	0.33	93.94	8.3778	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5075	0.33	92.28	8.3710	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4997	0.34	90.79	8.3679	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4835	0.35	89.31	8.3189	0.34	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4408	0.35	87.87	8.2835	0.35	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4339	0.36	86.45	8.2513	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4295	0.37	85.05	8.2123	0.37	275.03
18	8.6724	0.29	155.28	8.6511	0.29	204.78	64	8.4369	0.38	83.68	8.2221	0.38	276.52
20	8.6893	0.29	143.13	8.6575	0.29	216.96	66	8.4450	0.40	82.29	8.2448	0.40	277.87
22	8.6752	0.29	134.43	8.6436	0.29	226.01	68	8.4719	0.42	80.87	8.2419	0.42	279.24
24	8.6713	0.29	128.43	8.6283	0.29	231.38	70	8.3935	N/A	79.53	8.1316	0.44	280.59
26	8.6387	0.30	123.79	8.6180	0.29	236.45	72	8.2891	N/A	78.13	8.0297	N/A	281.99
28	8.6565	0.30	119.39	8.6127	0.29	240.78	74	8.2509	N/A	76.72	8.0001	N/A	283.39
30	8.6509	0.30	115.74	8.5714	0.30	244.17	76	8.2259	N/A	75.36	7.9425	N/A	284.80
32	8.6366	0.30	112.59	8.5833	0.30	247.37	78	N/A	N/A	N/A	7.8926	N/A	286.09
34	8.6477	0.30	109.93	8.5561	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6211	0.31	107.50	8.5474	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6075	0.31	105.12	8.5400	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5863	0.31	102.93	8.5234	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5863	0.31	101.02	8.4927	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5717	0.32	99.04	8.4626	0.31	261.05	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

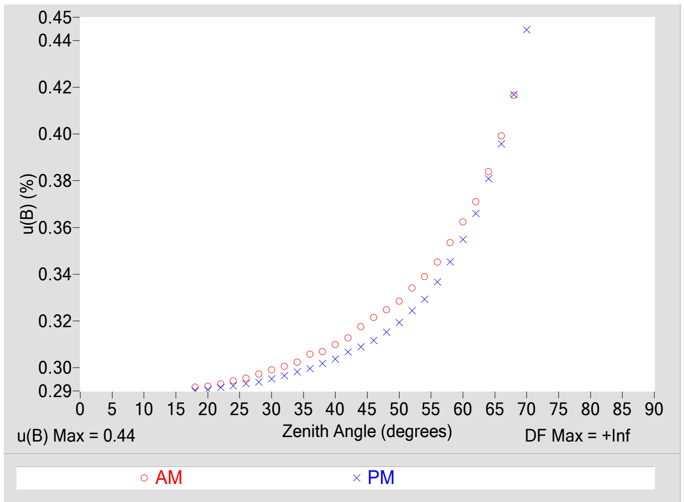


Figure 4. Residuals from Spline Interpolation

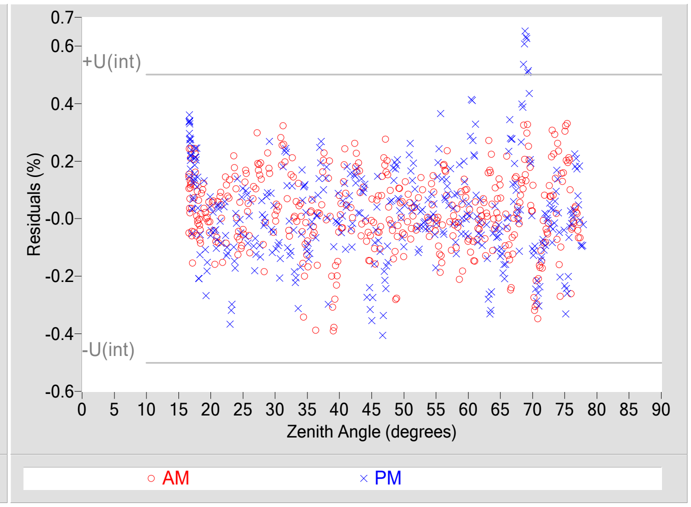


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	12288
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

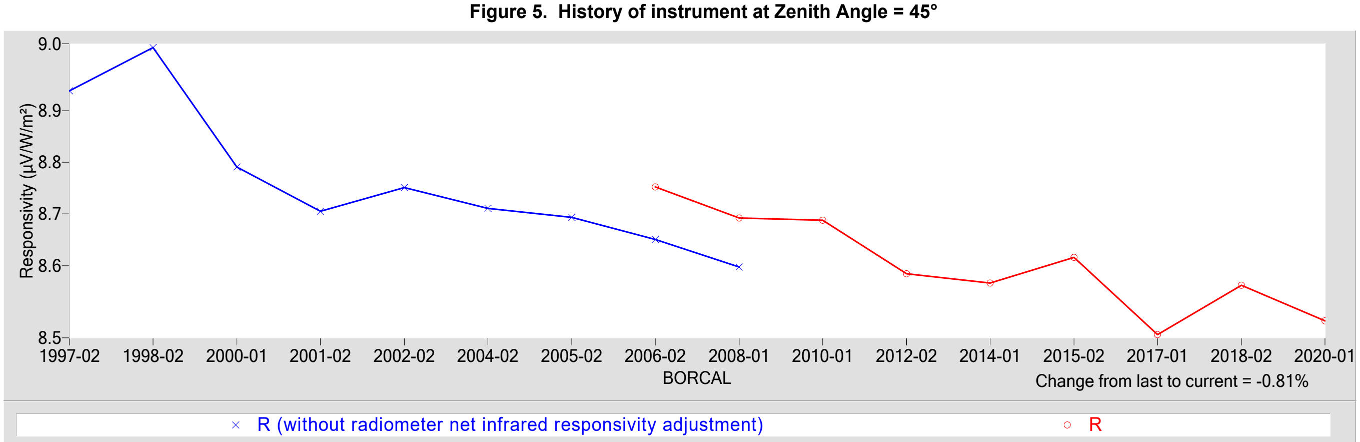
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4931	0.63119

† Rnet determination date: 06/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.9 / -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:**	30620F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30620F3 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

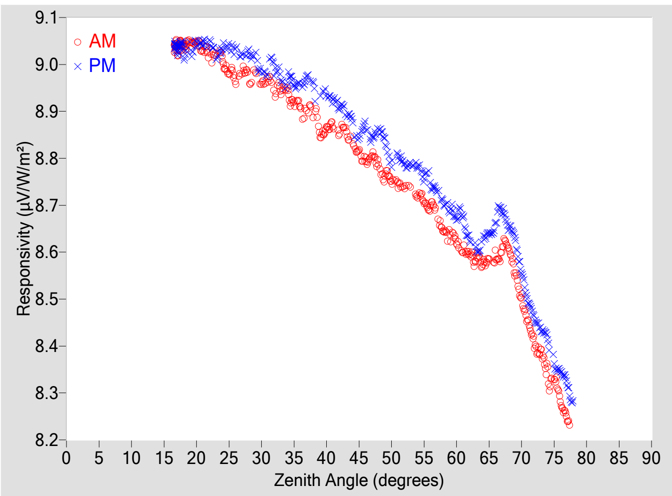


Figure 2. Responsivity vs Local Standard Time

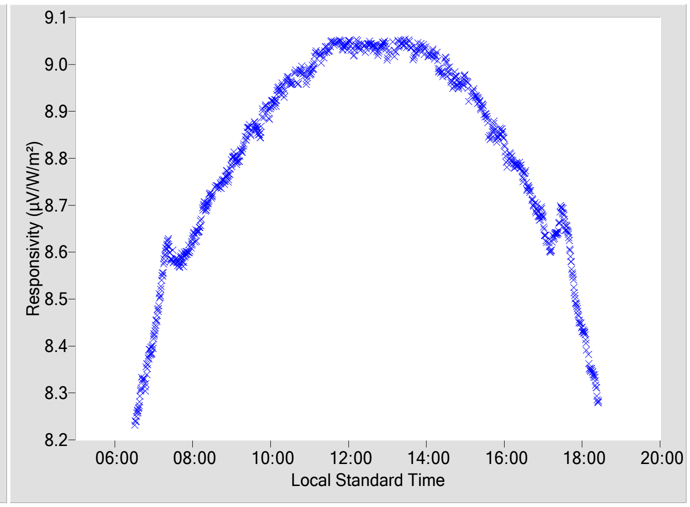


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7956	0.32	97.21	8.8683	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7857	0.33	95.57	8.8588	0.32	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7529	0.33	93.94	8.7891	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7394	0.33	92.28	8.7878	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7202	0.34	90.79	8.7836	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6983	0.35	89.31	8.7379	0.34	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6461	0.35	87.87	8.7049	0.35	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6239	0.36	86.45	8.6718	0.36	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5956	0.37	85.05	8.6291	0.37	275.03
18	9.0384	0.29	155.28	9.0301	0.29	204.78	64	8.5747	0.39	83.68	8.6281	0.38	276.52
20	9.0472	0.29	143.13	9.0449	0.29	216.96	66	8.5856	0.40	82.29	8.6639	0.40	277.87
22	9.0179	0.29	134.43	9.0466	0.29	226.01	68	8.6059	0.42	80.87	8.6518	0.42	279.24
24	9.0080	0.29	128.43	9.0346	0.29	231.38	70	8.5019	N/A	79.53	8.5597	0.45	280.59
26	8.9674	0.30	123.79	9.0303	0.29	236.45	72	8.4066	N/A	78.13	8.4573	N/A	281.99
28	8.9724	0.30	119.39	9.0269	0.29	240.78	74	8.3362	N/A	76.72	8.4123	N/A	283.39
30	8.9601	0.30	115.74	8.9864	0.30	244.17	76	8.2841	N/A	75.36	8.3456	N/A	284.80
32	8.9378	0.30	112.59	8.9923	0.30	247.37	78	N/A	N/A	N/A	8.2811	N/A	286.09
34	8.9441	0.30	109.93	8.9678	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9121	0.31	107.50	8.9559	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8865	0.31	105.12	8.9485	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8633	0.31	102.93	8.9364	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8535	0.31	101.02	8.9079	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8348	0.32	99.04	8.8736	0.31	261.05	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

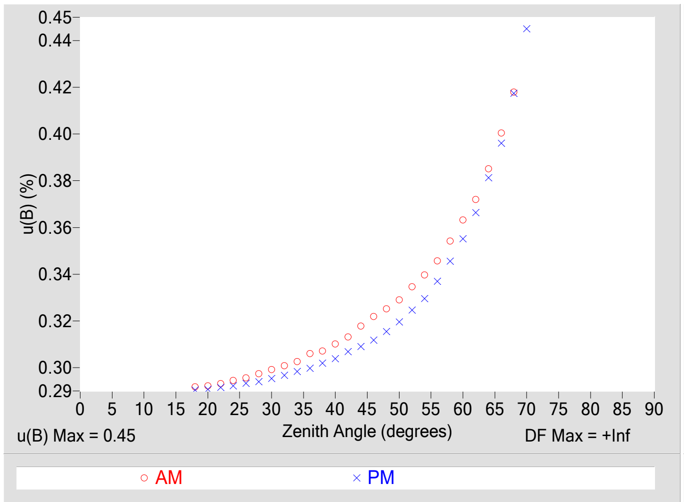


Figure 4. Residuals from Spline Interpolation

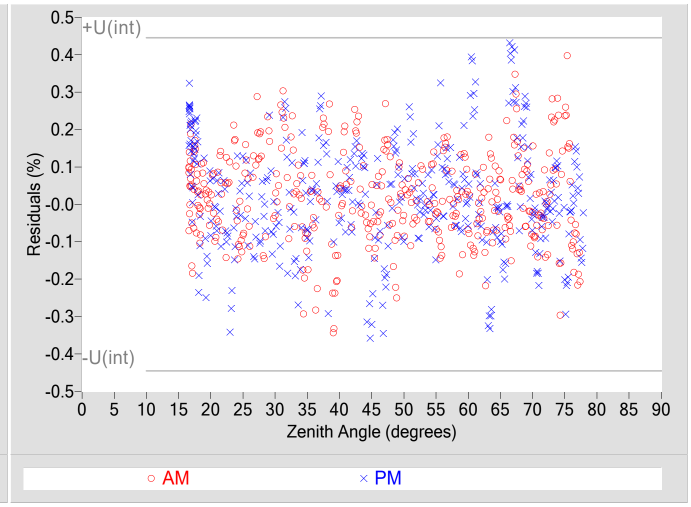


Table 3. Uncertainty using Spline Interpolation ‡

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)	17806
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

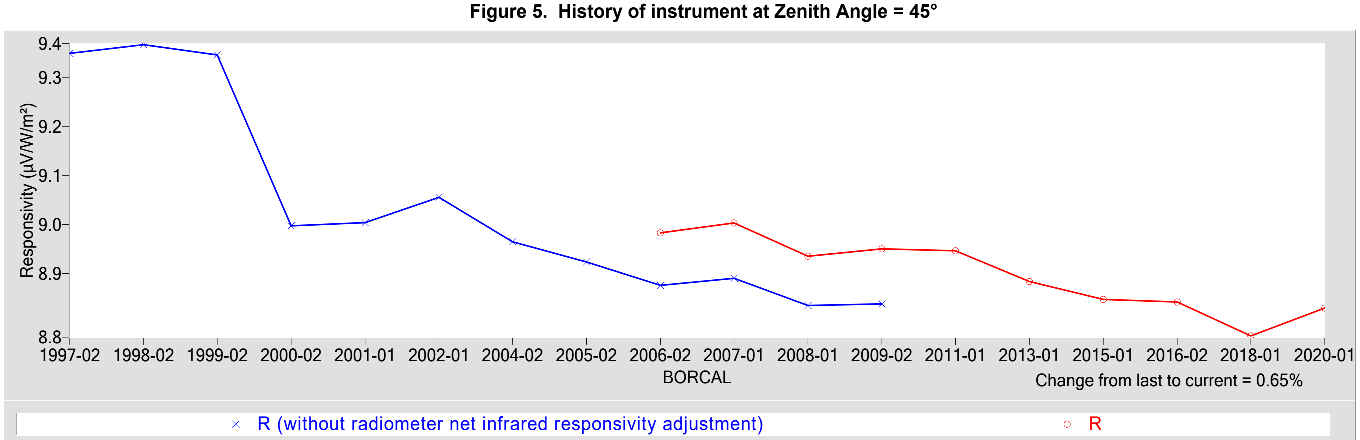
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8297	0.66913

† Rnet determination date: 07/10/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.8 / -2.3
Expanded Uncertainty, U (%)	+2.6 / -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:**	30663F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30663F3 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

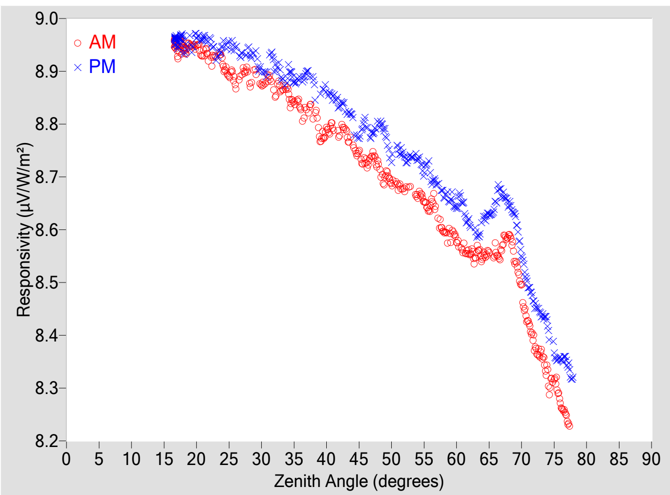


Figure 2. Responsivity vs Local Standard Time

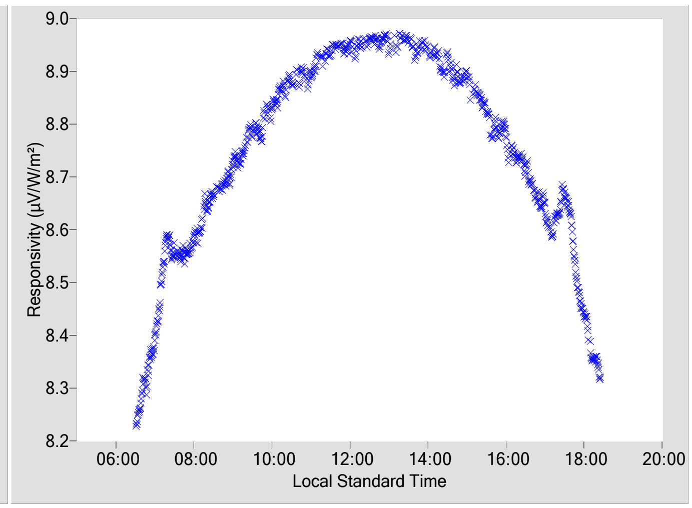


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7279	0.32	97.21	8.8015	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7221	0.32	95.57	8.8004	0.31	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6902	0.33	93.94	8.7355	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6772	0.33	92.28	8.7374	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6654	0.34	90.79	8.7361	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6458	0.34	89.31	8.6947	0.33	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5975	0.35	87.87	8.6670	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5819	0.36	86.45	8.6421	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5554	0.37	85.05	8.6126	0.36	275.03
18	8.9422	0.29	155.28	8.9521	0.29	204.78	64	8.5475	0.38	83.68	8.6192	0.38	276.52
20	8.9481	0.29	143.13	8.9670	0.29	216.96	66	8.5558	0.40	82.29	8.6541	0.39	277.87
22	8.9229	0.29	134.43	8.9585	0.29	226.01	68	8.5875	0.41	80.87	8.6491	0.41	279.24
24	8.9156	0.29	128.43	8.9468	0.29	231.38	70	8.4906	N/A	79.53	8.5563	0.44	280.59
26	8.8781	0.29	123.79	8.9439	0.29	236.45	72	8.3831	N/A	78.13	8.4587	N/A	281.99
28	8.8885	0.30	119.39	8.9407	0.29	240.78	74	8.3188	N/A	76.72	8.4164	N/A	283.39
30	8.8753	0.30	115.74	8.9038	0.29	244.17	76	8.2733	N/A	75.36	8.3555	N/A	284.80
32	8.8564	0.30	112.59	8.9125	0.30	247.37	78	N/A	N/A	N/A	8.3190	N/A	286.09
34	8.8645	0.30	109.93	8.8940	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8345	0.30	107.50	8.8851	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8096	0.31	105.12	8.8733	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7868	0.31	102.93	8.8629	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7804	0.31	101.02	8.8347	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7636	0.32	99.04	8.8072	0.31	261.05	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

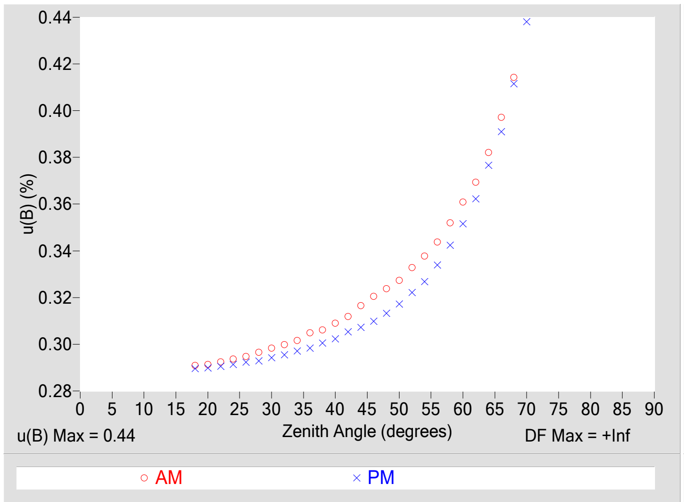


Figure 4. Residuals from Spline Interpolation

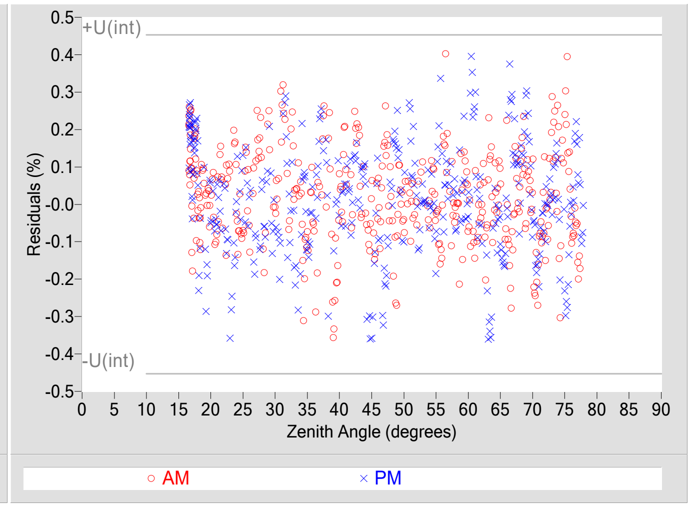


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	16042
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

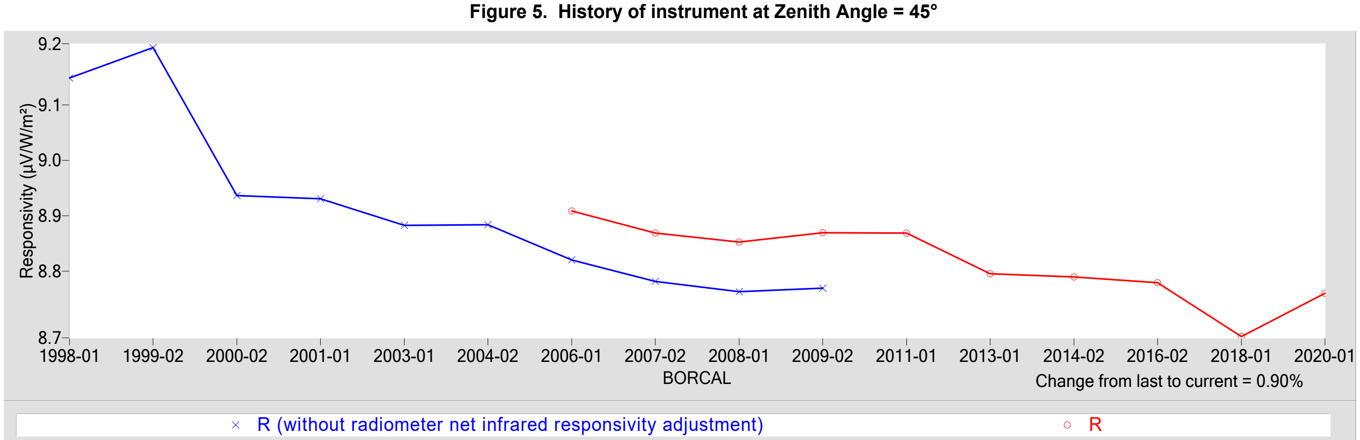
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7602	0.59430

† Rnet determination date: 04/04/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -2.0
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

[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:**	30666F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30666F3 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

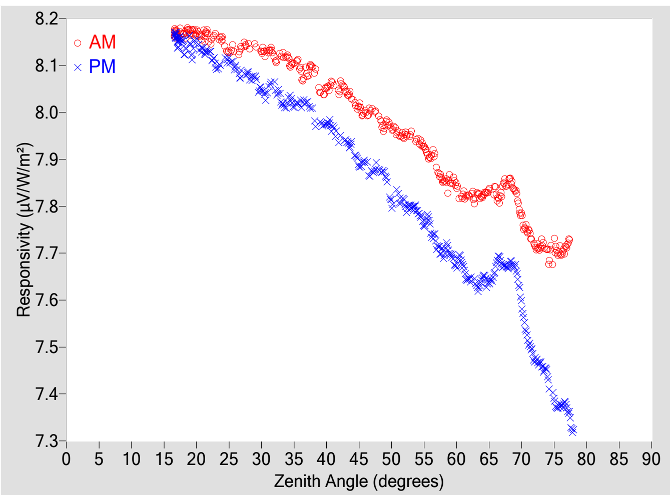


Figure 2. Responsivity vs Local Standard Time

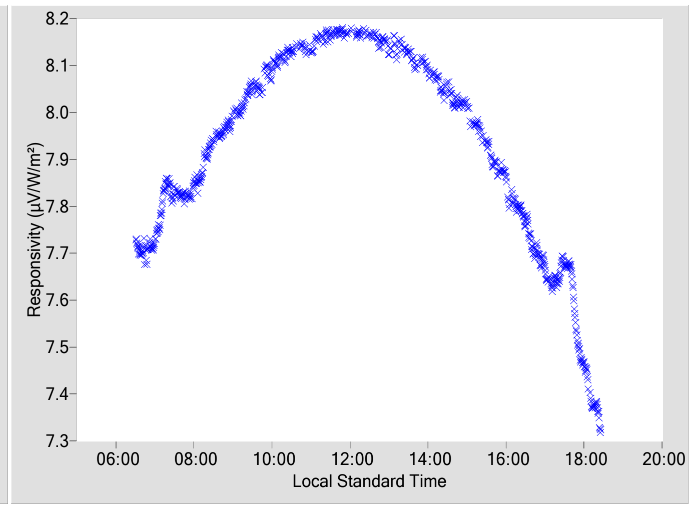


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0006	0.32	97.32	7.8954	0.32	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9883	0.33	95.41	7.8777	0.32	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9667	0.33	93.92	7.8068	0.32	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9517	0.34	92.38	7.8085	0.33	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9413	0.34	90.89	7.7902	0.33	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9046	0.35	89.33	7.7497	0.34	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8537	0.36	87.85	7.7008	0.35	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8440	0.37	86.46	7.6782	0.36	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8227	0.37	85.11	7.6445	0.37	275.05
18	8.1684	0.29	155.12	8.1361	0.29	204.90	64	7.8212	0.39	83.65	7.6466	0.39	276.44
20	8.1694	0.29	142.73	8.1518	0.29	216.66	66	7.8292	0.40	82.27	7.6703	0.41	277.84
22	8.1547	0.29	134.57	8.1294	0.29	225.42	68	7.8536	0.42	80.86	7.6733	0.43	279.26
24	8.1573	0.30	128.70	N/A	N/A	N/A	70	7.7780	N/A	79.51	7.5895	0.46	280.61
26	8.1299	0.30	124.08	8.0947	0.30	236.55	72	7.7143	N/A	78.07	7.4746	N/A	281.97
28	8.1413	0.30	119.22	8.0804	0.30	240.60	74	7.7003	N/A	76.74	7.4366	N/A	283.37
30	8.1312	0.30	115.74	8.0499	0.30	244.17	76	7.7020	N/A	75.33	7.3760	N/A	284.77
32	8.1113	0.30	112.54	8.0560	0.30	247.51	78	N/A	N/A	N/A	7.3226	N/A	286.10
34	8.1182	0.30	109.93	8.0206	0.30	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0861	0.31	107.32	8.0178	0.30	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0920	0.31	105.16	7.9955	0.30	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0532	0.31	102.89	7.9751	0.31	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0513	0.31	100.87	7.9427	0.31	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0278	0.32	99.04	7.9352	0.31	260.87	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

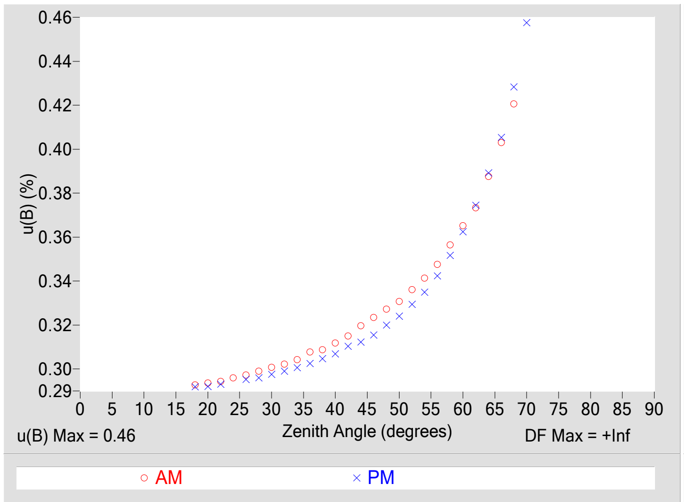


Figure 4. Residuals from Spline Interpolation

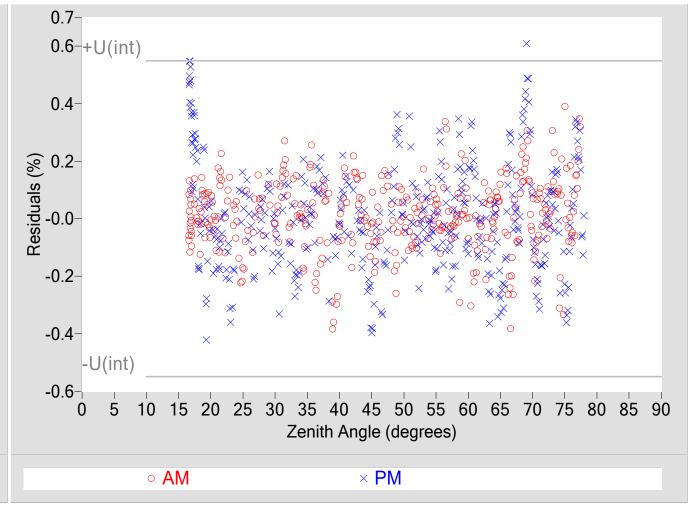


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.53
Effective degrees of freedom, DF(c)	9805
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

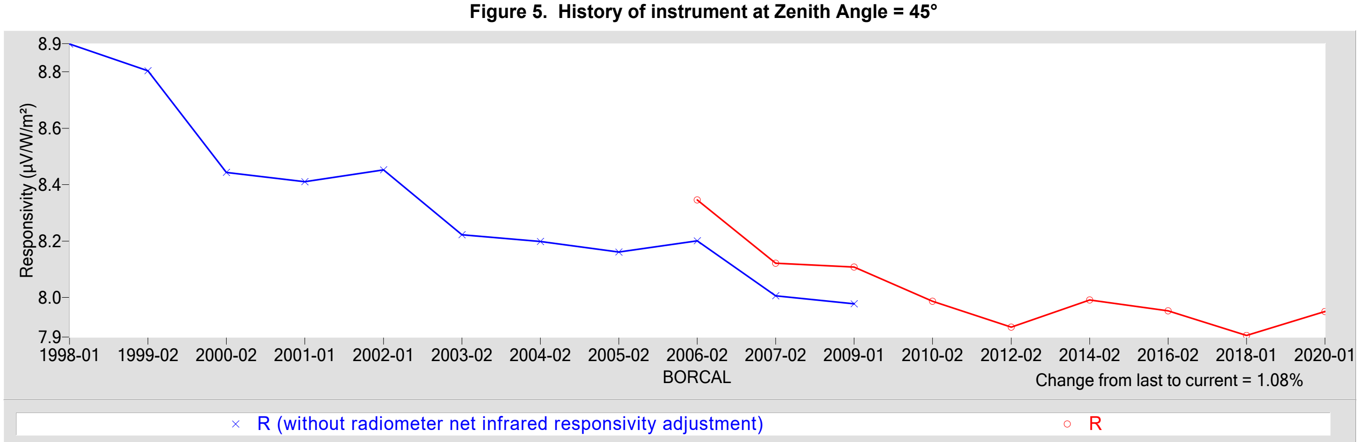
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9510	0.69195

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+2.3 / -3.4
Expanded Uncertainty, U (%)	+3.0 / -4.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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: 30667F3

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30667F3 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

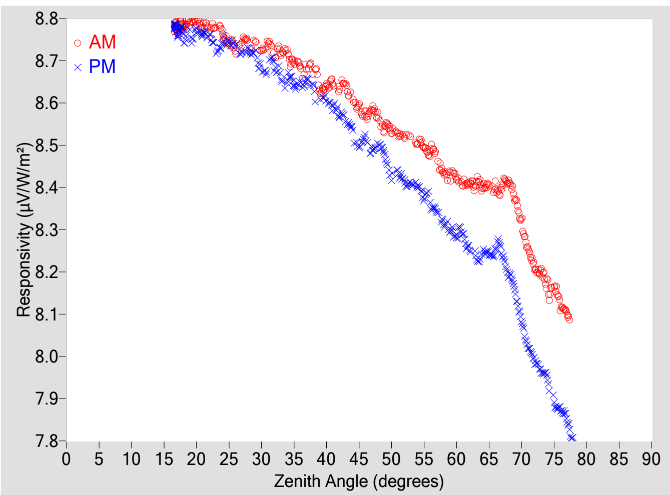


Figure 2. Responsivity vs Local Standard Time

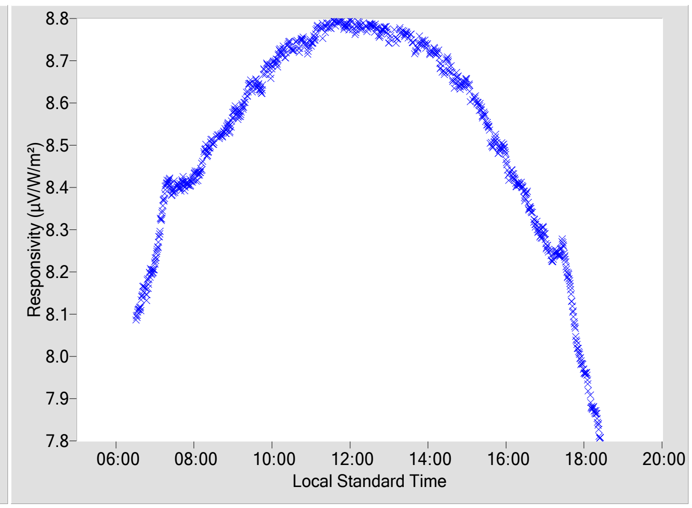


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5719	0.32	97.21	8.5152	0.31	262.85
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5662	0.32	95.57	8.4991	0.31	264.58
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5353	0.33	93.94	8.4263	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5200	0.33	92.28	8.4128	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5055	0.34	90.79	8.4037	0.33	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4861	0.35	89.31	8.3528	0.34	270.83
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4368	0.35	87.87	8.3157	0.35	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4234	0.36	86.45	8.2832	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4087	0.37	85.05	8.2558	0.37	275.03
18	8.7821	0.29	155.28	8.7602	0.29	204.78	64	8.4011	0.38	83.68	8.2470	0.38	276.52
20	8.7928	0.29	143.13	8.7709	0.29	216.96	66	8.3961	0.40	82.29	8.2552	0.40	277.87
22	8.7725	0.29	134.43	8.7580	0.29	226.01	68	8.4113	0.42	80.87	8.1929	0.42	279.24
24	8.7641	0.29	128.43	8.7425	0.29	231.38	70	8.3194	N/A	79.53	8.0862	0.44	280.59
26	8.7266	0.30	123.79	8.7356	0.29	236.45	72	8.2118	N/A	78.13	7.9889	N/A	281.99
28	8.7377	0.30	119.39	8.7256	0.29	240.78	74	8.1610	N/A	76.72	7.9427	N/A	283.39
30	8.7255	0.30	115.74	8.6827	0.29	244.17	76	8.1231	N/A	75.36	7.8739	N/A	284.80
32	8.7111	0.30	112.59	8.6867	0.30	247.37	78	N/A	N/A	N/A	7.8076	N/A	286.09
34	8.7201	0.30	109.93	8.6583	0.30	250.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6882	0.31	107.50	8.6440	0.30	252.77	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6674	0.31	105.12	8.6292	0.30	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6400	0.31	102.93	8.6062	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6323	0.31	101.02	8.5700	0.31	259.18	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6122	0.32	99.04	8.5318	0.31	261.05	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

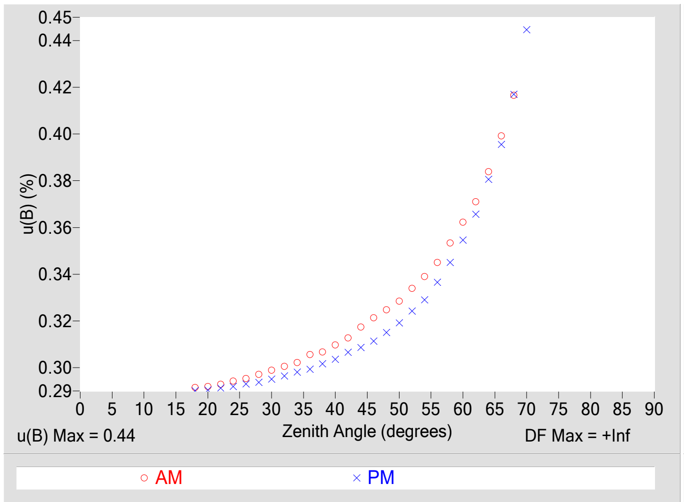


Figure 4. Residuals from Spline Interpolation

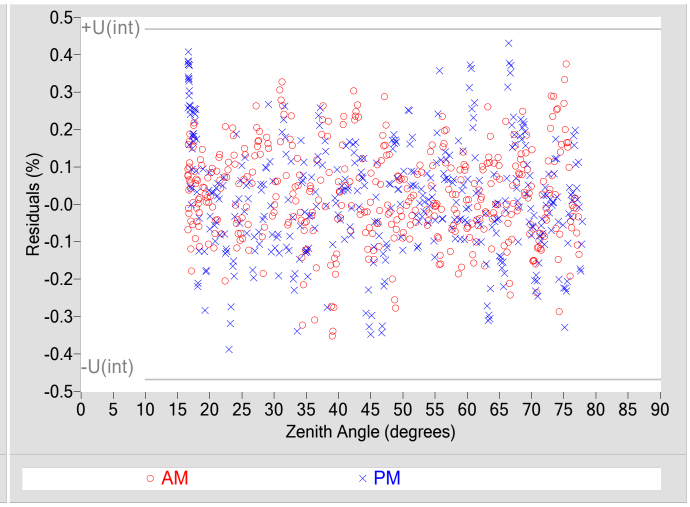


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	15142
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

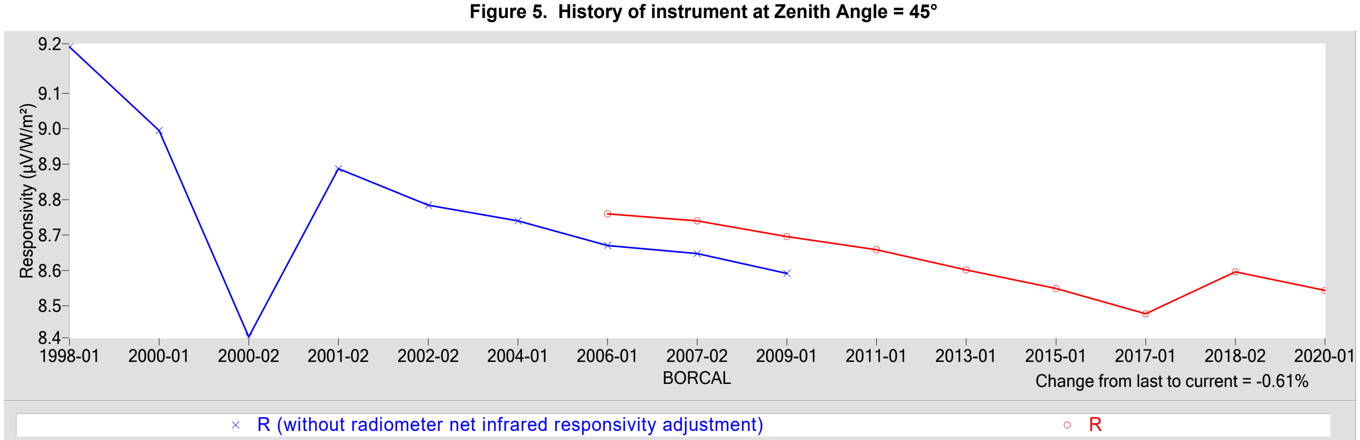
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.5440	0.62861

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+2.1 / -3.1
Expanded Uncertainty, U (%)	+2.8 / -3.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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* [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

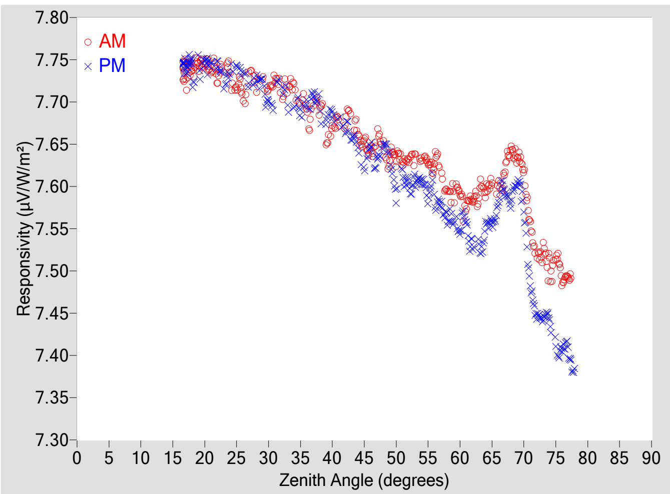


Figure 2. Responsivity vs Local Standard Time

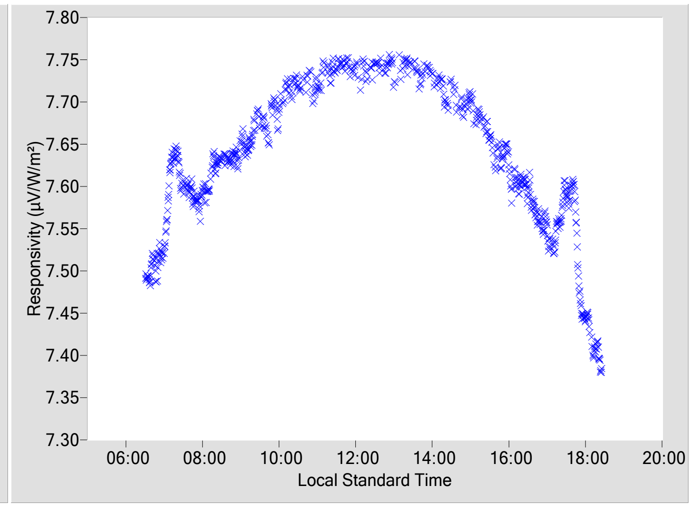


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6440	0.32	97.22	7.6481	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6481	0.33	95.50	7.6481	0.32	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6340	0.33	93.95	7.5936	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6322	0.33	92.34	7.6019	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6314	0.34	90.86	7.6059	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6275	0.35	89.32	7.5792	0.34	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5955	0.35	87.90	7.5623	0.35	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5917	0.36	86.45	7.5467	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5834	0.37	85.05	7.5325	0.37	275.04
18	7.7365	0.29	155.43	7.7386	0.29	204.45	64	7.5948	0.38	83.64	7.5508	0.38	276.47
20	7.7453	0.29	143.39	7.7486	0.29	217.61	66	7.5994	0.40	82.29	7.5827	0.40	277.87
22	7.7295	0.29	134.53	7.7442	0.29	225.52	68	7.6423	0.42	80.87	7.5828	0.42	279.24
24	7.7329	0.29	128.59	7.7391	0.29	231.60	70	7.6167	N/A	79.54	7.5724	0.44	280.59
26	7.7075	0.30	123.84	7.7333	0.29	236.53	72	7.5195	N/A	78.11	7.4472	N/A	282.00
28	7.7243	0.30	119.54	7.7268	0.29	240.62	74	7.5024	N/A	76.72	7.4397	N/A	283.40
30	7.7159	0.30	115.90	7.7017	0.30	244.09	76	7.4907	N/A	75.36	7.4089	N/A	284.80
32	7.7070	0.30	112.62	7.7134	0.30	247.74	78	N/A	N/A	N/A	7.3823	N/A	286.09
34	7.7151	0.30	109.92	7.6938	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6859	0.31	107.34	7.6969	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6915	0.31	104.99	7.6911	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6666	0.31	103.05	7.6843	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6748	0.31	100.91	7.6681	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6626	0.32	99.01	7.6457	0.31	261.04	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

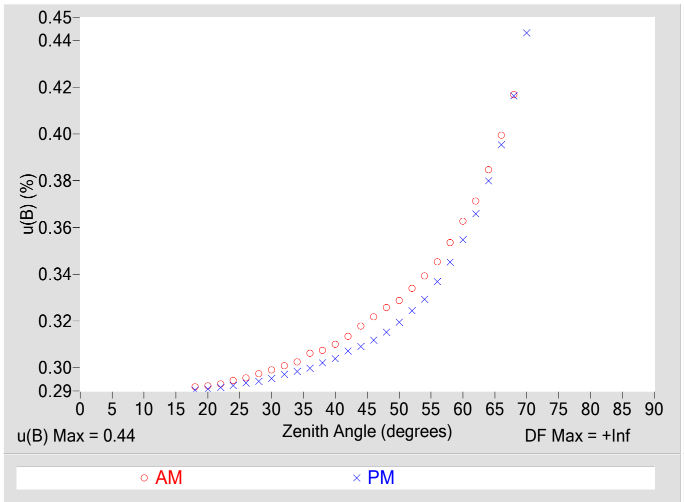


Figure 4. Residuals from Spline Interpolation

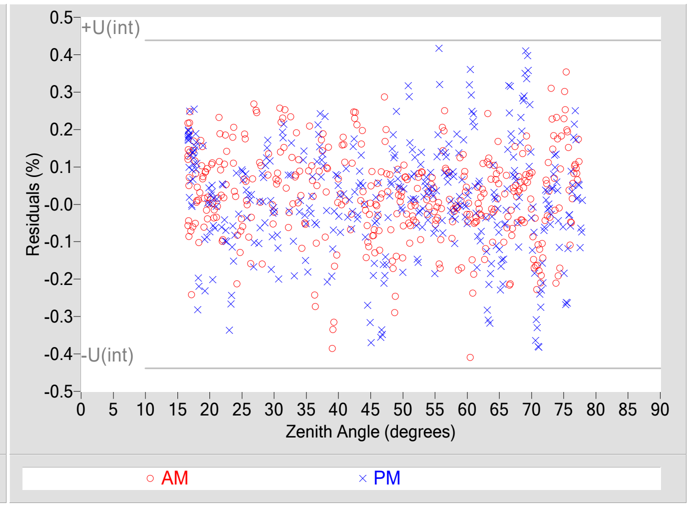


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	17486
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

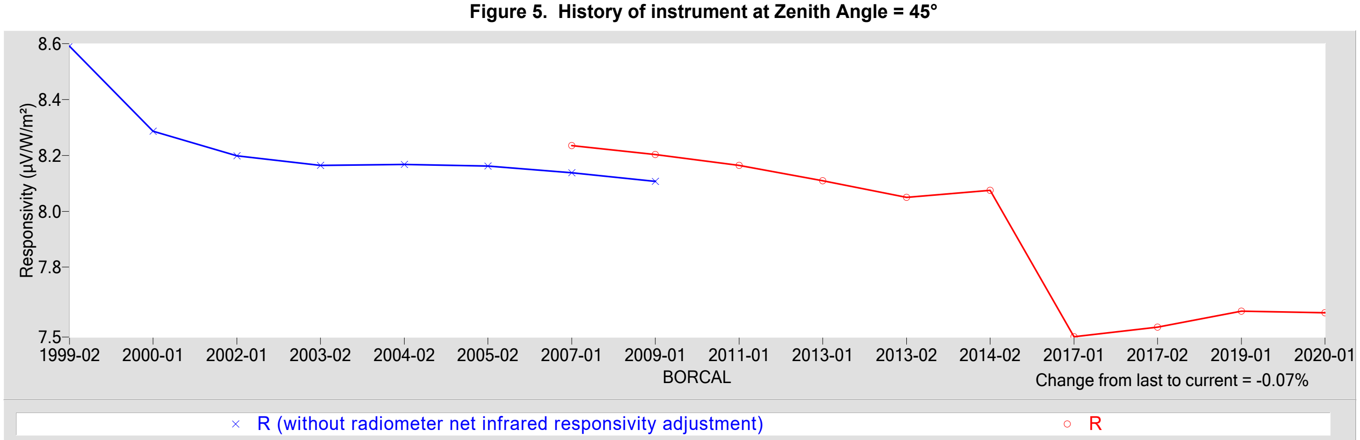
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6370	0.57412

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.0 / -1.2
Expanded Uncertainty, U (%)	+1.7 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	30674F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30674F3 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

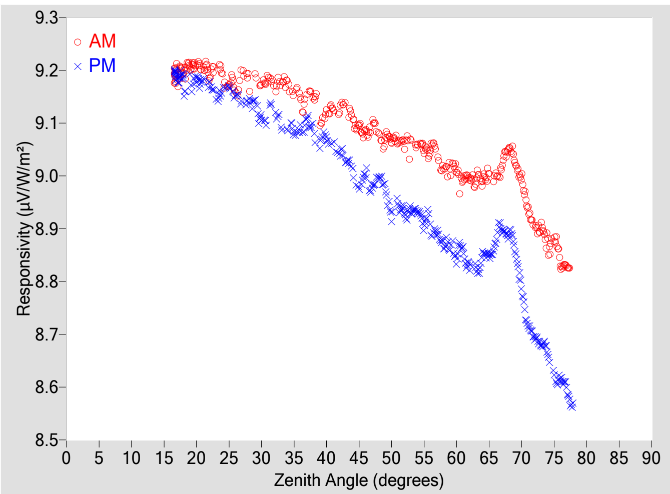


Figure 2. Responsivity vs Local Standard Time

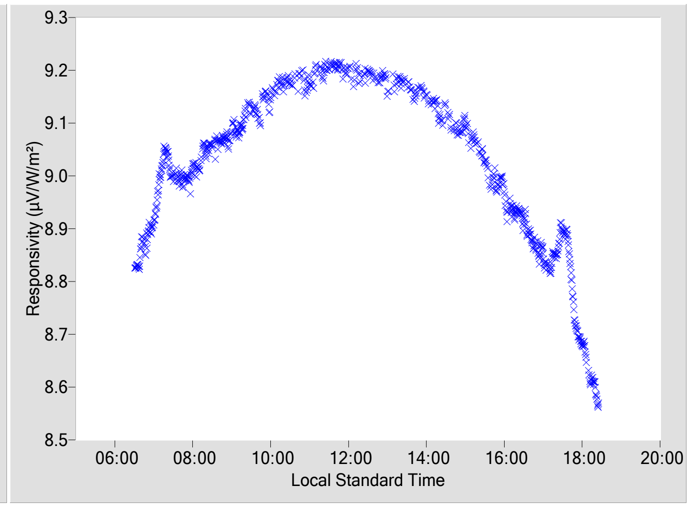


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	9.0839	0.32	97.22	9.0048	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0808	0.32	95.50	8.9973	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0678	0.33	93.95	8.9280	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0631	0.33	92.34	8.9313	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0571	0.34	90.86	8.9318	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0498	0.34	89.32	8.8940	0.33	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0139	0.35	87.90	8.8696	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0121	0.36	86.45	8.8444	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9954	0.37	85.05	8.8315	0.36	275.04
18	9.1967	0.29	155.43	9.1772	0.29	204.45	64	8.9929	0.38	83.64	8.8488	0.38	276.47
20	9.2114	0.29	143.39	9.1848	0.29	217.61	66	8.9982	0.40	82.29	8.8765	0.39	277.87
22	9.1901	0.29	134.53	9.1728	0.29	225.52	68	9.0505	0.41	80.87	8.8884	0.41	279.24
24	9.1908	0.29	128.59	9.1626	0.29	231.60	70	8.9961	N/A	79.54	8.7896	0.44	280.59
26	9.1630	0.29	123.84	9.1511	0.29	236.53	72	8.9052	N/A	78.11	8.6933	N/A	282.00
28	9.1834	0.30	119.54	9.1421	0.29	240.62	74	8.8706	N/A	76.72	8.6619	N/A	283.40
30	9.1744	0.30	115.90	9.1109	0.29	244.09	76	8.8375	N/A	75.36	8.6158	N/A	284.80
32	9.1652	0.30	112.62	9.1139	0.30	247.74	78	N/A	N/A	N/A	8.5657	N/A	286.09
34	9.1724	0.30	109.92	9.0875	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1429	0.31	107.34	9.0875	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1471	0.31	104.99	9.0810	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1168	0.31	103.05	9.0685	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1233	0.31	100.91	9.0434	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1095	0.32	99.01	9.0095	0.31	261.04	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

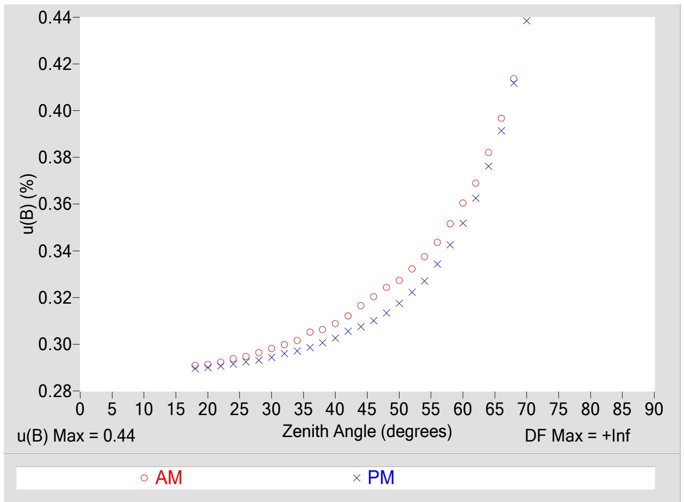


Figure 4. Residuals from Spline Interpolation

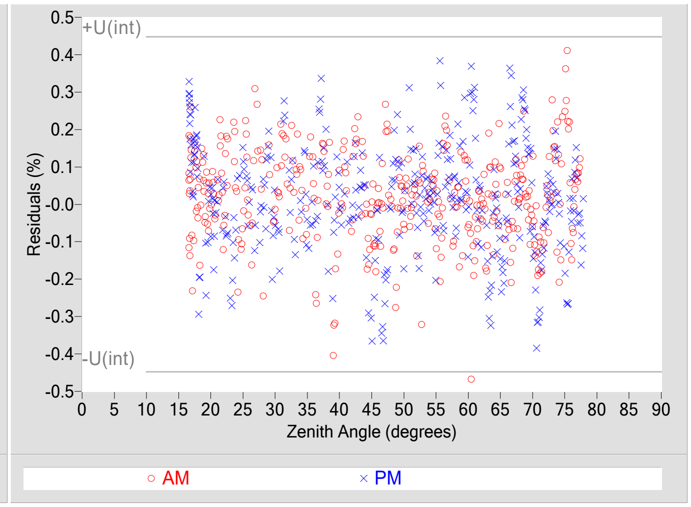


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	15811
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

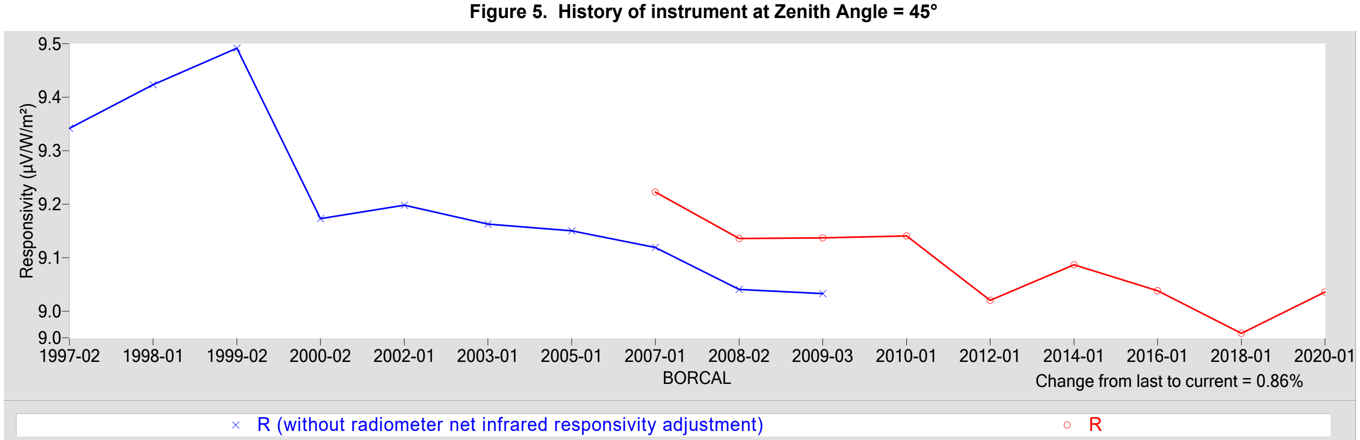
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0356	0.61487

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.5 / -2.1
Expanded Uncertainty, U (%)	+2.2 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	30720E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

30720E6 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

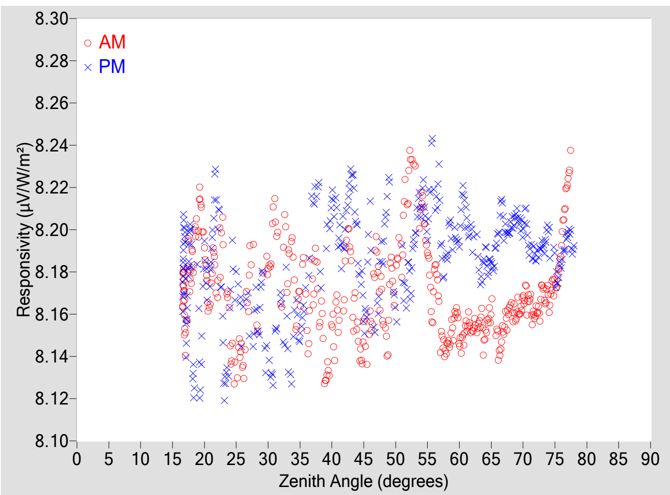


Figure 2. Responsivity vs Local Standard Time

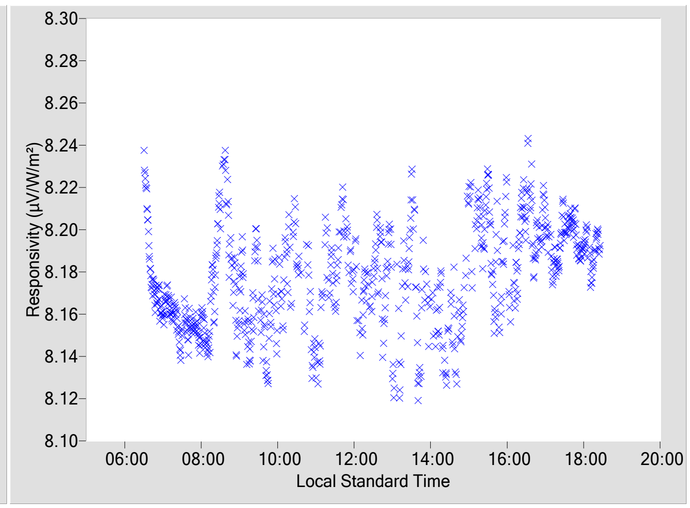


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1552	0.29	97.21	8.2005	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1612	0.29	95.60	8.1921	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1779	0.29	93.87	8.1629	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2224	0.29	92.31	8.1777	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2112	0.29	90.82	8.2116	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1695	0.30	89.36	8.2238	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1441	0.30	87.88	8.1873	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1479	0.30	86.41	8.1995	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1522	0.30	84.99	8.1972	0.29	275.07
18	8.1803	0.28	155.81	8.1720	0.28	204.70	64	8.1480	0.30	83.64	8.1886	0.30	276.46
20	8.1898	0.28	142.42	8.1819	0.28	217.26	66	8.1471	0.30	82.25	8.1959	0.30	277.83
22	8.1713	0.28	134.63	8.2132	0.28	225.36	68	8.1631	0.30	80.93	8.2015	0.30	279.24
24	8.1506	0.29	128.41	8.1551	0.28	231.51	70	8.1660	N/A	79.50	8.2028	0.30	280.63
26	8.1366	0.29	123.50	8.1587	0.28	236.26	72	8.1604	N/A	78.13	8.1873	N/A	281.99
28	8.1548	0.29	118.97	8.1599	0.28	240.74	74	8.1680	N/A	76.76	8.1972	N/A	283.39
30	8.1827	0.29	115.89	8.1417	0.28	244.17	76	8.1939	N/A	75.31	8.1839	N/A	284.71
32	8.1641	0.29	112.62	8.1675	0.28	247.39	78	N/A	N/A	N/A	8.1915	N/A	286.14
34	8.1864	0.29	110.00	8.1556	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1543	0.29	107.27	8.1725	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1607	0.29	105.09	8.1988	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1534	0.29	102.80	8.2124	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1763	0.29	100.91	8.1995	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1520	0.29	99.02	8.1944	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

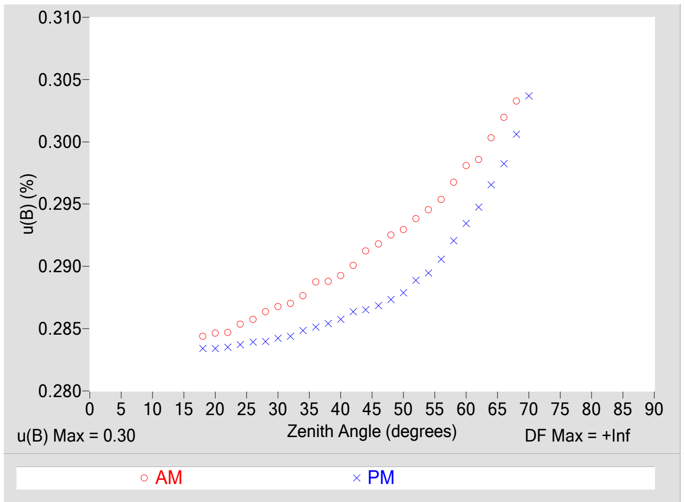


Figure 4. Residuals from Spline Interpolation

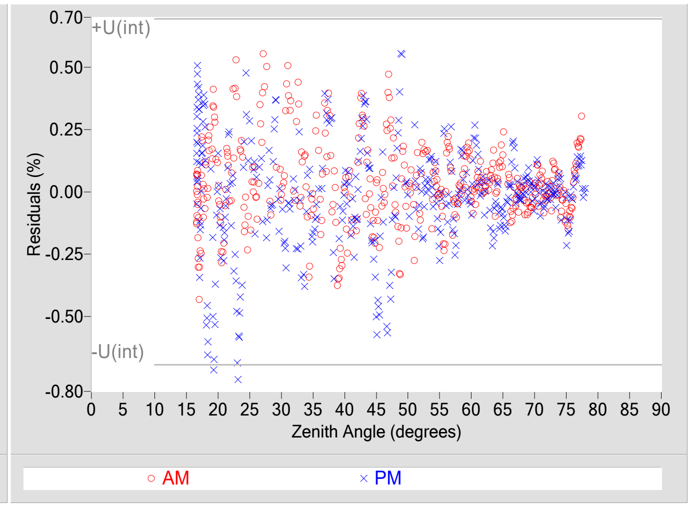


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.35
Combined Standard Uncertainty, u(c) (%)	±0.46
Effective degrees of freedom, DF(c)	2255
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.90
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

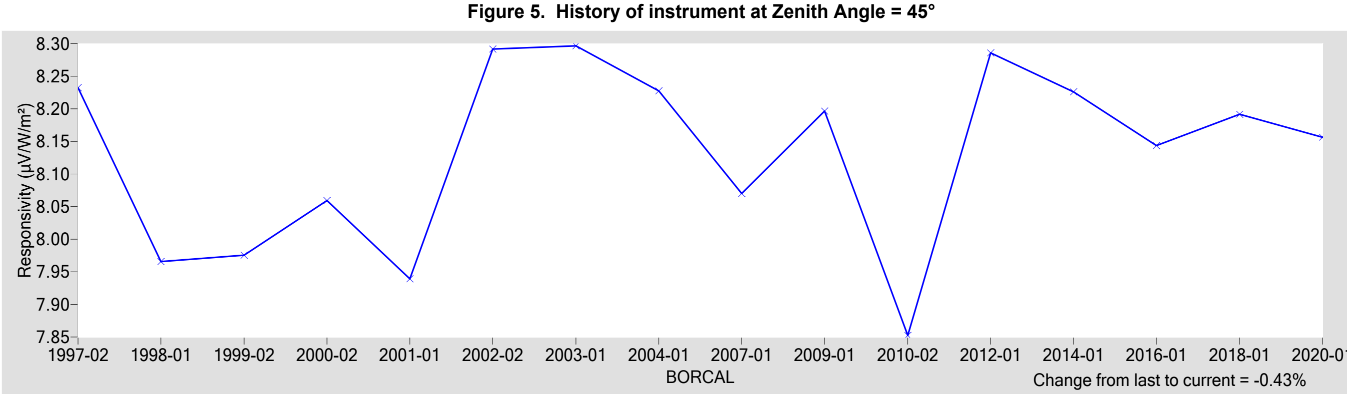
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1562	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.83 / -0.18
Expanded Uncertainty, U (%)	+1.4 / -0.76
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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 - 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

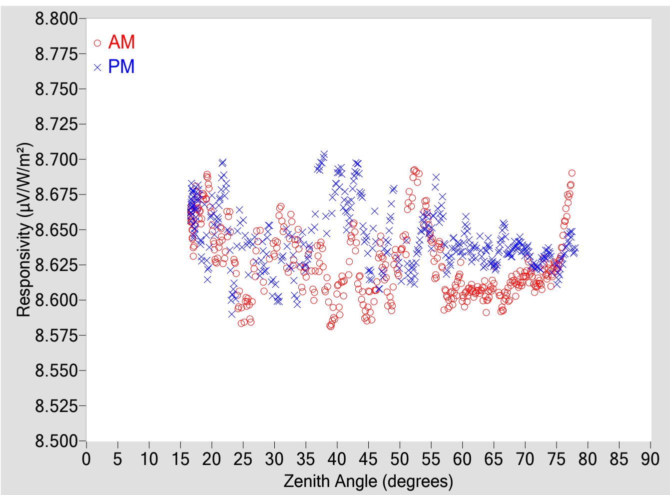


Figure 2. Responsivity vs Local Standard Time

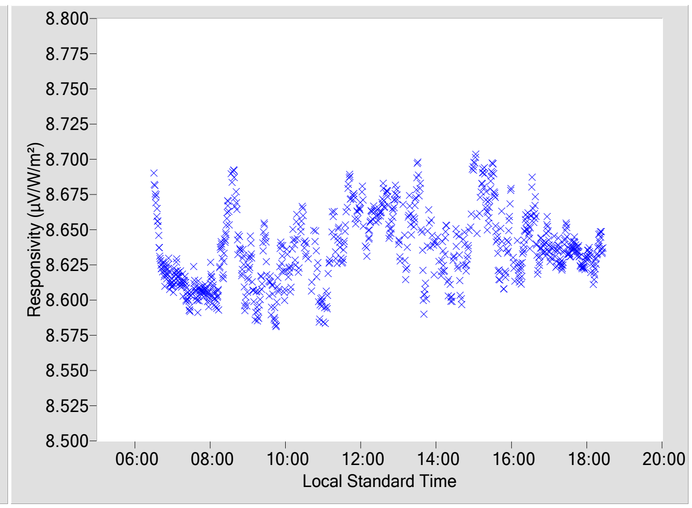


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6050	0.29	97.21	8.6518	0.29	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6058	0.29	95.60	8.6402	0.29	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6296	0.29	93.87	8.6210	0.29	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6796	0.29	92.31	8.6195	0.29	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6649	0.29	90.82	8.6537	0.29	269.30
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6283	0.30	89.36	8.6691	0.29	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6004	0.30	87.88	8.6282	0.29	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6022	0.30	86.41	8.6384	0.29	273.71
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6046	0.30	84.99	8.6357	0.29	275.07
18	8.6618	0.28	155.81	8.6632	0.28	204.70	64	8.5999	0.30	83.64	8.6392	0.30	276.46
20	8.6517	0.28	142.42	8.6627	0.28	217.26	66	8.5998	0.30	82.25	8.6390	0.30	277.83
22	8.6299	0.28	134.63	8.6851	0.28	225.36	68	8.6137	0.30	80.93	8.6354	0.30	279.24
24	8.6074	0.29	128.41	8.6294	0.28	231.51	70	8.6182	N/A	79.50	8.6351	0.30	280.63
26	8.5921	0.29	123.50	8.6337	0.28	236.26	72	8.6121	N/A	78.13	8.6233	N/A	281.99
28	8.6127	0.29	118.97	8.6299	0.28	240.74	74	8.6194	N/A	76.76	8.6294	N/A	283.39
30	8.6365	0.29	115.89	8.6128	0.28	244.17	76	8.6459	N/A	75.31	8.6292	N/A	284.71
32	8.6213	0.29	112.62	8.6451	0.28	247.39	78	N/A	N/A	N/A	8.6356	N/A	286.14
34	8.6367	0.29	110.00	8.6341	0.28	250.24	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6094	0.29	107.27	8.6495	0.29	252.56	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6122	0.29	105.09	8.6780	0.29	255.08	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6051	0.29	102.80	8.6879	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6331	0.29	100.91	8.6640	0.29	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6010	0.29	99.02	8.6648	0.29	261.02	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

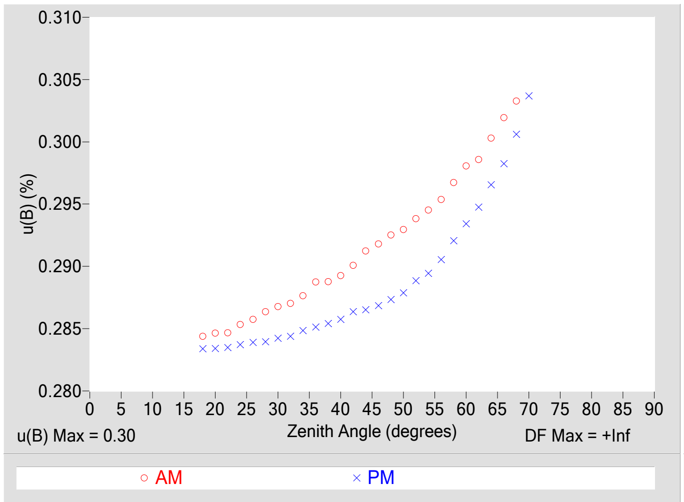


Figure 4. Residuals from Spline Interpolation

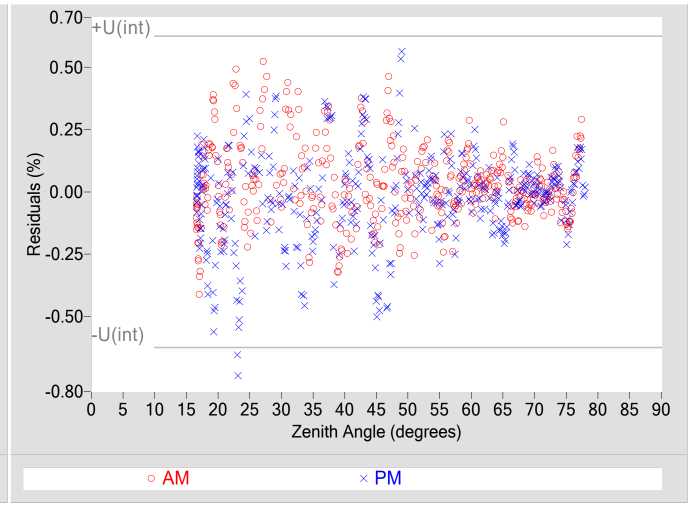


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.44
Effective degrees of freedom, DF(c)	2737
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.85
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

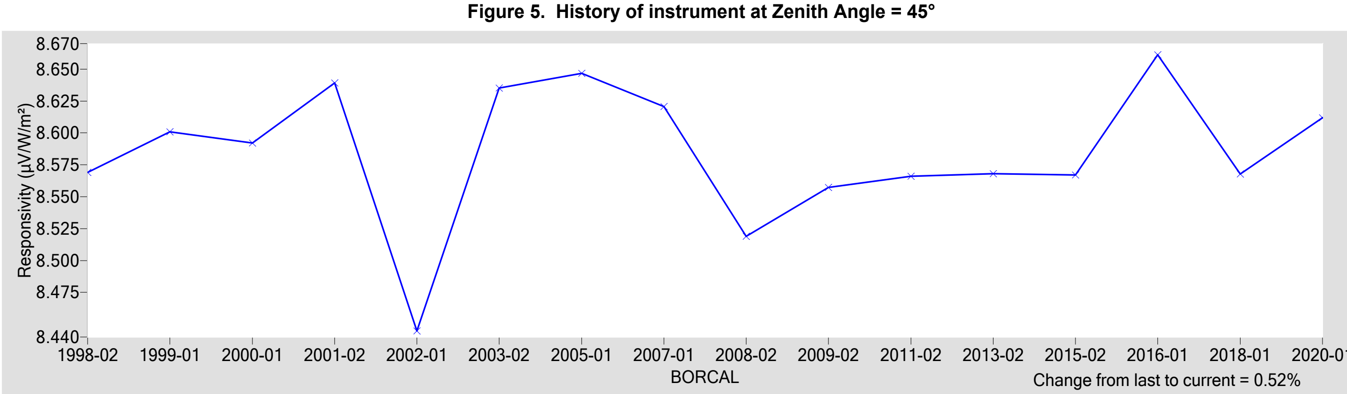
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6119	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.88 / -0.13
Expanded Uncertainty, U (%)	+1.5 / -0.72
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:**	30797F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30797F3 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

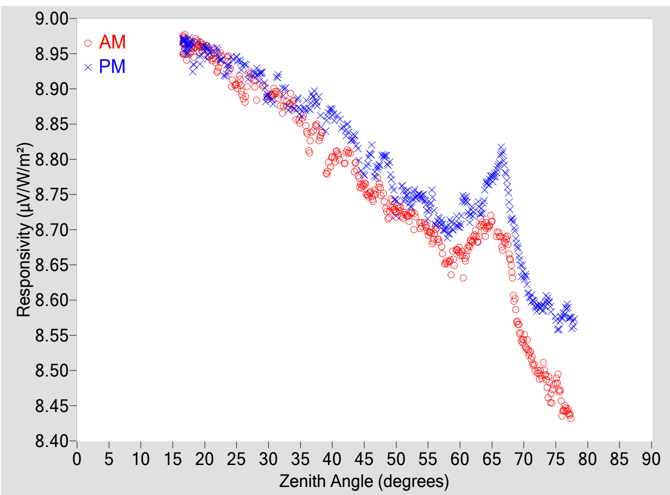


Figure 2. Responsivity vs Local Standard Time

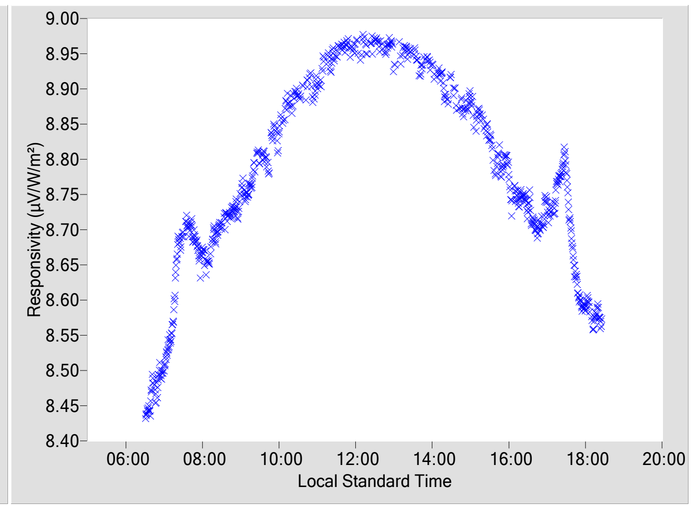


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7496	0.32	97.22	8.8106	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7456	0.32	95.50	8.8046	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7259	0.33	93.95	8.7365	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7186	0.33	92.34	8.7437	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7054	0.34	90.86	8.7467	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6937	0.34	89.32	8.7138	0.33	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6536	0.35	87.90	8.6966	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6685	0.36	86.45	8.7097	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6849	0.37	85.05	8.7264	0.36	275.04
18	8.9554	0.29	155.43	8.9522	0.29	204.45	64	8.7019	0.38	83.64	8.7594	0.38	276.47
20	8.9612	0.29	143.39	8.9589	0.29	217.61	66	8.6932	0.40	82.29	8.7940	0.39	277.87
22	8.9323	0.29	134.53	8.9520	0.29	225.52	68	8.6474	0.41	80.87	8.7184	0.41	279.24
24	8.9261	0.29	128.59	8.9399	0.29	231.60	70	8.5425	N/A	79.54	8.6377	0.44	280.59
26	8.8914	0.30	123.84	8.9316	0.29	236.53	72	8.4986	N/A	78.11	8.5894	N/A	282.00
28	8.9030	0.30	119.54	8.9240	0.29	240.62	74	8.4715	N/A	76.72	8.5943	N/A	283.40
30	8.8889	0.30	115.90	8.8907	0.29	244.09	76	8.4500	N/A	75.36	8.5772	N/A	284.80
32	8.8707	0.30	112.62	8.8960	0.30	247.74	78	N/A	N/A	N/A	8.5679	N/A	286.09
34	8.8729	0.30	109.92	8.8720	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8339	0.31	107.34	8.8743	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8304	0.31	104.99	8.8657	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7982	0.31	103.05	8.8649	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7993	0.31	100.91	8.8409	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7784	0.32	99.01	8.8111	0.31	261.04	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

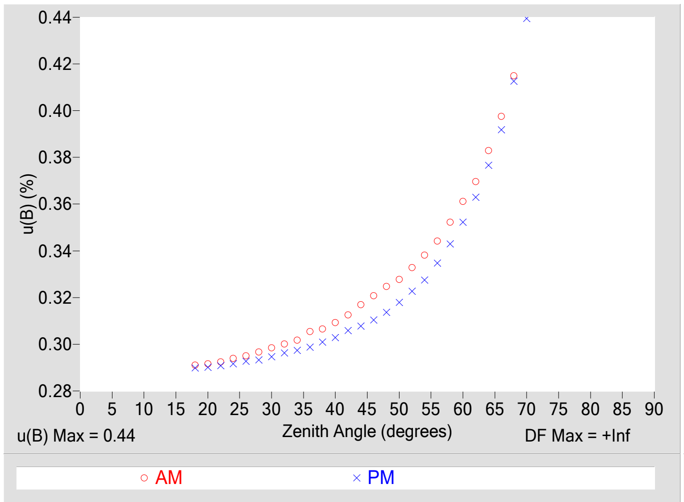


Figure 4. Residuals from Spline Interpolation

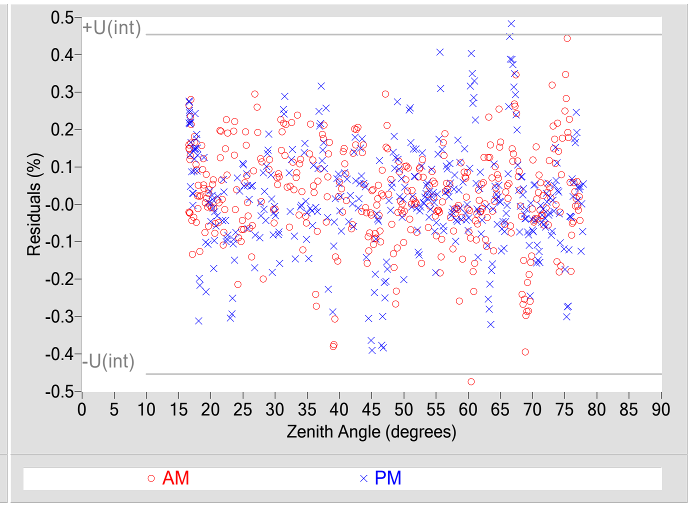


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	15254
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

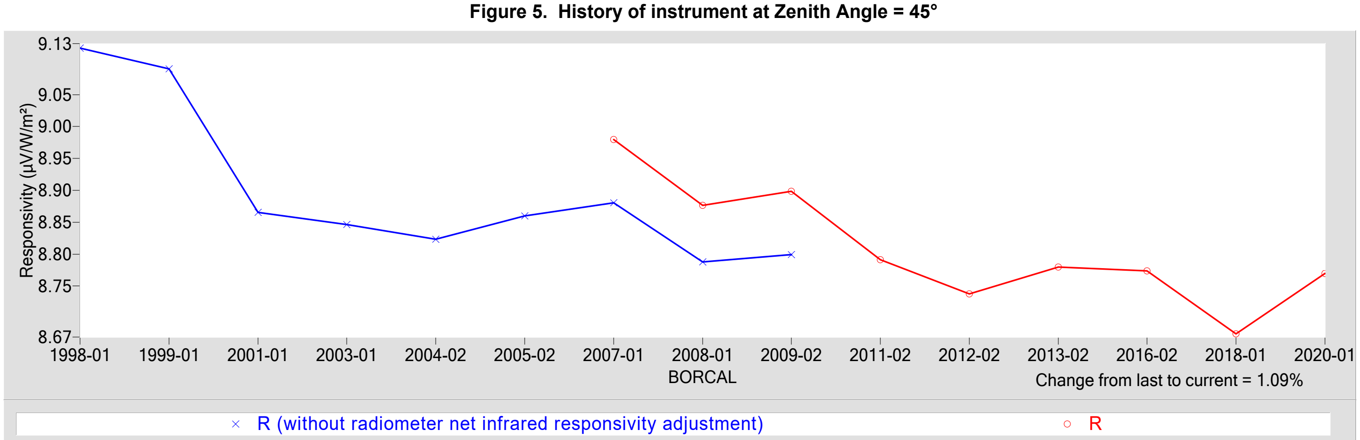
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7698	0.61400

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.4 / -1.3
Expanded Uncertainty, U (%)	+2.1 / -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:**	30811F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30811F3 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

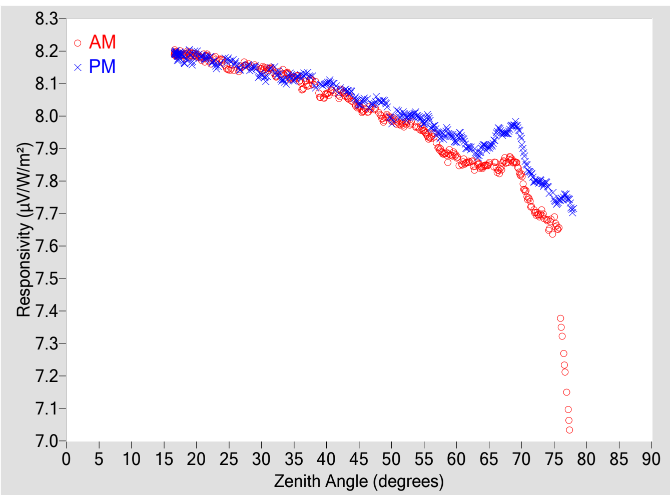


Figure 2. Responsivity vs Local Standard Time

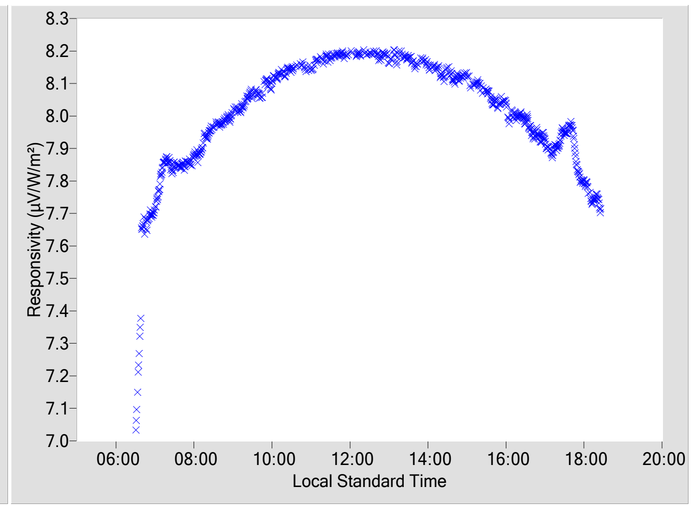


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0192	0.32	97.32	8.0516	0.31	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0069	0.32	95.41	8.0462	0.31	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9883	0.33	93.92	7.9876	0.32	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9753	0.33	92.38	8.0045	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9656	0.34	90.89	8.0011	0.33	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9336	0.34	89.33	7.9743	0.33	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8844	0.35	87.85	7.9404	0.34	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8755	0.36	86.46	7.9269	0.35	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8582	0.37	85.11	7.9028	0.36	275.05
18	8.1875	0.29	155.12	8.1754	0.29	204.90	64	7.8428	0.38	83.65	7.9042	0.38	276.44
20	8.1862	0.29	142.73	8.1965	0.29	216.66	66	7.8450	0.40	82.27	7.9381	0.39	277.84
22	8.1714	0.29	134.57	8.1817	0.29	225.42	68	7.8655	0.41	80.86	7.9547	0.41	279.26
24	8.1714	0.29	128.70	N/A	N/A	N/A	70	7.8124	N/A	79.51	7.9197	0.44	280.61
26	8.1405	0.30	124.08	8.1604	0.29	236.55	72	7.7028	N/A	78.07	7.8016	N/A	281.97
28	8.1556	0.30	119.22	8.1515	0.29	240.60	74	7.6717	N/A	76.74	7.7834	N/A	283.37
30	8.1462	0.30	115.74	8.1274	0.29	244.17	76	7.4263	N/A	75.31	7.7435	N/A	284.77
32	8.1245	0.30	112.54	8.1417	0.30	247.51	78	N/A	N/A	N/A	7.7097	N/A	286.10
34	8.1318	0.30	109.93	8.1120	0.30	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0994	0.31	107.32	8.1224	0.30	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1051	0.31	105.16	8.1078	0.30	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0684	0.31	102.89	8.1011	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0675	0.31	100.87	8.0781	0.31	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0452	0.32	99.04	8.0765	0.31	260.87	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

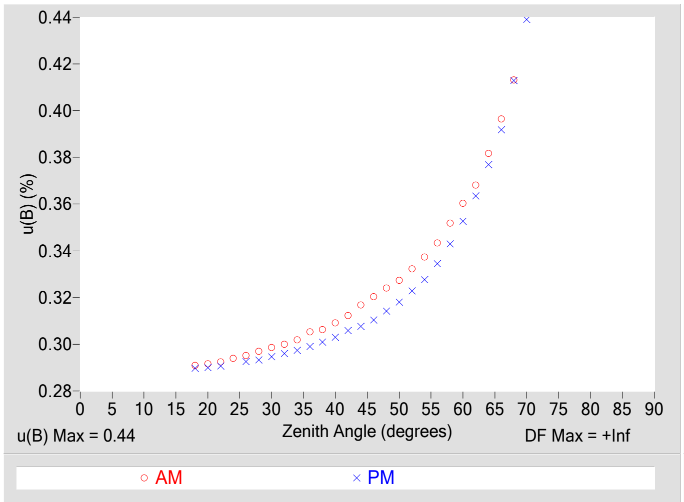


Figure 4. Residuals from Spline Interpolation

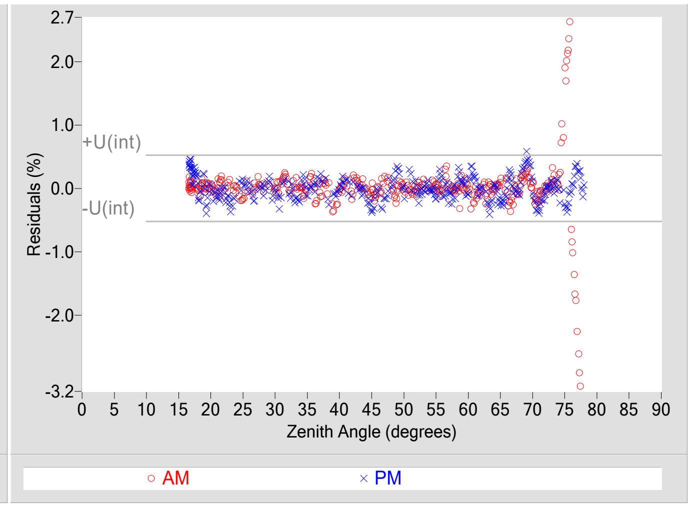


Table 3. Uncertainty using Spline Interpolation ‡

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)	10039
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

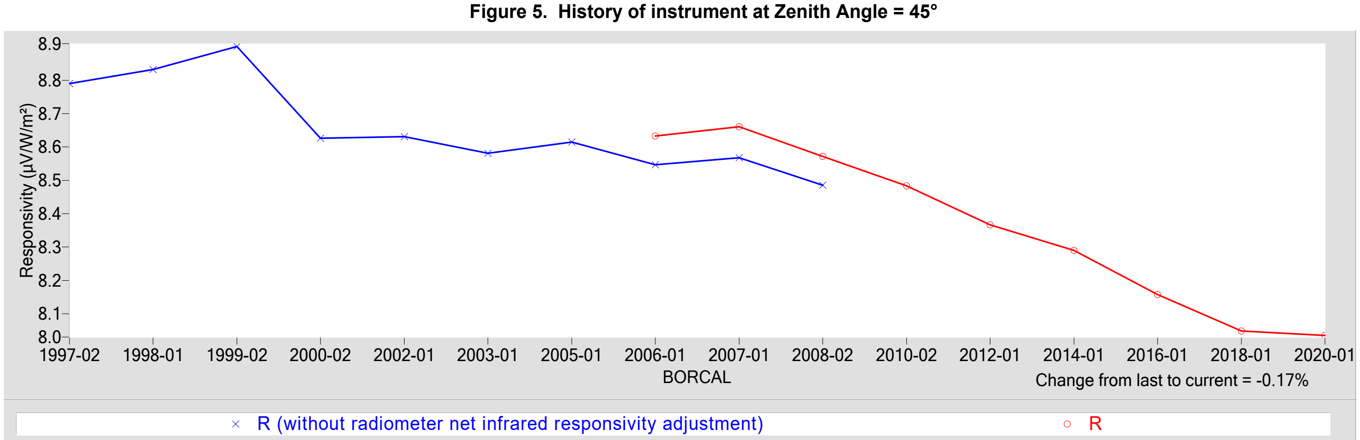
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0344	0.55500

† Rnet determination date: 04/05/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.4 / -2.0
Expanded Uncertainty, U (%)	+2.1 / -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: 30825F3
Calibration Date: 5/19/2020
Due Date: 5/19/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30825F3 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

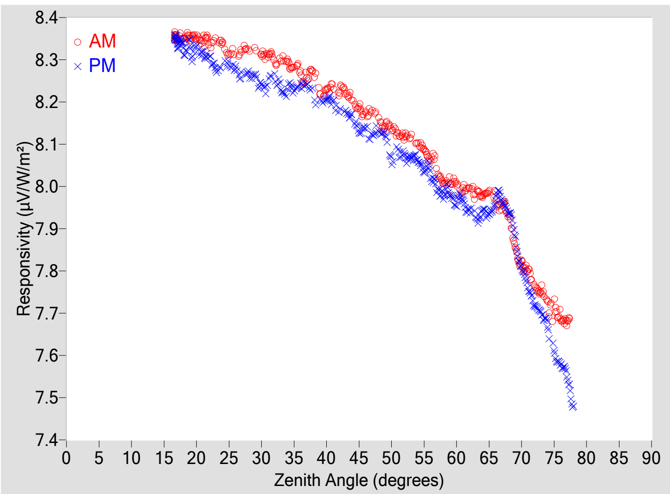


Figure 2. Responsivity vs Local Standard Time

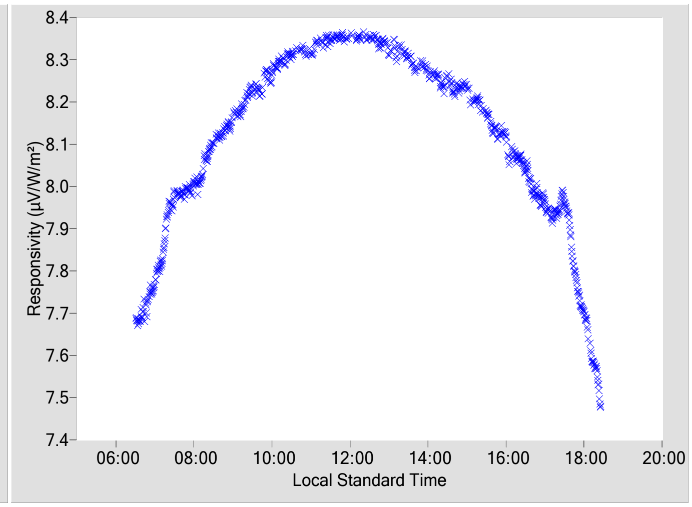


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	8.1741	0.32	97.32	8.1405	0.31	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1578	0.33	95.41	8.1291	0.32	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1366	0.33	93.92	8.0634	0.32	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1194	0.33	92.38	8.0757	0.33	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1025	0.34	90.89	8.0632	0.33	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0648	0.35	89.33	8.0263	0.34	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0094	0.35	87.85	7.9815	0.35	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0065	0.36	86.46	7.9615	0.36	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9960	0.37	85.11	7.9443	0.37	275.05
18	8.3502	0.29	155.12	8.3233	0.29	204.90	64	7.9775	0.38	83.65	7.9411	0.38	276.44
20	8.3520	0.29	142.73	8.3325	0.29	216.66	66	7.9746	0.40	82.27	7.9677	0.40	277.84
22	8.3390	0.29	134.57	8.3068	0.29	225.42	68	7.9301	0.42	80.86	7.9375	0.42	279.26
24	8.3414	0.29	128.70	N/A	N/A	N/A	70	7.8169	N/A	79.51	7.8058	0.45	280.61
26	8.3123	0.30	124.08	8.2775	0.29	236.55	72	7.7614	N/A	78.07	7.7195	N/A	281.97
28	8.3227	0.30	119.22	8.2669	0.29	240.60	74	7.7206	N/A	76.74	7.6673	N/A	283.37
30	8.3134	0.30	115.74	8.2427	0.30	244.17	76	7.6898	N/A	75.33	7.5791	N/A	284.77
32	8.2920	0.30	112.54	8.2577	0.30	247.51	78	N/A	N/A	N/A	7.4804	N/A	286.10
34	8.2966	0.30	109.93	8.2291	0.30	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2630	0.31	107.32	8.2382	0.30	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2683	0.31	105.16	8.2186	0.30	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2300	0.31	102.89	8.2061	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2271	0.31	100.87	8.1798	0.31	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2042	0.32	99.04	8.1710	0.31	260.87	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

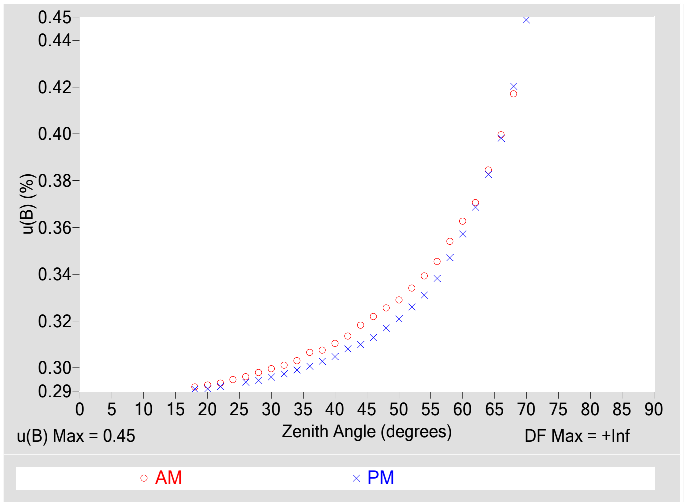


Figure 4. Residuals from Spline Interpolation

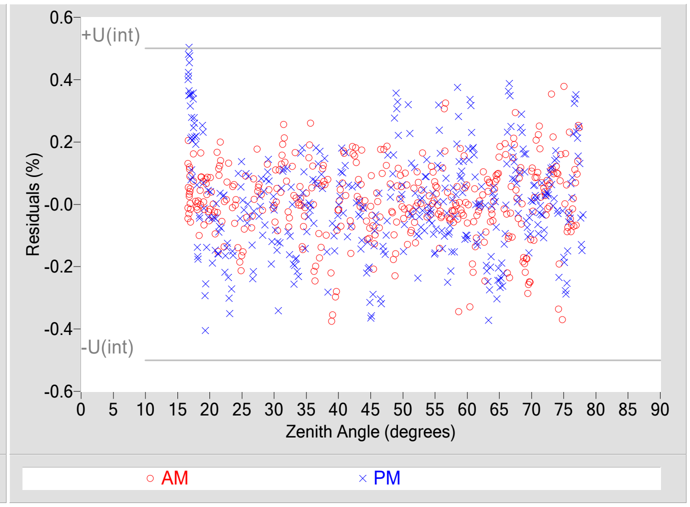


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	12186
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

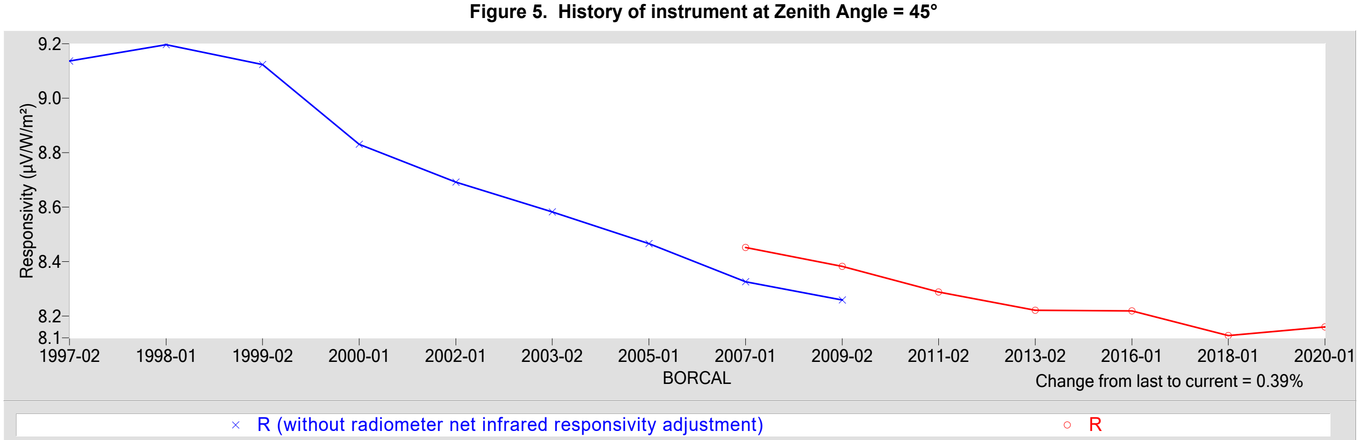
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1595	0.63800

† Rnet determination date: 06/28/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.9 / -2.4
Expanded Uncertainty, U (%)	+2.6 / -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:**	30890F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30890F3 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

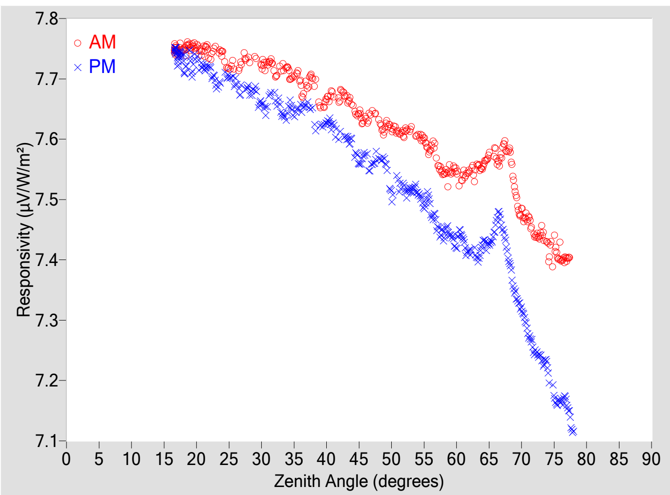


Figure 2. Responsivity vs Local Standard Time

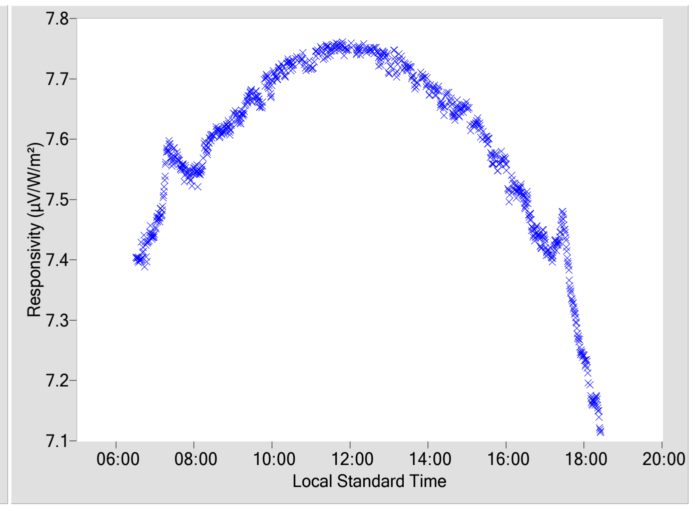


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6340	0.32	97.32	7.5758	0.31	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6292	0.33	95.41	7.5676	0.32	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6176	0.33	93.92	7.5089	0.32	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6109	0.33	92.38	7.5200	0.33	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6064	0.34	90.89	7.5132	0.33	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5830	0.35	89.33	7.4827	0.34	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5437	0.35	87.85	7.4425	0.35	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5468	0.36	86.46	7.4277	0.36	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5463	0.37	85.11	7.4142	0.37	275.05
18	7.7490	0.29	155.12	7.7230	0.29	204.90	64	7.5535	0.38	83.65	7.4249	0.38	276.44
20	7.7520	0.29	142.73	7.7367	0.29	216.66	66	7.5736	0.40	82.27	7.4572	0.40	277.84
22	7.7393	0.29	134.57	7.7196	0.29	225.42	68	7.5810	0.42	80.86	7.3996	0.42	279.26
24	7.7438	0.29	128.70	N/A	N/A	N/A	70	7.4775	N/A	79.51	7.3167	0.45	280.61
26	7.7159	0.30	124.08	7.6924	0.29	236.55	72	7.4395	N/A	78.07	7.2481	N/A	281.97
28	7.7313	0.30	119.22	7.6829	0.29	240.60	74	7.4212	N/A	76.74	7.2190	N/A	283.37
30	7.7238	0.30	115.74	7.6606	0.30	244.17	76	7.4056	N/A	75.33	7.1667	N/A	284.77
32	7.7070	0.30	112.54	7.6704	0.30	247.51	78	N/A	N/A	N/A	7.1162	N/A	286.10
34	7.7179	0.30	109.93	7.6430	0.30	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6885	0.31	107.32	7.6511	0.30	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6966	0.31	105.16	7.6383	0.30	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6671	0.31	102.89	7.6275	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6712	0.31	100.87	7.6061	0.31	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6568	0.32	99.04	7.6009	0.31	260.87	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

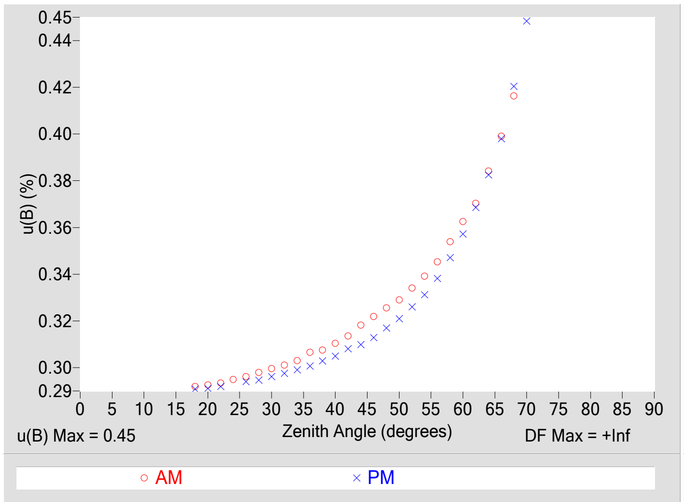


Figure 4. Residuals from Spline Interpolation

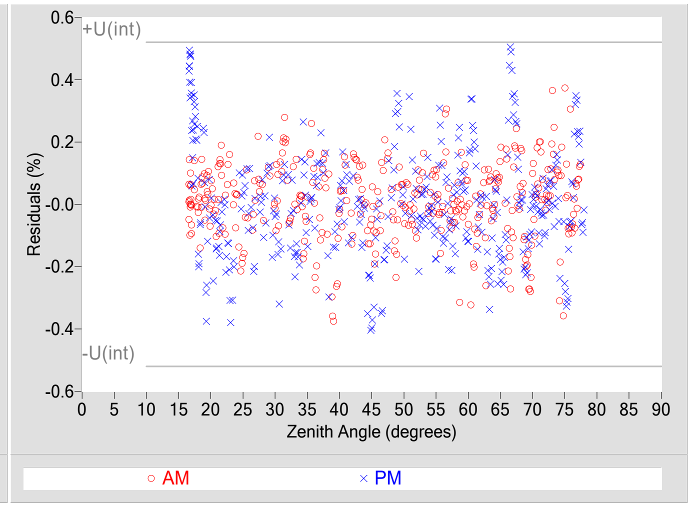


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	10857
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

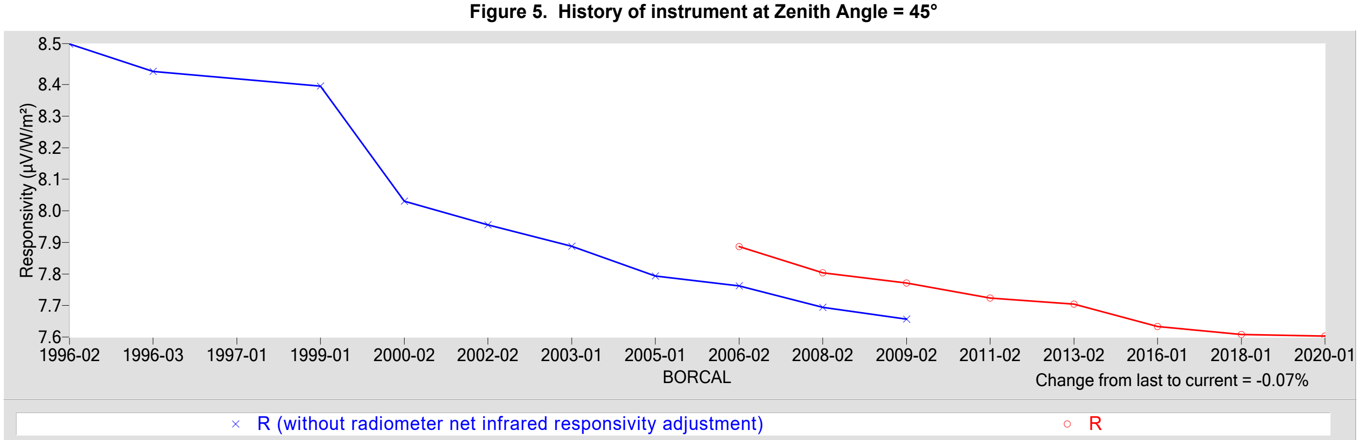
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6027	0.59445

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.6 / -2.3
Expanded Uncertainty, U (%)	+2.3 / -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:**	30895F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30895F3 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

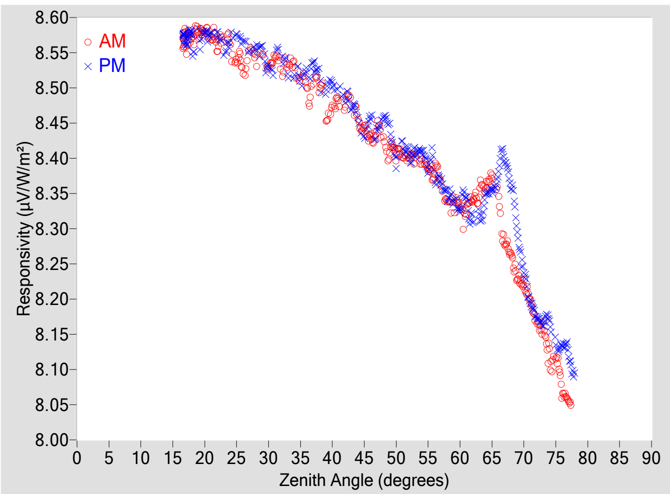


Figure 2. Responsivity vs Local Standard Time

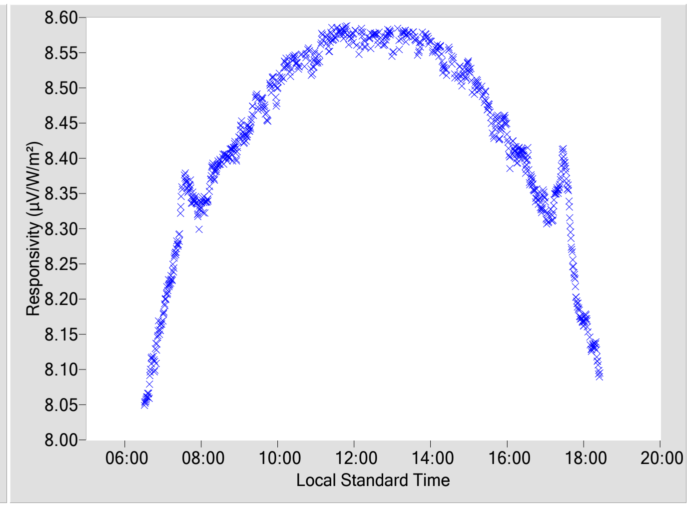


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4301	0.32	97.22	8.4582	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4271	0.32	95.50	8.4572	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4087	0.33	93.95	8.3985	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4025	0.33	92.34	8.4050	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3939	0.34	90.86	8.4098	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3800	0.34	89.32	8.3704	0.33	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3401	0.35	87.90	8.3469	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3329	0.36	86.45	8.3270	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3402	0.37	85.05	8.3154	0.36	275.04
18	8.5702	0.29	155.43	8.5677	0.29	204.45	64	8.3578	0.38	83.64	8.3444	0.37	276.47
20	8.5802	0.29	143.39	8.5795	0.29	217.61	66	8.3481	0.40	82.29	8.3829	0.39	277.87
22	8.5595	0.29	134.53	8.5758	0.29	225.52	68	8.2629	0.41	80.87	8.3598	0.41	279.24
24	8.5602	0.29	128.59	8.5714	0.29	231.60	70	8.2200	N/A	79.54	8.2409	0.44	280.59
26	8.5264	0.29	123.84	8.5650	0.29	236.53	72	8.1671	N/A	78.11	8.1737	N/A	282.00
28	8.5424	0.30	119.54	8.5570	0.29	240.62	74	8.1173	N/A	76.72	8.1665	N/A	283.40
30	8.5309	0.30	115.90	8.5309	0.29	244.09	76	8.0723	N/A	75.36	8.1344	N/A	284.80
32	8.5217	0.30	112.62	8.5396	0.30	247.74	78	N/A	N/A	N/A	8.0923	N/A	286.09
34	8.5293	0.30	109.92	8.5162	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4967	0.30	107.34	8.5217	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4991	0.31	104.99	8.5105	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4702	0.31	103.05	8.5038	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4748	0.31	100.91	8.4861	0.30	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4566	0.32	99.01	8.4576	0.31	261.04	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

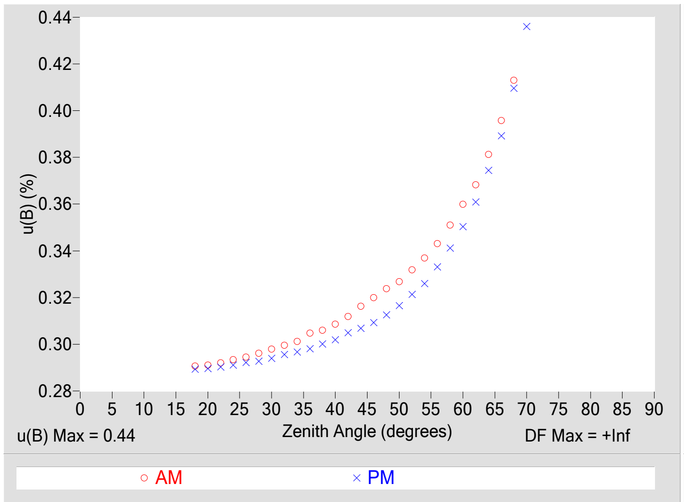


Figure 4. Residuals from Spline Interpolation

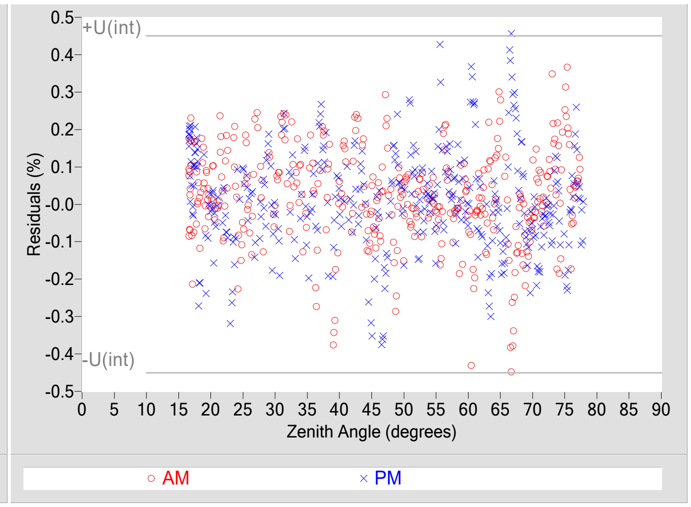


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	15259
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.96
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

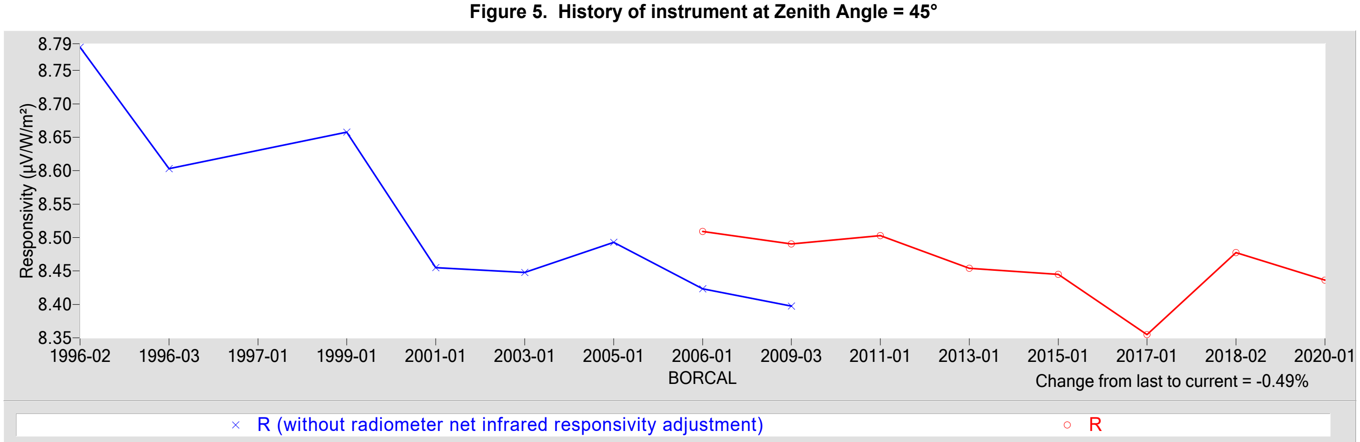
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4363	0.54800

† Rnet determination date: 04/04/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.2 / -1.3
Expanded Uncertainty, U (%)	+1.9 / -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
Manufacturer: Eppley
Model: PSP
Serial Number: 30897F3
Calibration Date: 5/19/2020
Due Date: 5/19/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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
30897F3 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

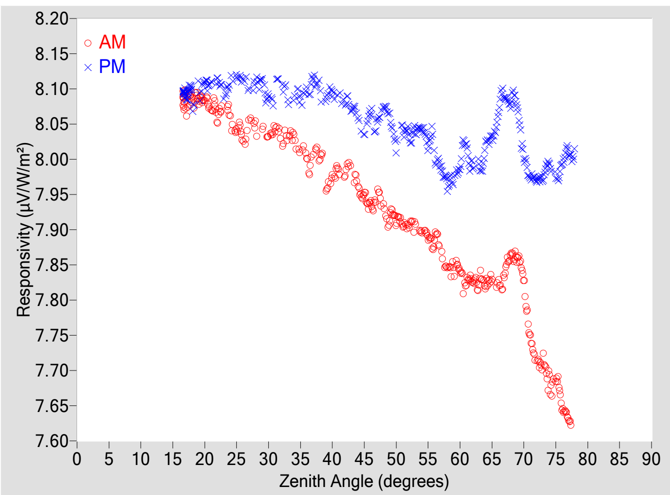


Figure 2. Responsivity vs Local Standard Time

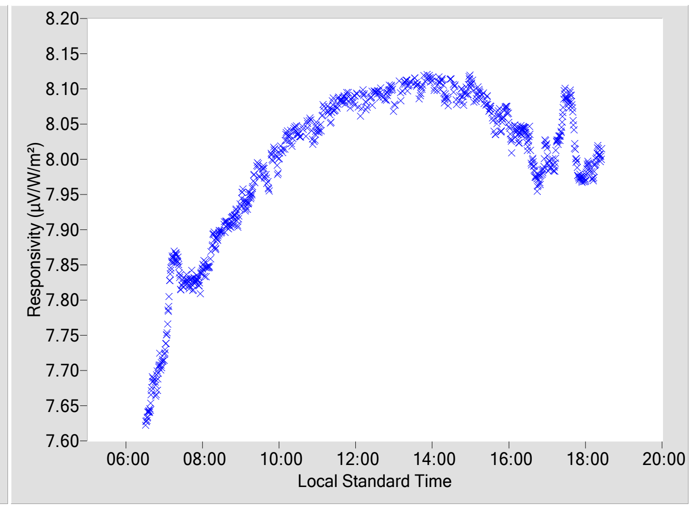


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9362	0.32	97.22	8.0670	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9333	0.33	95.50	8.0725	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9150	0.33	93.95	8.0228	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9071	0.33	92.34	8.0345	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8971	0.34	90.86	8.0427	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8846	0.35	89.32	7.9998	0.34	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8474	0.35	87.90	7.9653	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8416	0.36	86.45	7.9906	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8267	0.37	85.05	7.9927	0.37	275.04
18	8.0826	0.29	155.43	8.0915	0.29	204.45	64	7.8226	0.38	83.64	8.0184	0.38	276.47
20	8.0837	0.29	143.39	8.1101	0.29	217.61	66	7.8230	0.40	82.29	8.0679	0.39	277.87
22	8.0613	0.29	134.53	8.1117	0.29	225.52	68	7.8637	0.42	80.87	8.0819	0.42	279.24
24	8.0606	0.29	128.59	8.1122	0.29	231.60	70	7.8279	N/A	79.54	8.0068	0.44	280.59
26	8.0294	0.30	123.84	8.1117	0.29	236.53	72	7.7148	N/A	78.11	7.9706	N/A	282.00
28	8.0457	0.30	119.54	8.1108	0.29	240.62	74	7.6820	N/A	76.72	7.9909	N/A	283.40
30	8.0332	0.30	115.90	8.0893	0.30	244.09	76	7.6499	N/A	75.36	7.9948	N/A	284.80
32	8.0242	0.30	112.62	8.1010	0.30	247.74	78	N/A	N/A	N/A	8.0076	N/A	286.09
34	8.0284	0.30	109.92	8.0871	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9979	0.31	107.34	8.0962	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0014	0.31	104.99	8.0971	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9723	0.31	103.05	8.0931	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9789	0.31	100.91	8.0817	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9632	0.32	99.01	8.0598	0.31	261.04	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

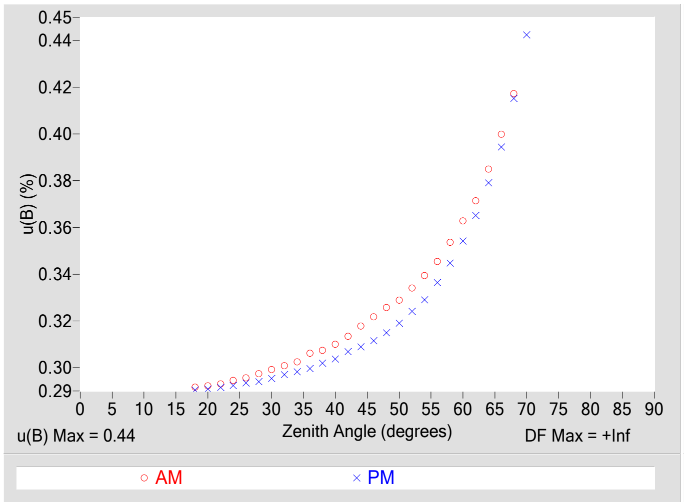


Figure 4. Residuals from Spline Interpolation

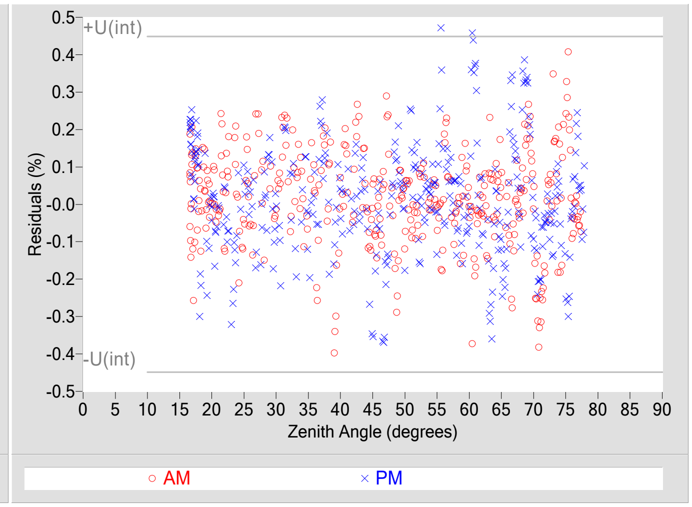


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	16120
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

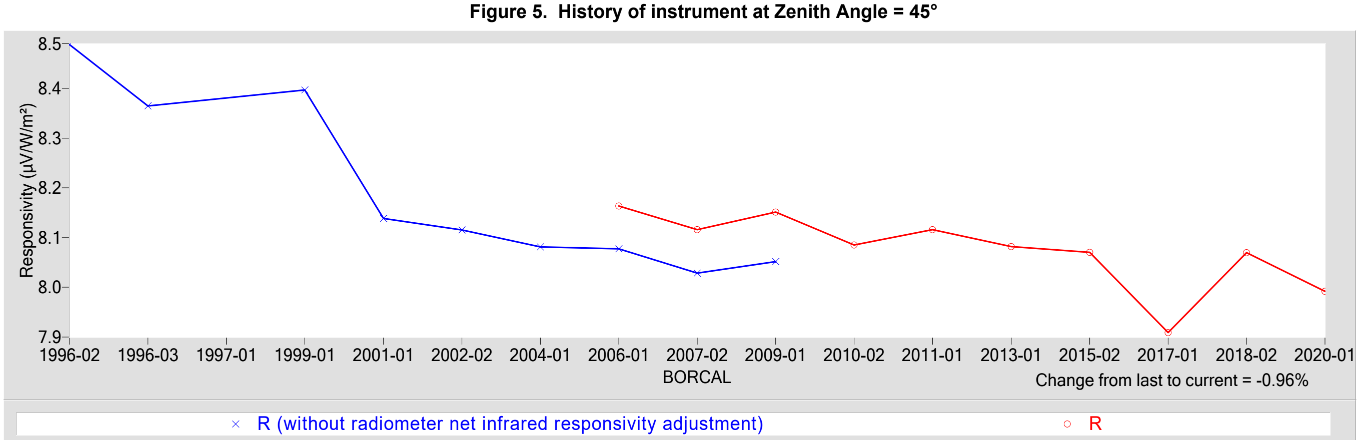
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9920	0.59840

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.4 / -1.9
Expanded Uncertainty, U (%)	+2.1 / -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:**	30899F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30899F3 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 - 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

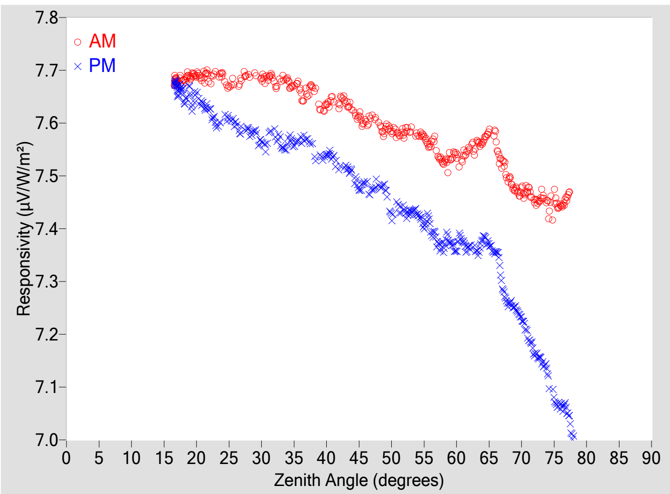


Figure 2. Responsivity vs Local Standard Time

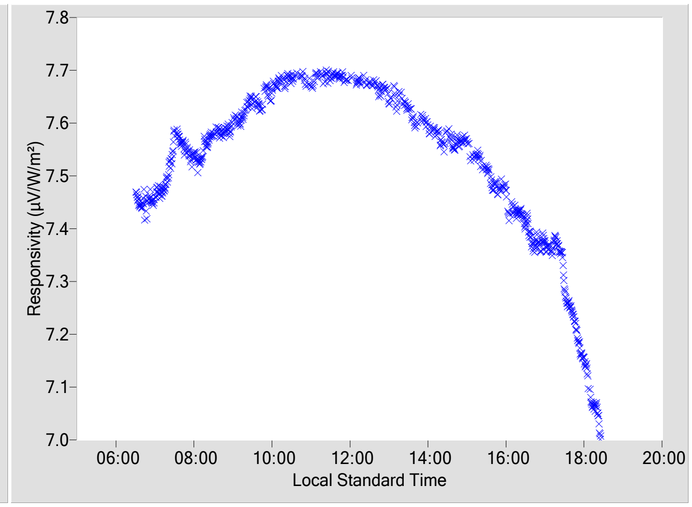


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6027	0.32	97.32	7.4879	0.31	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5983	0.32	95.41	7.4807	0.31	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5845	0.33	93.92	7.4258	0.32	266.19
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5823	0.33	92.38	7.4361	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5775	0.34	90.89	7.4286	0.33	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5590	0.34	89.33	7.4005	0.33	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5258	0.35	87.85	7.3670	0.34	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5395	0.36	86.46	7.3646	0.35	273.69
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5507	0.37	85.11	7.3656	0.36	275.05
18	7.6813	0.29	155.12	7.6500	0.29	204.90	64	7.5631	0.38	83.65	7.3798	0.38	276.44
20	7.6915	0.29	142.73	7.6569	0.29	216.66	66	7.5716	0.40	82.27	7.3552	0.39	277.84
22	7.6839	0.29	134.57	7.6267	0.29	225.42	68	7.4951	0.41	80.86	7.2579	0.41	279.26
24	7.6926	0.29	128.70	N/A	N/A	N/A	70	7.4712	N/A	79.51	7.2288	0.44	280.61
26	7.6726	0.30	124.08	7.5986	0.29	236.55	72	7.4511	N/A	78.07	7.1641	N/A	281.97
28	7.6894	0.30	119.22	7.5863	0.29	240.60	74	7.4435	N/A	76.74	7.1246	N/A	283.37
30	7.6851	0.30	115.74	7.5661	0.29	244.17	76	7.4429	N/A	75.33	7.0657	N/A	284.77
32	7.6712	0.30	112.54	7.5813	0.30	247.51	78	N/A	N/A	N/A	7.0066	N/A	286.10
34	7.6822	0.30	109.93	7.5605	0.30	250.14	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6568	0.31	107.32	7.5683	0.30	252.80	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6657	0.31	105.16	7.5489	0.30	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6361	0.31	102.89	7.5395	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6396	0.31	100.87	7.5151	0.31	259.17	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6247	0.32	99.04	7.5122	0.31	260.87	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

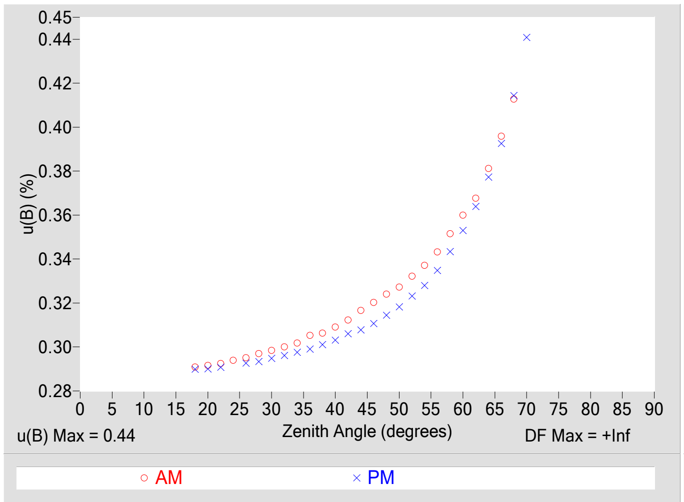


Figure 4. Residuals from Spline Interpolation

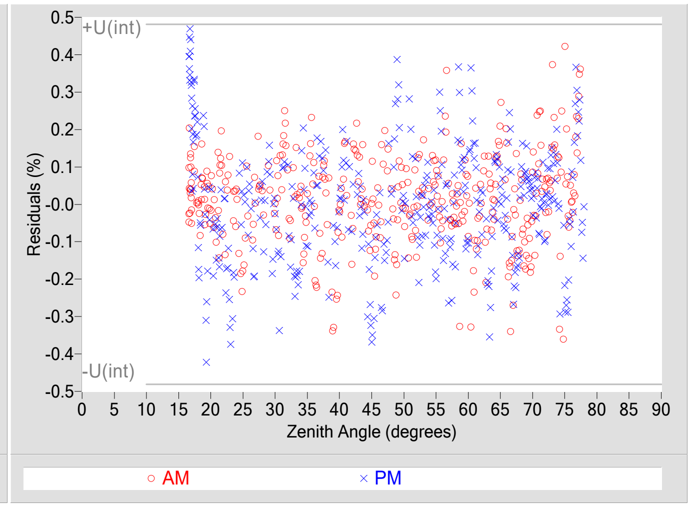


Table 3. Uncertainty using Spline Interpolation ‡

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)	13035
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

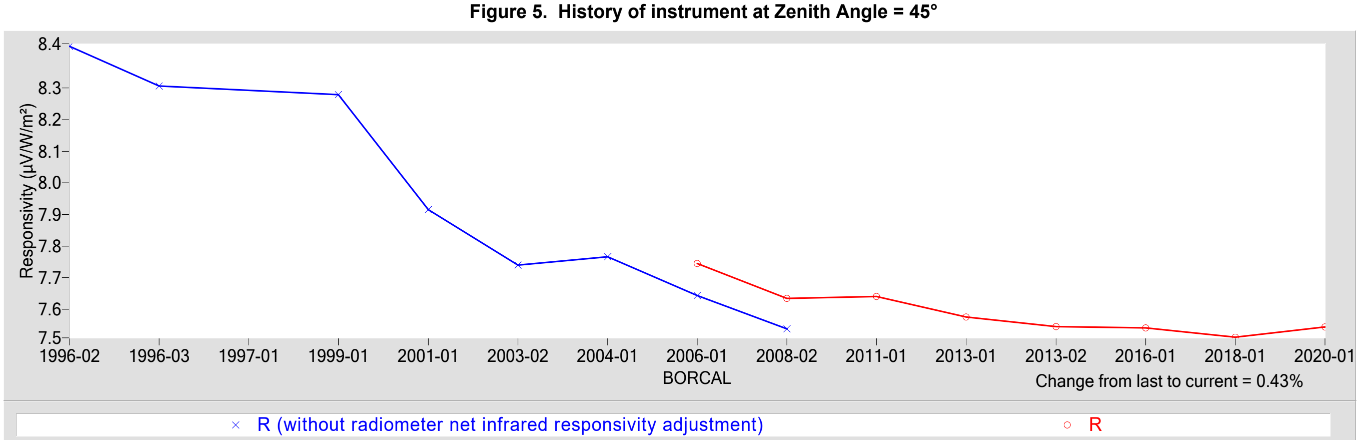
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5449	0.52200

† Rnet determination date: 04/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.9 / -2.4
Expanded Uncertainty, U (%)	+2.6 / -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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30902F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30902F3 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

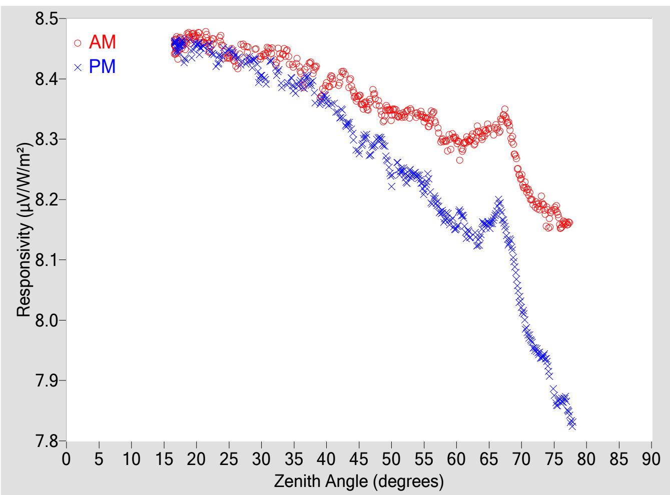


Figure 2. Responsivity vs Local Standard Time

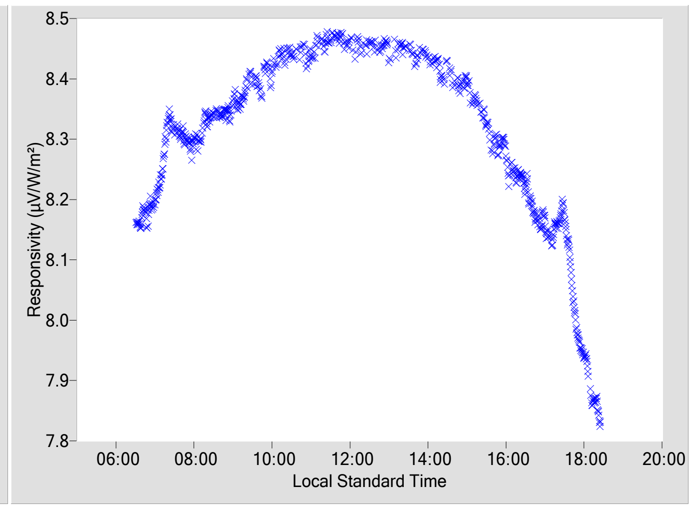


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3567	0.32	97.22	8.3048	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3595	0.32	95.50	8.3012	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3436	0.33	93.95	8.2361	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3415	0.33	92.34	8.2410	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3399	0.34	90.86	8.2390	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3333	0.34	89.32	8.1997	0.33	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2981	0.35	87.90	8.1712	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2981	0.36	86.45	8.1535	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2980	0.37	85.05	8.1427	0.36	275.04
18	8.4565	0.29	155.43	8.4495	0.29	204.45	64	8.3062	0.38	83.64	8.1552	0.38	276.47
20	8.4711	0.29	143.39	8.4575	0.29	217.61	66	8.3167	0.40	82.29	8.1783	0.39	277.87
22	8.4531	0.29	134.53	8.4521	0.29	225.52	68	8.3238	0.41	80.87	8.1302	0.41	279.24
24	8.4543	0.29	128.59	8.4450	0.29	231.60	70	8.2348	N/A	79.54	8.0239	0.44	280.59
26	8.4271	0.29	123.84	8.4364	0.29	236.53	72	8.1915	N/A	78.11	7.9519	N/A	282.00
28	8.4455	0.30	119.54	8.4324	0.29	240.62	74	8.1694	N/A	76.72	7.9229	N/A	283.40
30	8.4369	0.30	115.90	8.4049	0.29	244.09	76	8.1575	N/A	75.36	7.8675	N/A	284.80
32	8.4278	0.30	112.62	8.4116	0.30	247.74	78	N/A	N/A	N/A	7.8277	N/A	286.09
34	8.4386	0.30	109.92	8.3918	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4078	0.30	107.34	8.3913	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4145	0.31	104.99	8.3779	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3873	0.31	103.05	8.3638	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3953	0.31	100.91	8.3401	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3821	0.32	99.01	8.3084	0.31	261.04	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

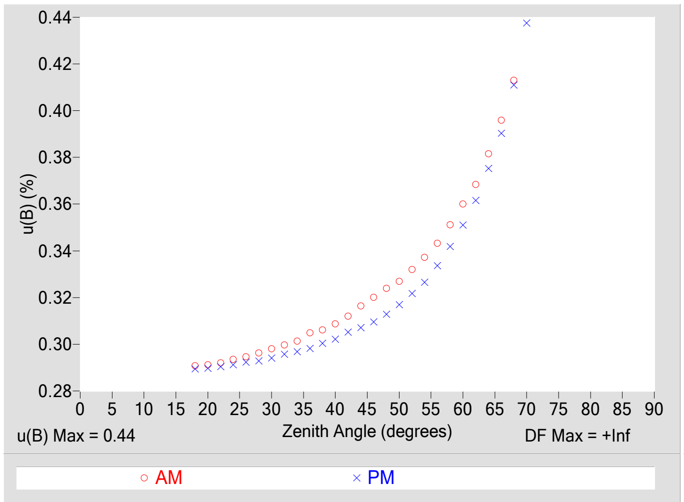


Figure 4. Residuals from Spline Interpolation

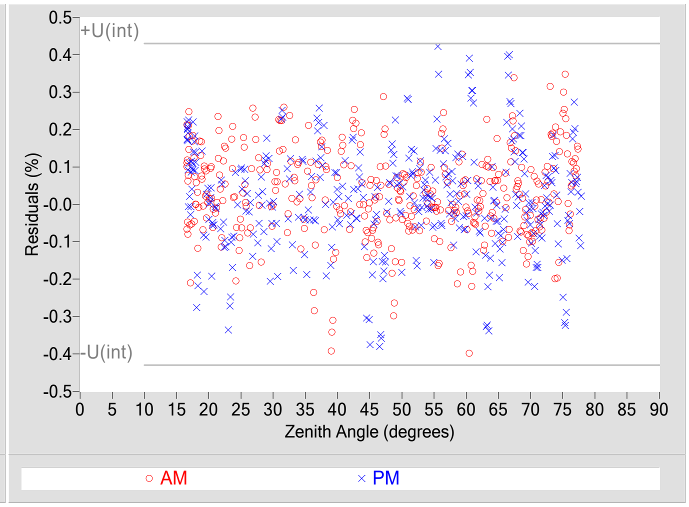


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	17885
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.96
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

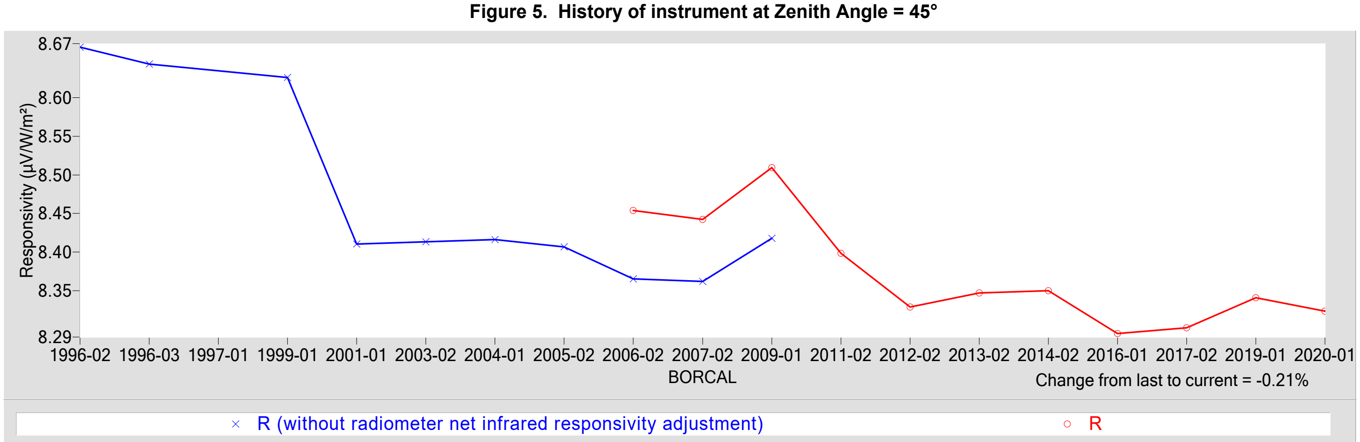
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3237	0.55035

† Rnet determination date: 07/10/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.4 / -2.0
Expanded Uncertainty, U (%)	+2.1 / -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: 30929F3
Calibration Date: 5/19/2020
Due Date: 5/19/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30929F3 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

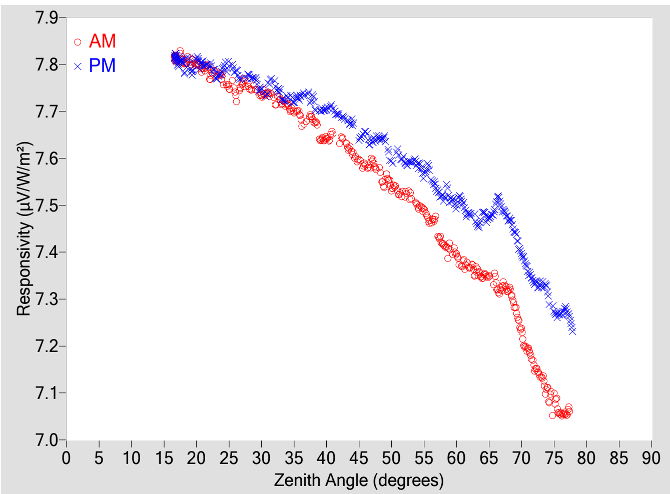


Figure 2. Responsivity vs Local Standard Time

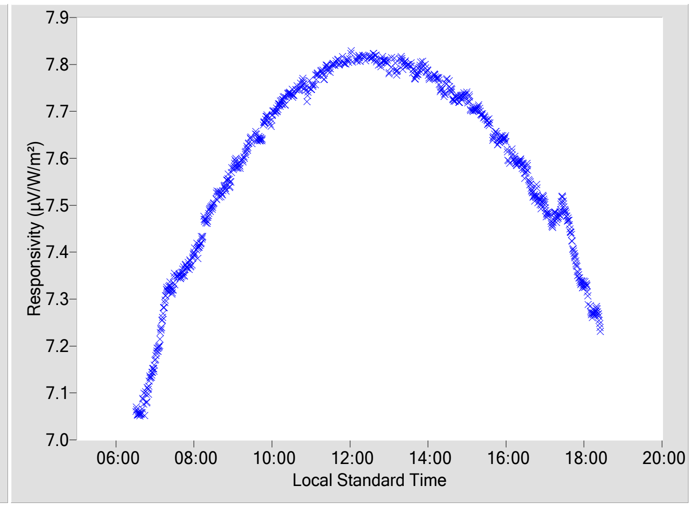


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5864	0.32	97.40	7.6552	0.31	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5751	0.33	95.37	7.6421	0.32	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5395	0.33	93.93	7.5918	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5238	0.34	92.20	7.5940	0.33	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4995	0.34	90.84	7.5869	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4655	0.35	89.29	7.5603	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4154	0.36	87.85	7.5170	0.35	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3937	0.36	86.43	7.5037	0.36	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3676	0.37	85.04	7.4815	0.37	275.06
18	7.8057	0.29	155.25	7.7972	0.29	204.43	64	7.3472	0.39	83.66	7.4811	0.39	276.47
20	7.8022	0.29	142.77	7.8123	0.29	217.82	66	7.3376	0.40	82.27	7.5010	0.40	277.85
22	7.7751	0.29	134.07	7.7987	0.29	225.95	68	7.3194	0.42	80.85	7.4700	0.42	279.26
24	7.7698	0.30	128.59	7.7874	0.29	231.33	70	7.2311	N/A	79.52	7.3949	0.45	280.61
26	7.7364	0.30	123.57	7.7857	0.29	236.63	72	7.1560	N/A	78.11	7.3357	N/A	281.97
28	7.7535	0.30	119.37	7.7770	0.30	240.77	74	7.0983	N/A	76.70	7.3136	N/A	283.37
30	7.7361	0.30	115.85	7.7484	0.30	244.10	76	7.0555	N/A	75.34	7.2695	N/A	284.78
32	7.7191	0.30	112.56	7.7590	0.30	247.52	78	N/A	N/A	N/A	7.2353	N/A	286.07
34	7.7149	0.30	109.94	7.7282	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6870	0.31	107.40	7.7302	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6810	0.31	105.08	7.7227	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6426	0.31	102.96	7.7058	0.31	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6383	0.31	100.76	7.6907	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6118	0.32	99.06	7.6759	0.31	260.99	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

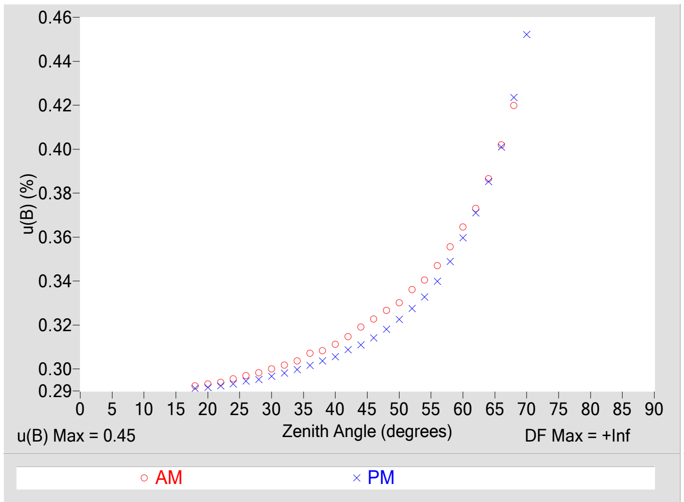


Figure 4. Residuals from Spline Interpolation

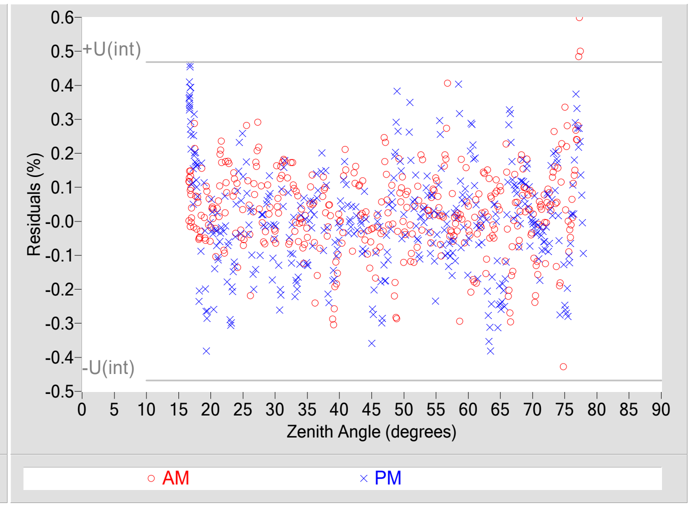


Table 3. Uncertainty using Spline Interpolation ‡

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)	15697
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

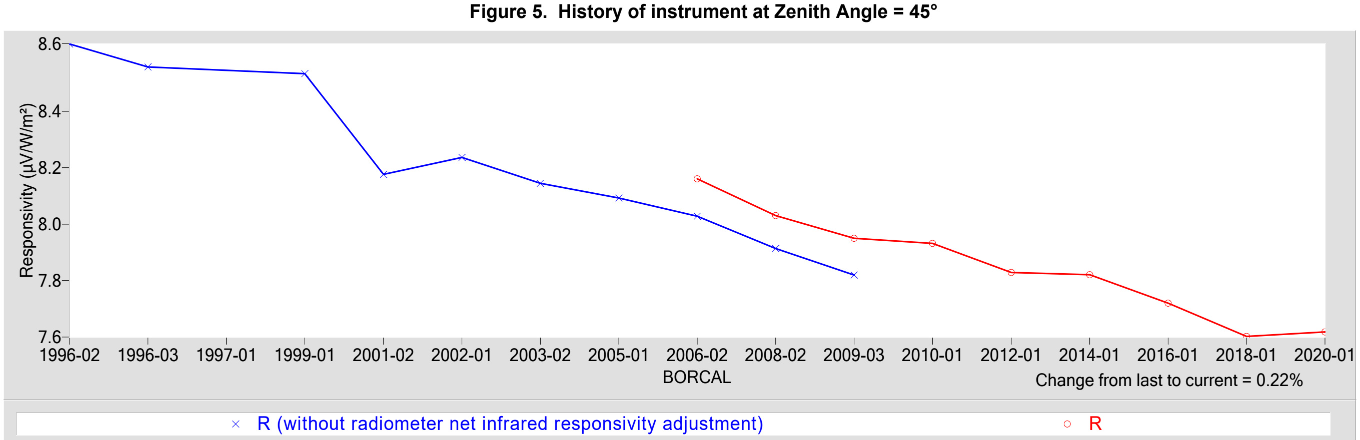
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6185	0.63036

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.8 / -3.0
Expanded Uncertainty, U (%)	+2.6 / -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:**	30938F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30938F3 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

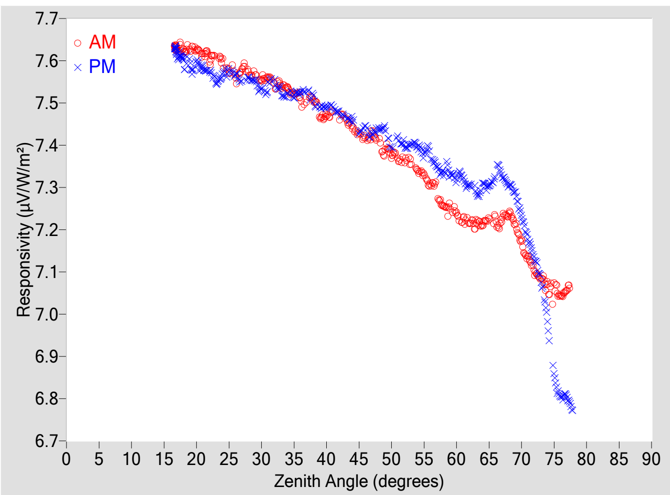


Figure 2. Responsivity vs Local Standard Time

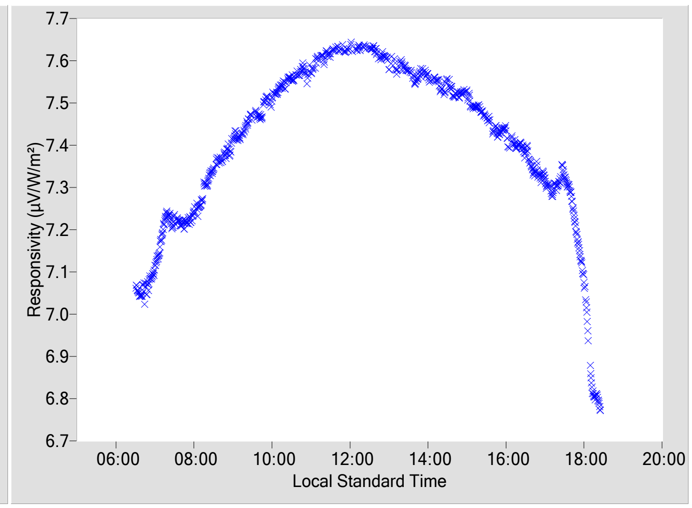


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM			PM			Zenith Angle (deg.)	AM			PM		
	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle		R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4192	0.32	97.40	7.4440	0.31	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4105	0.33	95.37	7.4376	0.32	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3786	0.33	93.93	7.3943	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3638	0.33	92.20	7.4007	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3407	0.34	90.84	7.3971	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3068	0.34	89.29	7.3730	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2556	0.35	87.85	7.3351	0.35	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2381	0.36	86.43	7.3224	0.36	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2153	0.37	85.04	7.3054	0.37	275.06
18	7.6242	0.29	155.25	7.5961	0.29	204.43	64	7.2115	0.38	83.66	7.3057	0.38	276.47
20	7.6272	0.29	142.77	7.5978	0.29	217.82	66	7.2213	0.40	82.27	7.3335	0.39	277.82
22	7.6008	0.29	134.07	7.5738	0.29	225.95	68	7.2370	0.42	80.85	7.3051	0.42	279.26
24	7.5966	0.29	128.59	7.5648	0.29	231.33	70	7.1712	N/A	79.52	7.2309	0.44	280.61
26	7.5613	0.30	123.57	7.5669	0.29	236.63	72	7.1015	N/A	78.11	7.1308	N/A	281.97
28	7.5731	0.30	119.37	7.5592	0.29	240.77	74	7.0622	N/A	76.70	6.9801	N/A	283.37
30	7.5563	0.30	115.85	7.5347	0.30	244.10	76	7.0440	N/A	75.34	6.8061	N/A	284.78
32	7.5382	0.30	112.56	7.5486	0.30	247.52	78	N/A	N/A	N/A	6.7729	N/A	286.07
34	7.5362	0.30	109.94	7.5198	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5093	0.31	107.40	7.5240	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5064	0.31	105.08	7.5097	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4701	0.31	102.96	7.4910	0.30	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4667	0.31	100.76	7.4759	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4429	0.32	99.06	7.4601	0.31	260.99	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

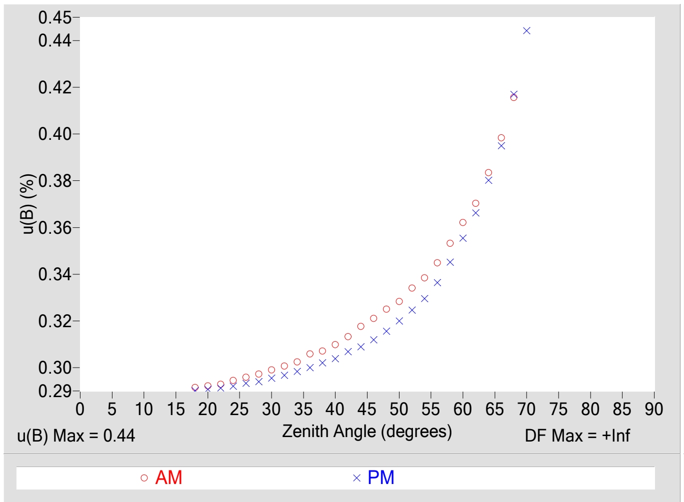


Figure 4. Residuals from Spline Interpolation

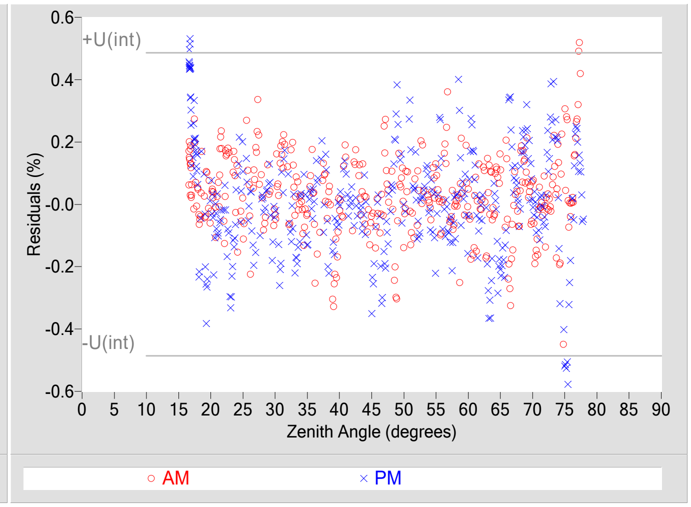


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	13174
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

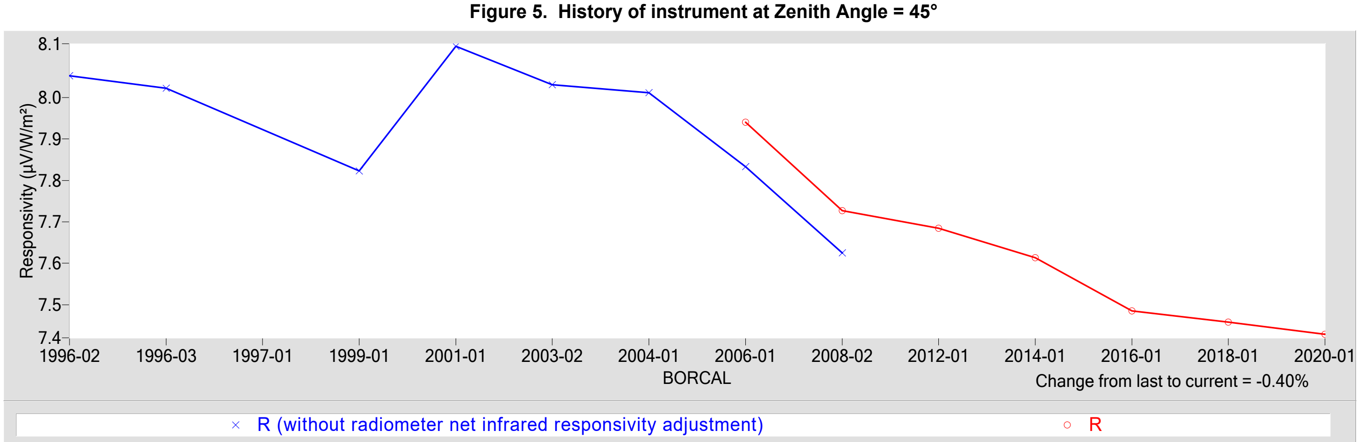
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.4287	0.55200

† Rnet determination date: 04/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -2.6
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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30939F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30939F3 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

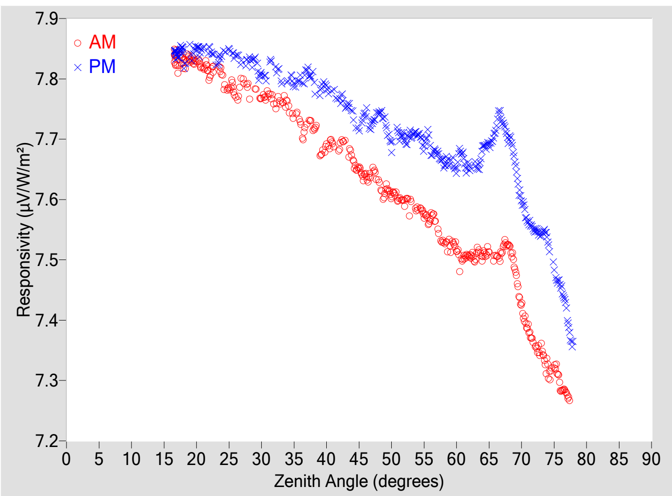


Figure 2. Responsivity vs Local Standard Time

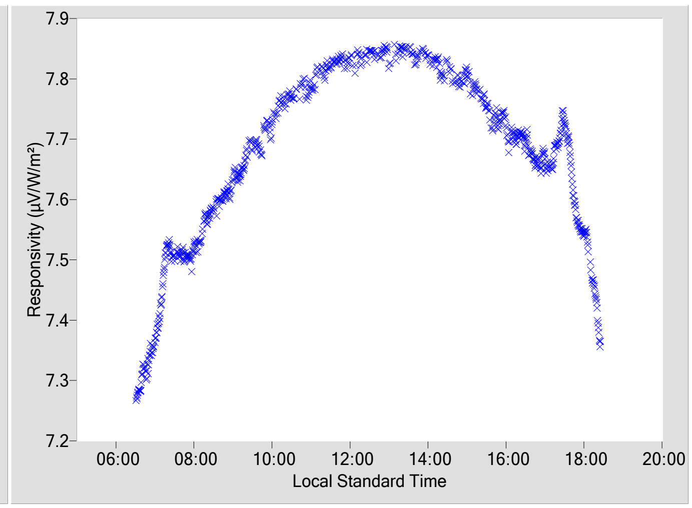


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6394	0.32	97.22	7.7437	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6304	0.33	95.50	7.7442	0.32	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6081	0.33	93.95	7.6917	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5971	0.33	92.34	7.7007	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5839	0.34	90.86	7.7084	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5687	0.35	89.32	7.6784	0.34	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5294	0.35	87.90	7.6597	0.35	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5193	0.36	86.45	7.6527	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5060	0.37	85.05	7.6549	0.37	275.04
18	7.8262	0.29	155.43	7.8399	0.29	204.45	64	7.5079	0.39	83.64	7.6832	0.38	276.47
20	7.8294	0.29	143.39	7.8521	0.29	217.61	66	7.5047	0.40	82.29	7.7179	0.40	277.87
22	7.8075	0.29	134.53	7.8479	0.29	225.52	68	7.5242	0.42	80.87	7.6999	0.42	279.24
24	7.8035	0.29	128.59	7.8423	0.29	231.60	70	7.4257	N/A	79.54	7.6012	0.44	280.59
26	7.7737	0.30	123.84	7.8373	0.29	236.53	72	7.3589	N/A	78.11	7.5488	N/A	282.00
28	7.7839	0.30	119.54	7.8332	0.29	240.62	74	7.3188	N/A	76.72	7.5301	N/A	283.40
30	7.7691	0.30	115.90	7.8082	0.30	244.09	76	7.2910	N/A	75.36	7.4557	N/A	284.80
32	7.7545	0.30	112.62	7.8151	0.30	247.74	78	N/A	N/A	N/A	7.3605	N/A	286.09
34	7.7559	0.30	109.92	7.7953	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7219	0.31	107.34	7.7979	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7162	0.31	104.99	7.7935	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6862	0.31	103.05	7.7840	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6858	0.31	100.91	7.7665	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6677	0.32	99.01	7.7420	0.31	261.04	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

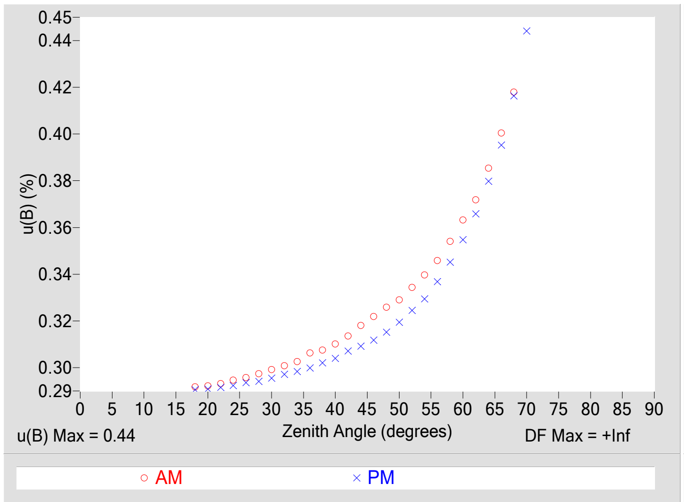


Figure 4. Residuals from Spline Interpolation

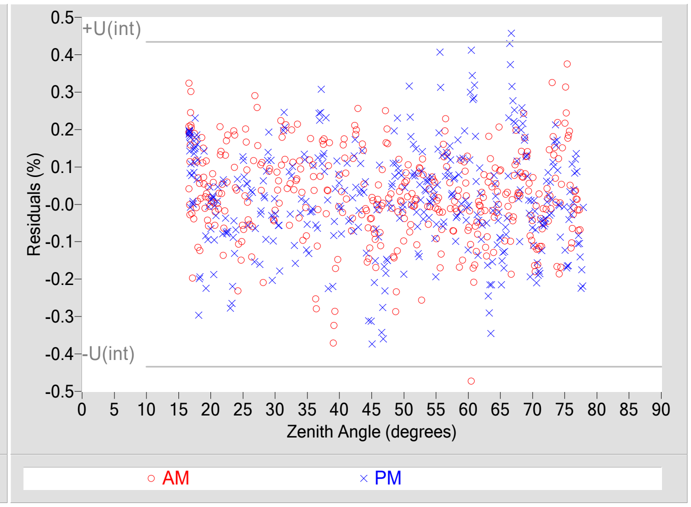


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	18163
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

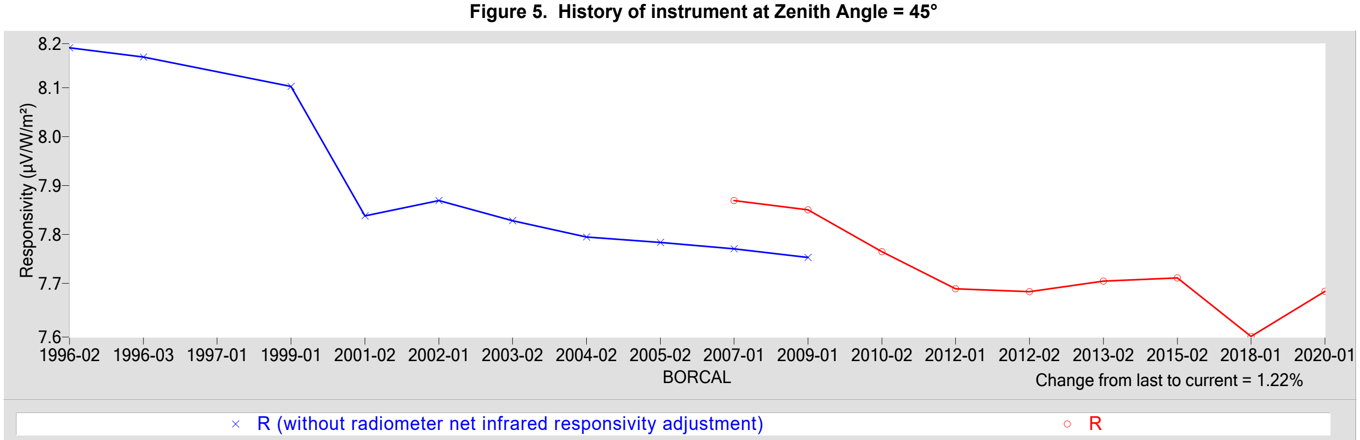
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6836	0.58311

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -2.1
Expanded Uncertainty, U (%)	+2.4 / -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:**	30946F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

30946F3 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

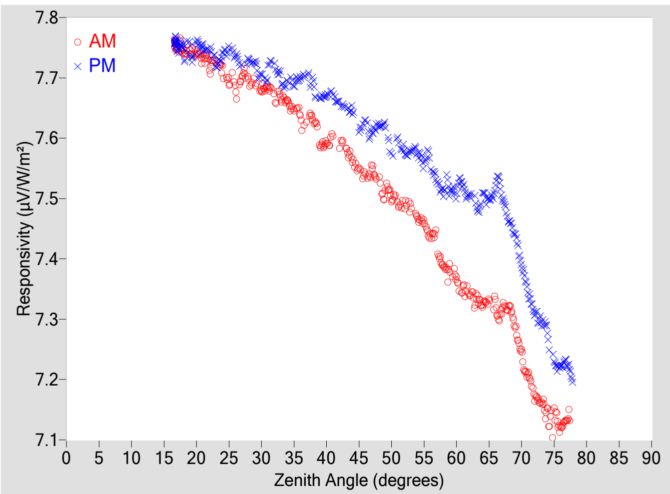


Figure 2. Responsivity vs Local Standard Time

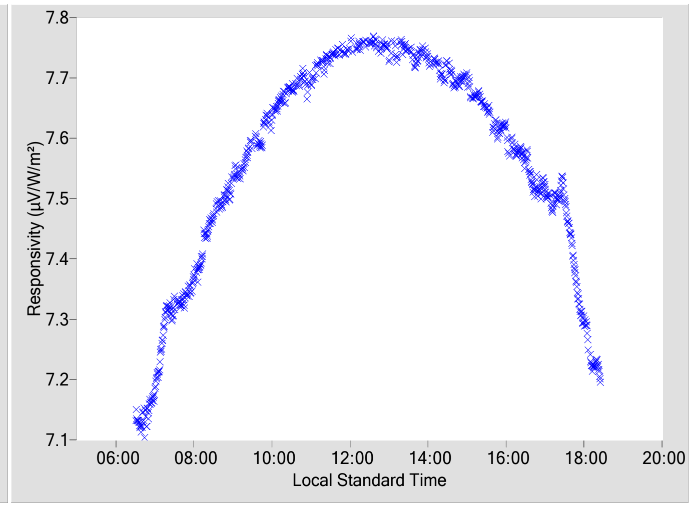


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5408	0.32	97.40	7.6284	0.32	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5307	0.33	95.37	7.6206	0.32	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5022	0.33	93.93	7.5727	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4894	0.34	92.20	7.5786	0.33	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4686	0.34	90.84	7.5752	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4378	0.35	89.29	7.5532	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3872	0.36	87.85	7.5125	0.35	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3661	0.37	86.43	7.5133	0.36	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3405	0.37	85.04	7.5049	0.37	275.06
18	7.7436	0.29	155.25	7.7436	0.29	204.43	64	7.3236	0.39	83.66	7.5047	0.39	276.47
20	7.7414	0.29	142.77	7.7593	0.29	217.82	66	7.3224	0.40	82.27	7.5221	0.40	277.85
22	7.7164	0.29	134.07	7.7464	0.29	225.95	68	7.3193	0.42	80.85	7.4631	0.43	279.26
24	7.7122	0.30	128.59	7.7364	0.29	231.33	70	7.2444	N/A	79.52	7.3875	0.46	280.61
26	7.6805	0.30	123.57	7.7358	0.30	236.63	72	7.1743	N/A	78.11	7.3107	N/A	281.97
28	7.6957	0.30	119.37	7.7299	0.30	240.77	74	7.1388	N/A	76.70	7.2741	N/A	283.37
30	7.6806	0.30	115.85	7.7064	0.30	244.10	76	7.1202	N/A	75.34	7.2225	N/A	284.78
32	7.6633	0.30	112.56	7.7191	0.30	247.52	78	N/A	N/A	N/A	7.1983	N/A	286.07
34	7.6616	0.30	109.94	7.6916	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6341	0.31	107.40	7.6993	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6297	0.31	105.08	7.6874	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5921	0.31	102.96	7.6709	0.31	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5897	0.32	100.76	7.6577	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5642	0.32	99.06	7.6457	0.31	260.99	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

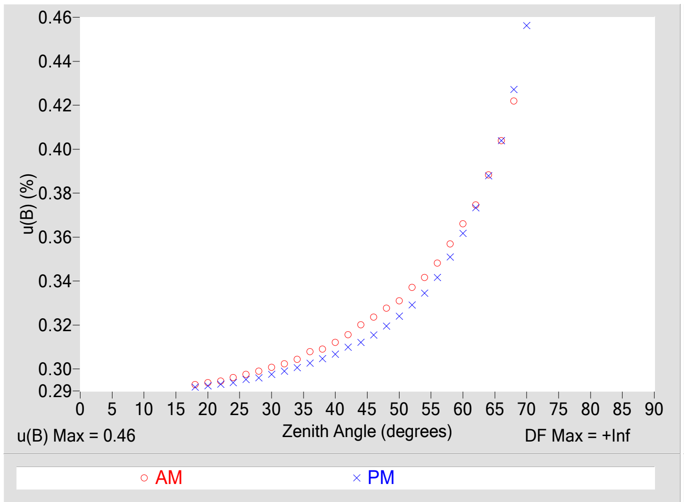


Figure 4. Residuals from Spline Interpolation

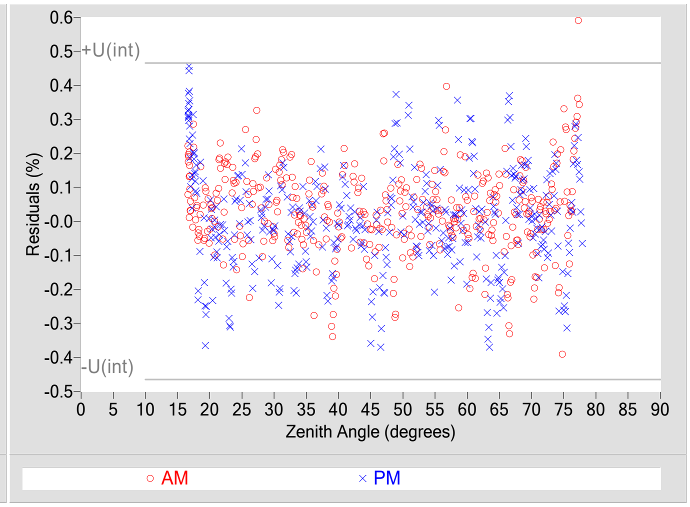


Table 3. Uncertainty using Spline Interpolation ‡

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)	16450
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

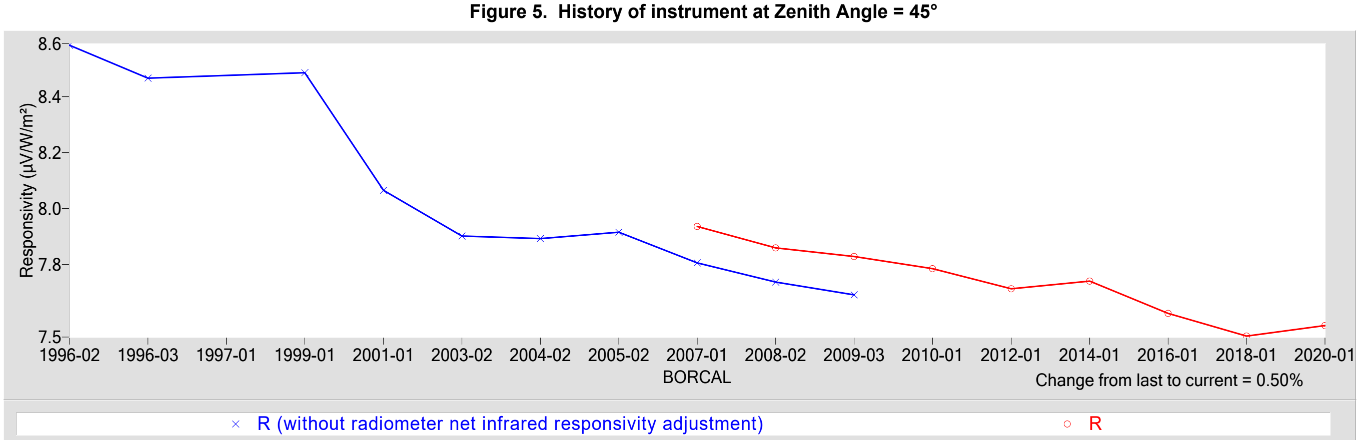
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5812	0.66251

† Rnet determination date: 04/24/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+1.8 / -2.8
Expanded Uncertainty, U (%)	+2.5 / -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:**	30951F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

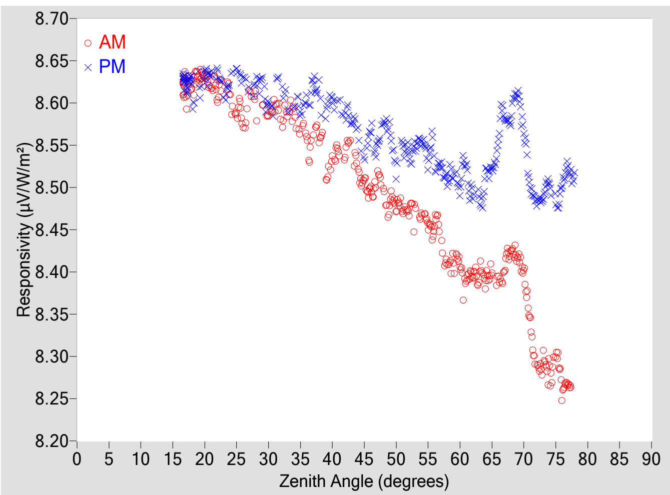


Figure 2. Responsivity vs Local Standard Time

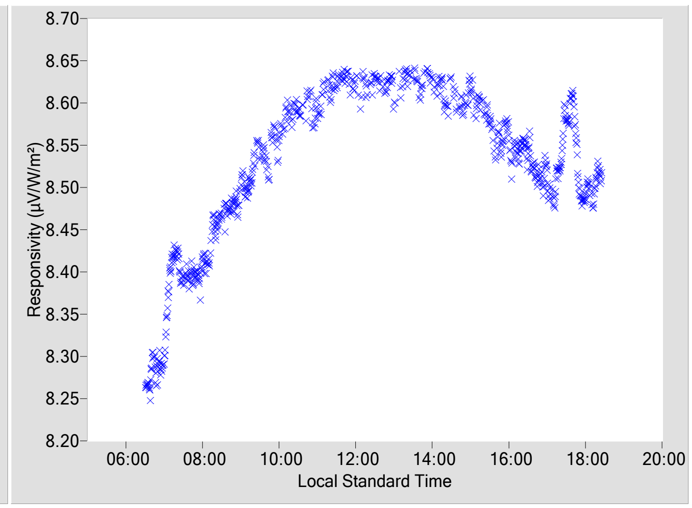


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	8.4965	0.32	97.22	8.5682	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4970	0.33	95.50	8.5758	0.32	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4792	0.33	93.95	8.5253	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4734	0.33	92.34	8.5404	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4665	0.34	90.86	8.5536	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4547	0.35	89.32	8.5250	0.34	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4107	0.35	87.90	8.5092	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4089	0.36	86.45	8.5016	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3963	0.37	85.05	8.4951	0.37	275.04
18	8.6197	0.29	155.43	8.6175	0.29	204.45	64	8.3927	0.38	83.64	8.5141	0.38	276.47
20	8.6312	0.29	143.39	8.6363	0.29	217.61	66	8.3904	0.40	82.29	8.5593	0.39	277.87
22	8.6097	0.29	134.53	8.6343	0.29	225.52	68	8.4244	0.42	80.87	8.5836	0.42	279.24
24	8.6072	0.29	128.59	8.6281	0.29	231.60	70	8.3993	N/A	79.54	8.5667	0.44	280.59
26	8.5761	0.30	123.84	8.6282	0.29	236.53	72	8.2900	N/A	78.11	8.4833	N/A	282.00
28	8.6012	0.30	119.54	8.6238	0.29	240.62	74	8.2797	N/A	76.72	8.5018	N/A	283.40
30	8.5870	0.30	115.90	8.5994	0.30	244.09	76	8.2654	N/A	75.36	8.5041	N/A	284.80
32	8.5759	0.30	112.62	8.6124	0.30	247.74	78	N/A	N/A	N/A	8.5128	N/A	286.09
34	8.5840	0.30	109.92	8.5951	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5531	0.31	107.34	8.6017	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5570	0.31	104.99	8.6060	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5297	0.31	103.05	8.6017	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5386	0.31	100.91	8.5876	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5228	0.32	99.01	8.5650	0.31	261.04	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

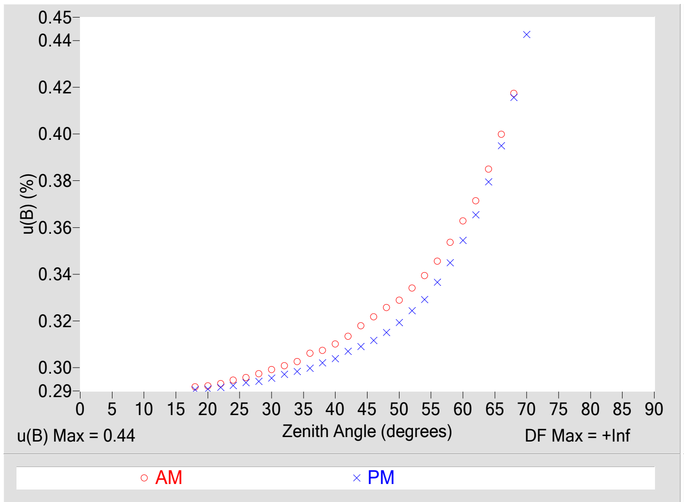


Figure 4. Residuals from Spline Interpolation

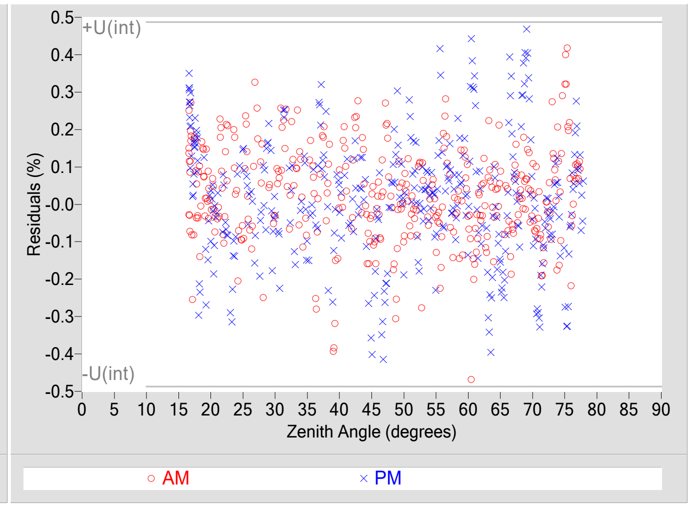


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	12523
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

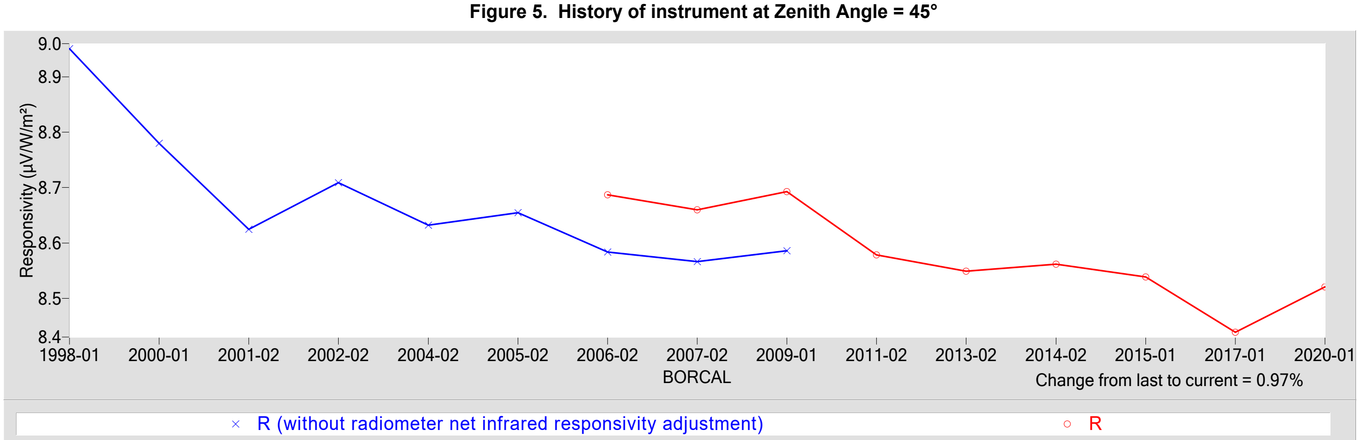
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5207	0.64270

† Rnet determination date: 07/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.1 / -1.3
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:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30954F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30954F3 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

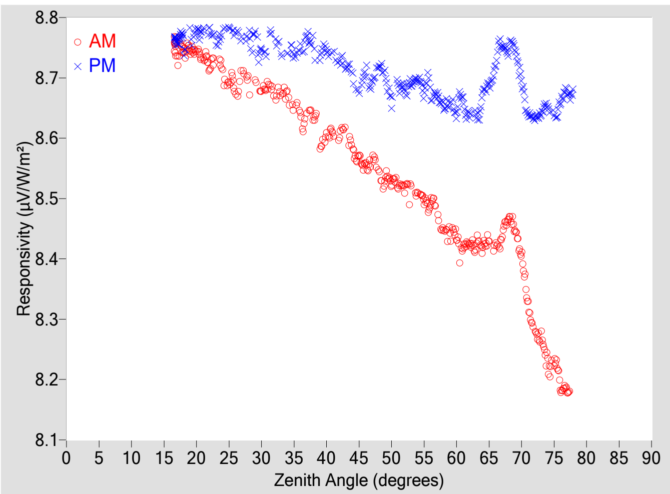


Figure 2. Responsivity vs Local Standard Time

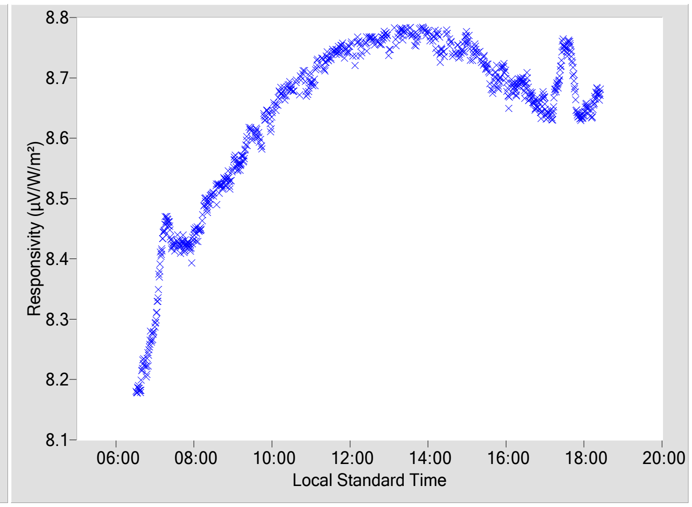


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	8.5557	0.32	97.22	8.7101	0.31	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5460	0.33	95.50	8.7175	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5278	0.33	93.95	8.6642	0.32	266.12
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5188	0.33	92.34	8.6813	0.32	267.74
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5079	0.34	90.86	8.6968	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4903	0.35	89.32	8.6697	0.34	270.84
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4480	0.35	87.90	8.6531	0.34	272.24
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4374	0.36	86.45	8.6426	0.35	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4235	0.37	85.05	8.6406	0.36	275.04
18	8.7440	0.29	155.43	8.7609	0.29	204.45	64	8.4213	0.38	83.64	8.6716	0.38	276.47
20	8.7452	0.29	143.39	8.7791	0.29	217.61	66	8.4209	0.40	82.29	8.7248	0.39	277.87
22	8.7191	0.29	134.53	8.7776	0.29	225.52	68	8.4663	0.42	80.87	8.7462	0.41	279.24
24	8.7115	0.29	128.59	8.7757	0.29	231.60	70	8.4063	N/A	79.54	8.6972	0.44	280.59
26	8.6779	0.30	123.84	8.7740	0.29	236.53	72	8.2818	N/A	78.11	8.6328	N/A	282.00
28	8.6932	0.30	119.54	8.7703	0.29	240.62	74	8.2268	N/A	76.72	8.6502	N/A	283.40
30	8.6802	0.30	115.90	8.7477	0.30	244.09	76	8.1913	N/A	75.36	8.6615	N/A	284.80
32	8.6667	0.30	112.62	8.7586	0.30	247.74	78	N/A	N/A	N/A	8.6762	N/A	286.09
34	8.6685	0.30	109.92	8.7407	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6348	0.31	107.34	8.7475	0.30	252.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6314	0.31	104.99	8.7491	0.30	255.11	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6014	0.31	103.05	8.7437	0.30	257.22	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6030	0.31	100.91	8.7278	0.31	259.33	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5837	0.32	99.01	8.7024	0.31	261.04	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

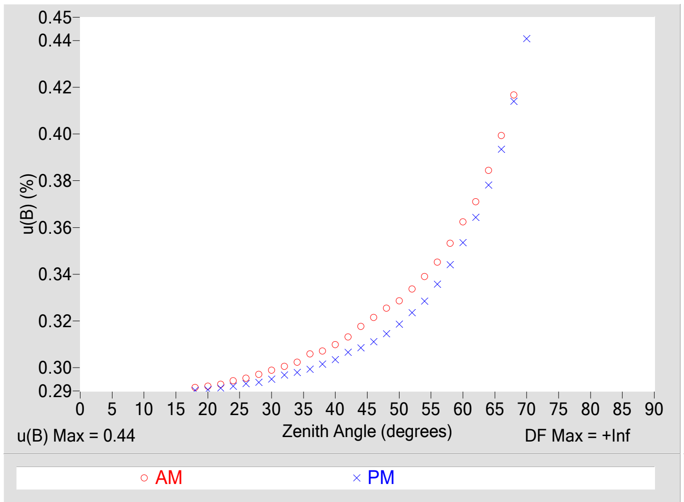


Figure 4. Residuals from Spline Interpolation

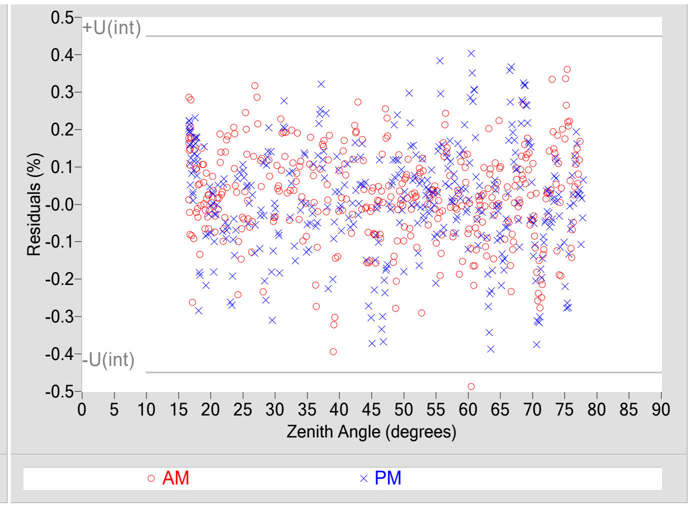


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	15846
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

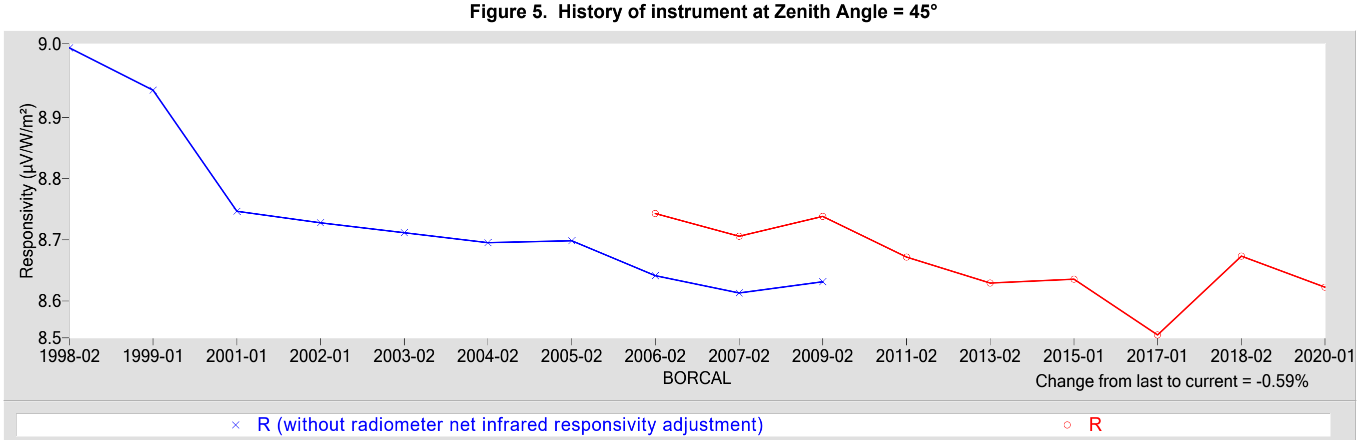
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6226	0.63330

† Rnet determination date: 06/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.6 / -2.1
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
Manufacturer: Eppley
Model: PSP
Serial Number: 30958F3
Calibration Date: 5/19/2020
Due Date: 5/19/2021
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

30958F3 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

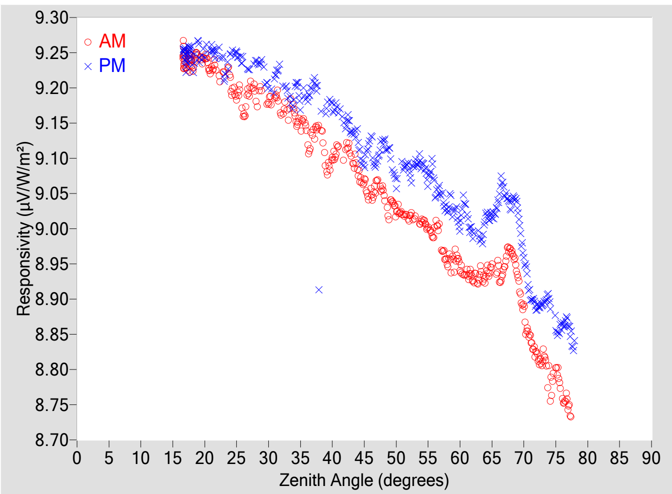


Figure 2. Responsivity vs Local Standard Time

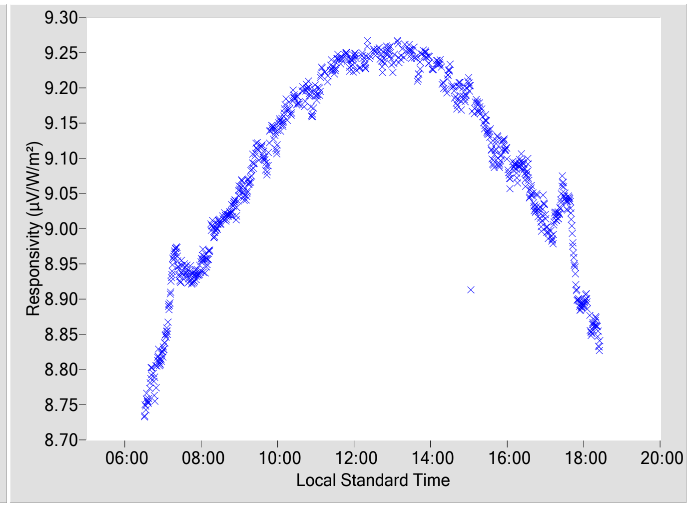


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.0484	0.32	97.12	9.1292	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0518	0.32	95.56	9.1246	0.31	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0276	0.33	93.91	9.0686	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0156	0.33	92.28	9.0840	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0103	0.34	90.78	9.0920	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9971	0.34	89.35	9.0642	0.33	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9533	0.35	87.89	9.0282	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9474	0.36	86.46	9.0079	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9287	0.37	85.06	8.9945	0.36	275.04
18	9.2331	0.29	155.82	9.2429	0.29	204.36	64	8.9343	0.38	83.61	9.0159	0.38	276.48
20	9.2433	0.29	142.89	9.2534	0.29	217.44	66	8.9412	0.40	82.26	9.0433	0.39	277.88
22	9.2212	0.29	134.62	9.2511	0.29	225.85	68	8.9686	0.41	80.88	9.0348	0.41	279.21
24	9.2094	0.29	128.47	9.2483	0.29	231.63	70	8.8794	N/A	79.51	8.9606	0.44	280.60
26	9.1633	0.30	123.40	9.2383	0.29	236.25	72	8.8204	N/A	78.14	8.8880	N/A	282.00
28	9.1888	0.30	119.46	9.2367	0.29	240.69	74	8.7810	N/A	76.73	8.8977	N/A	283.36
30	9.1817	0.30	115.76	9.2030	0.29	244.01	76	8.7615	N/A	75.34	8.8627	N/A	284.81
32	9.1628	0.30	112.81	9.2180	0.30	247.32	78	N/A	N/A	N/A	8.8338	N/A	286.10
34	9.1647	0.30	109.84	9.1878	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1325	0.30	107.40	9.1836	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1432	0.31	105.13	9.0399	0.30	255.10	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1017	0.31	102.88	9.1723	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1105	0.31	100.89	9.1482	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0771	0.32	98.93	9.1221	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

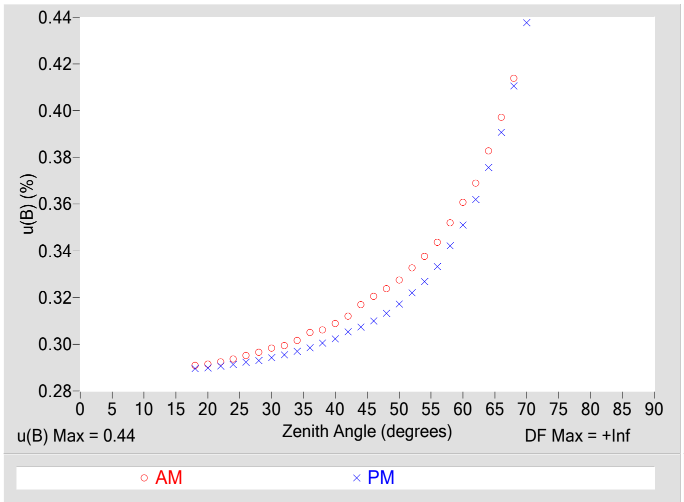


Figure 4. Residuals from Spline Interpolation

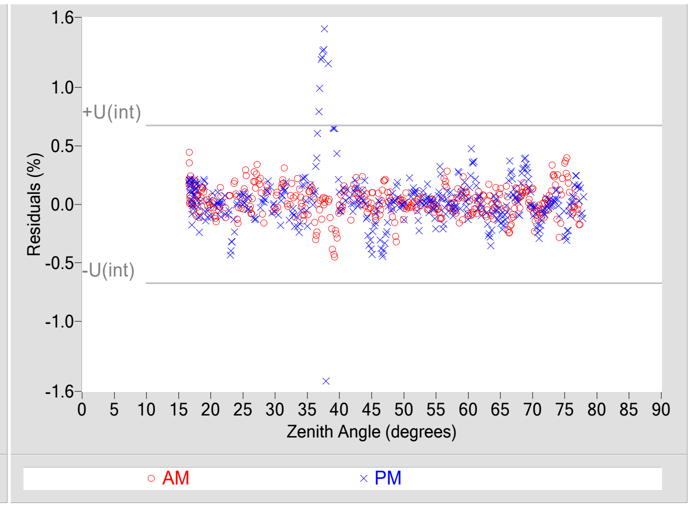


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.34
Combined Standard Uncertainty, u(c) (%)	±0.55
Effective degrees of freedom, DF(c)	5051
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

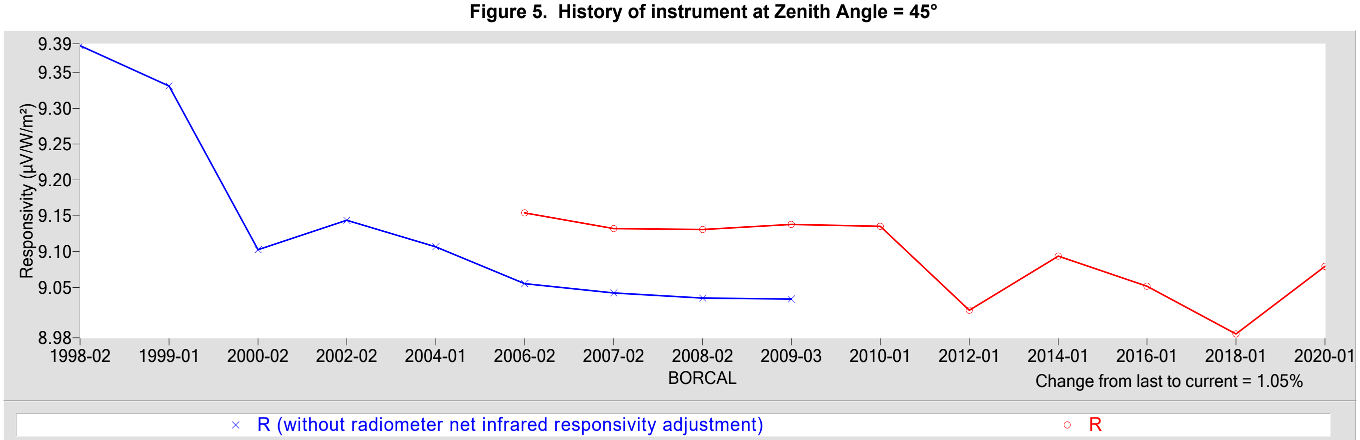
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0796	0.61540

† Rnet determination date: 06/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.5 / -1.5
Expanded Uncertainty, U (%)	+2.2 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	31097F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

31097F3 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 - 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

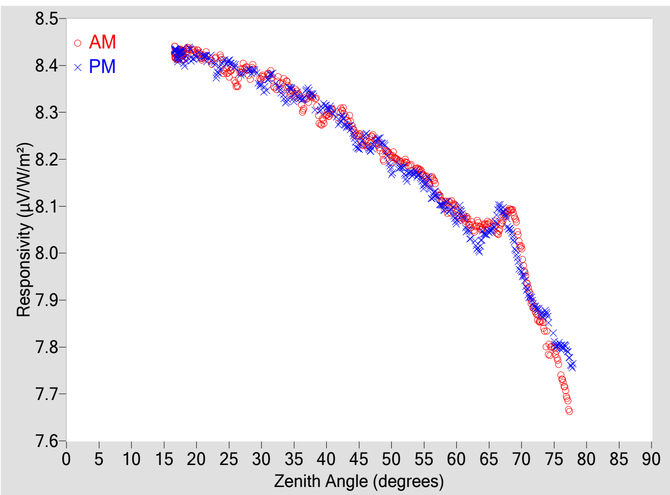


Figure 2. Responsivity vs Local Standard Time

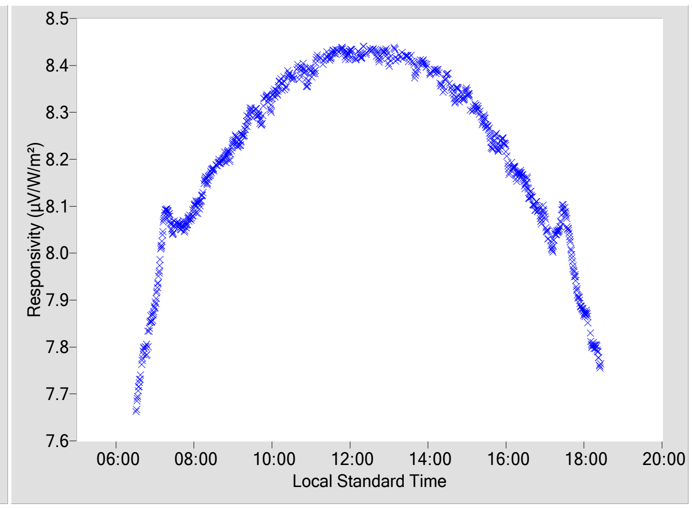


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2321	0.32	97.12	8.2535	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2300	0.32	95.56	8.2443	0.31	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2066	0.33	93.91	8.1761	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1950	0.33	92.28	8.1720	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1793	0.34	90.78	8.1666	0.32	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1548	0.34	89.35	8.1336	0.33	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1056	0.35	87.89	8.0979	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0917	0.36	86.46	8.0704	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0623	0.37	85.06	8.0394	0.36	275.04
18	8.4213	0.29	155.82	8.4175	0.29	204.36	64	8.0553	0.38	83.61	8.0369	0.37	276.48
20	8.4307	0.29	142.89	8.4224	0.29	217.44	66	8.0568	0.39	82.26	8.0728	0.39	277.88
22	8.4117	0.29	134.62	8.4156	0.29	225.85	68	8.0912	0.41	80.88	8.0570	0.41	279.21
24	8.4016	0.29	128.47	8.4069	0.29	231.63	70	8.0022	N/A	79.51	7.9599	0.43	280.60
26	8.3607	0.29	123.40	8.3980	0.29	236.25	72	7.8802	N/A	78.14	7.8867	N/A	282.00
28	8.3839	0.30	119.46	8.3901	0.29	240.69	74	7.8061	N/A	76.73	7.8655	N/A	283.36
30	8.3751	0.30	115.76	8.3594	0.29	244.01	76	7.7451	N/A	75.34	7.8022	N/A	284.81
32	8.3541	0.30	112.81	8.3727	0.29	247.32	78	N/A	N/A	N/A	7.7597	N/A	286.10
34	8.3578	0.30	109.84	8.3354	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3242	0.30	107.40	8.3286	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3318	0.31	105.13	8.3293	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2956	0.31	102.88	8.3105	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2988	0.31	100.89	8.2806	0.30	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2625	0.32	98.93	8.2540	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

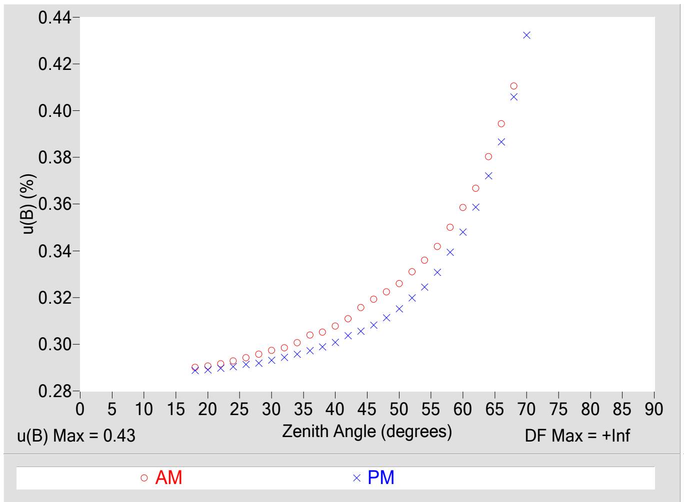


Figure 4. Residuals from Spline Interpolation

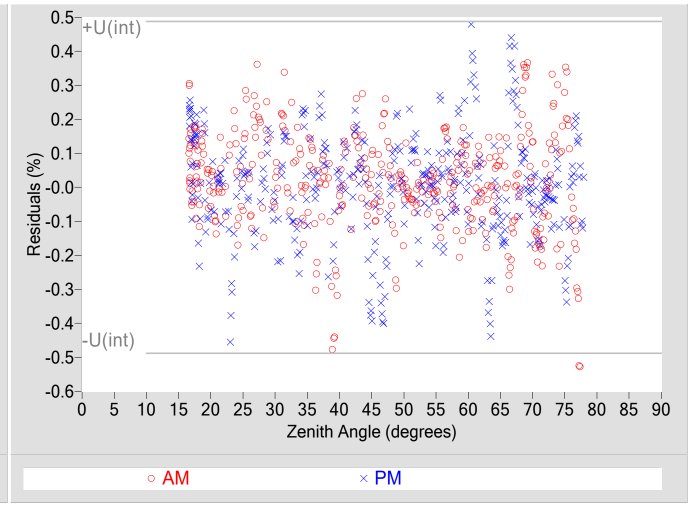


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	12149
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

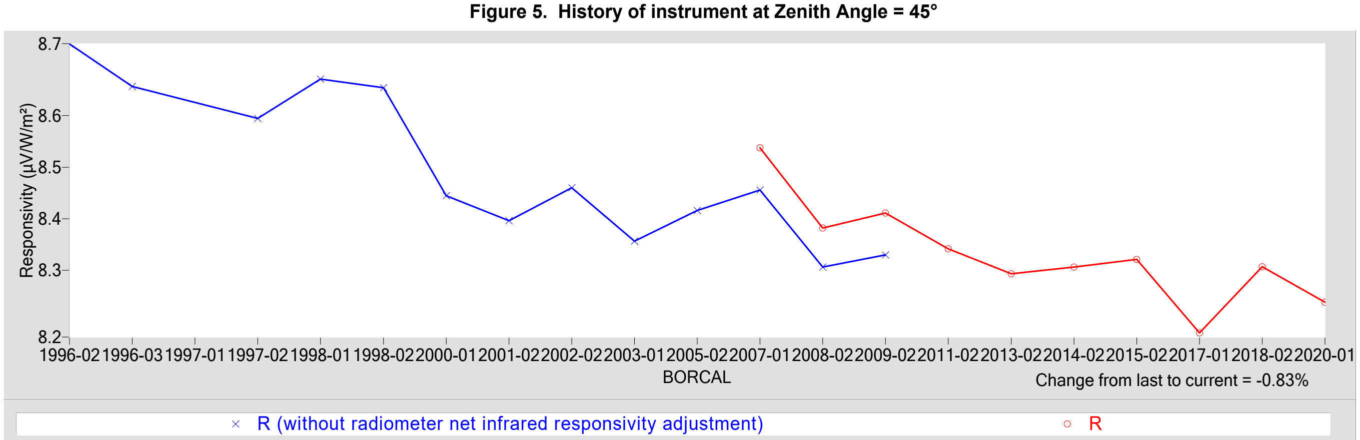
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.2374	0.48715

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.70
Offset Uncertainty, U(off) (%)	+1.7 / -2.0
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

[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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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:

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

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

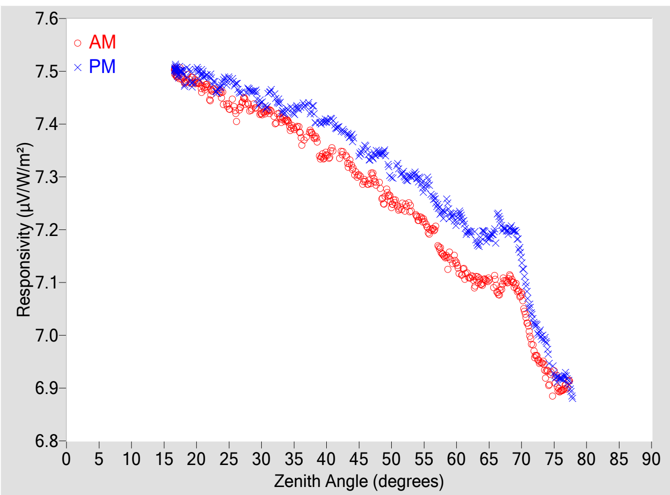


Figure 2. Responsivity vs Local Standard Time

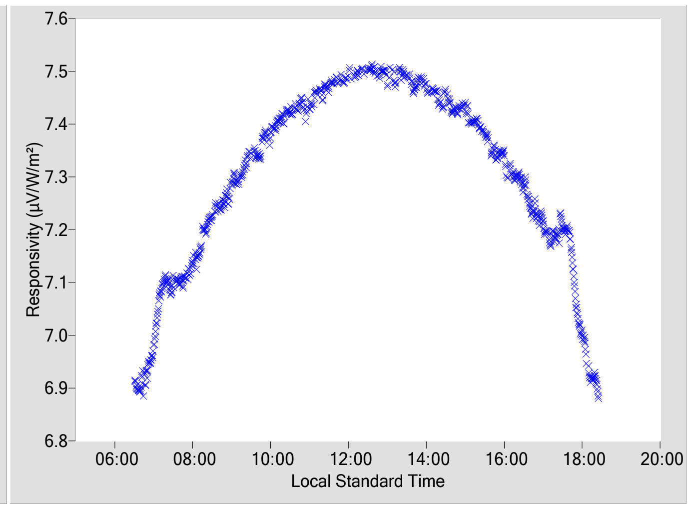


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.2926	0.32	97.40	7.3564	0.31	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2838	0.33	95.37	7.3449	0.32	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2514	0.33	93.93	7.2982	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2426	0.33	92.20	7.3015	0.33	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2227	0.34	90.84	7.2975	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1982	0.35	89.29	7.2715	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1510	0.35	87.85	7.2316	0.35	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1349	0.36	86.43	7.2187	0.36	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1085	0.37	85.04	7.1957	0.37	275.06
18	7.4833	0.29	155.25	7.4898	0.29	204.43	64	7.0985	0.38	83.66	7.1948	0.38	276.47
20	7.4802	0.29	142.77	7.5032	0.29	217.82	66	7.0972	0.40	82.27	7.2006	0.40	277.83
22	7.4527	0.29	134.07	7.4905	0.29	225.95	68	7.1067	0.42	80.85	7.1982	0.42	279.26
24	7.4517	0.29	128.59	7.4767	0.29	231.33	70	7.0740	N/A	79.52	7.1418	0.45	280.61
26	7.4209	0.30	123.57	7.4754	0.29	236.63	72	6.9665	N/A	78.11	7.0231	N/A	281.97
28	7.4342	0.30	119.37	7.4658	0.29	240.77	74	6.9221	N/A	76.70	6.9714	N/A	283.37
30	7.4218	0.30	115.85	7.4424	0.30	244.10	76	6.8953	N/A	75.34	6.9185	N/A	284.78
32	7.4058	0.30	112.56	7.4528	0.30	247.52	78	N/A	N/A	N/A	6.8827	N/A	286.07
34	7.4061	0.30	109.94	7.4271	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3795	0.31	107.40	7.4323	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3775	0.31	105.08	7.4230	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3421	0.31	102.96	7.4064	0.30	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3416	0.31	100.76	7.3915	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3179	0.32	99.06	7.3748	0.31	260.99	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

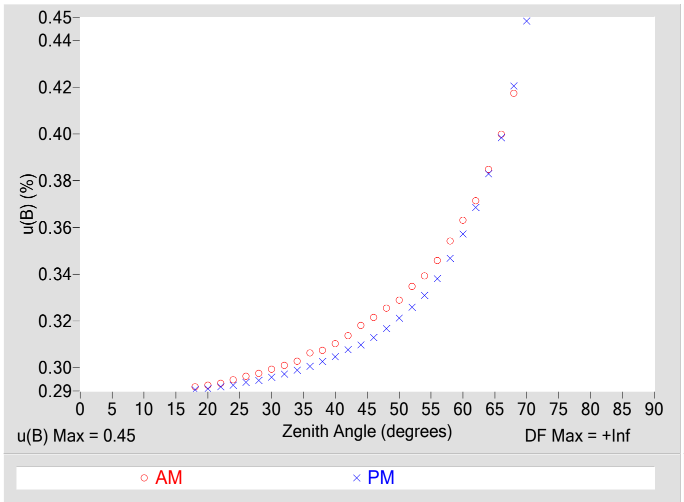


Figure 4. Residuals from Spline Interpolation

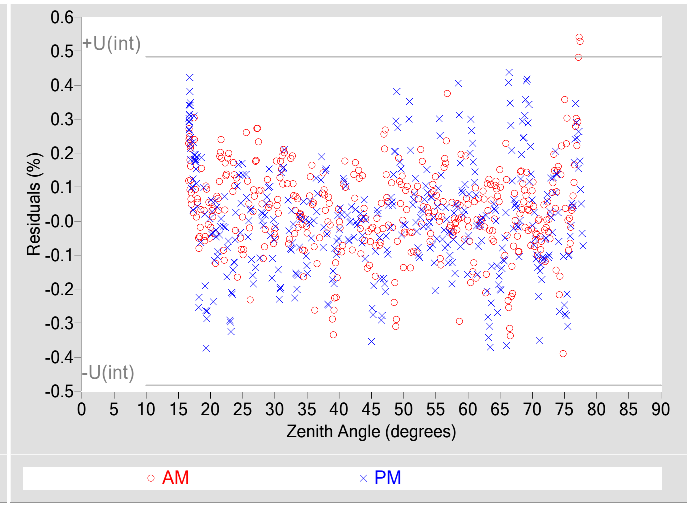


Table 3. Uncertainty using Spline Interpolation ‡

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)	13750
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

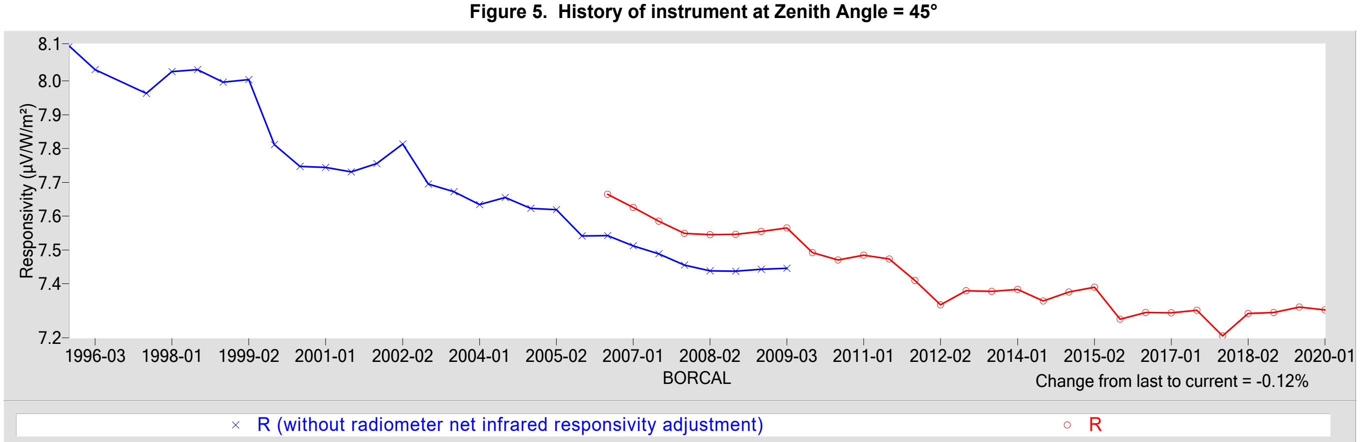
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.3223	0.57866

† Rnet determination date: 05/08/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.8 / -2.6
Expanded Uncertainty, U (%)	+2.5 / -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:**	31100F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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:

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

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

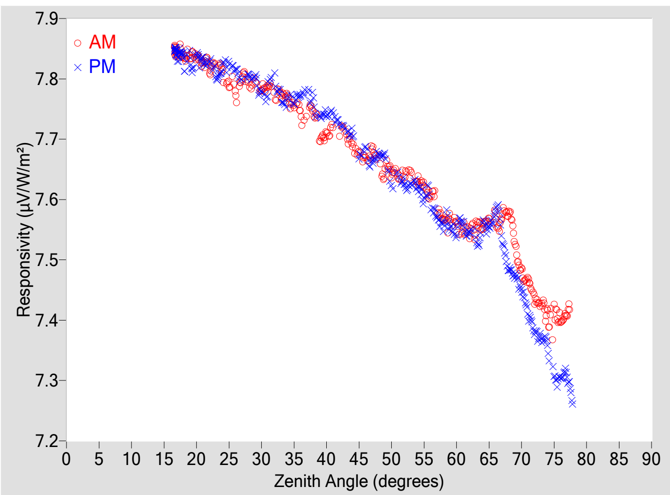


Figure 2. Responsivity vs Local Standard Time

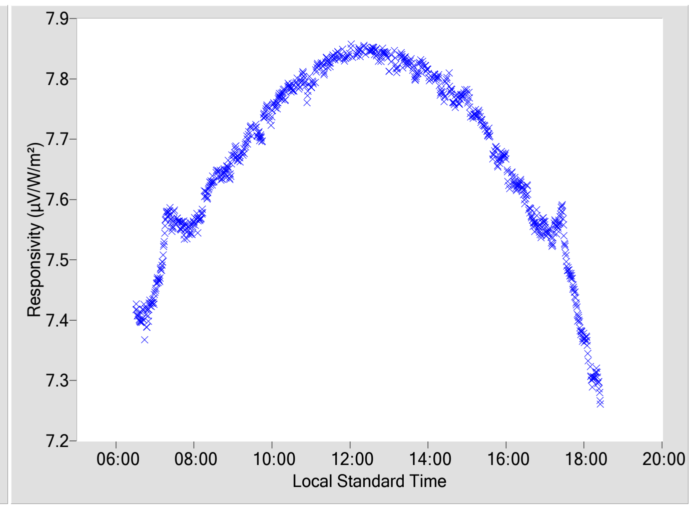


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.6710	0.32	97.40	7.6861	0.32	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6667	0.33	95.37	7.6733	0.32	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6455	0.33	93.93	7.6204	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6435	0.34	92.20	7.6265	0.33	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6305	0.34	90.84	7.6201	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6062	0.35	89.29	7.5927	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5669	0.36	87.85	7.5576	0.35	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5609	0.37	86.43	7.5486	0.36	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5451	0.37	85.04	7.5462	0.37	275.06
18	7.8364	0.29	155.25	7.8303	0.29	204.43	64	7.5530	0.39	83.66	7.5593	0.39	276.47
20	7.8375	0.29	142.77	7.8398	0.29	217.82	66	7.5688	0.40	82.27	7.5809	0.40	277.85
22	7.8124	0.29	134.07	7.8293	0.29	225.95	68	7.5765	0.42	80.85	7.4848	0.43	279.26
24	7.8099	0.30	128.59	7.8190	0.29	231.33	70	7.4815	N/A	79.52	7.4475	0.46	280.61
26	7.7759	0.30	123.57	7.8150	0.29	236.63	72	7.4364	N/A	78.11	7.3818	N/A	281.97
28	7.7926	0.30	119.37	7.8062	0.30	240.77	74	7.4039	N/A	76.70	7.3546	N/A	283.37
30	7.7827	0.30	115.85	7.7796	0.30	244.10	76	7.4005	N/A	75.34	7.3051	N/A	284.78
32	7.7689	0.30	112.56	7.7986	0.30	247.52	78	N/A	N/A	N/A	7.2639	N/A	286.07
34	7.7714	0.30	109.94	7.7639	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7425	0.31	107.40	7.7723	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7423	0.31	105.08	7.7603	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7090	0.31	102.96	7.7415	0.31	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7136	0.32	100.76	7.7263	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6911	0.32	99.06	7.7092	0.31	260.99	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

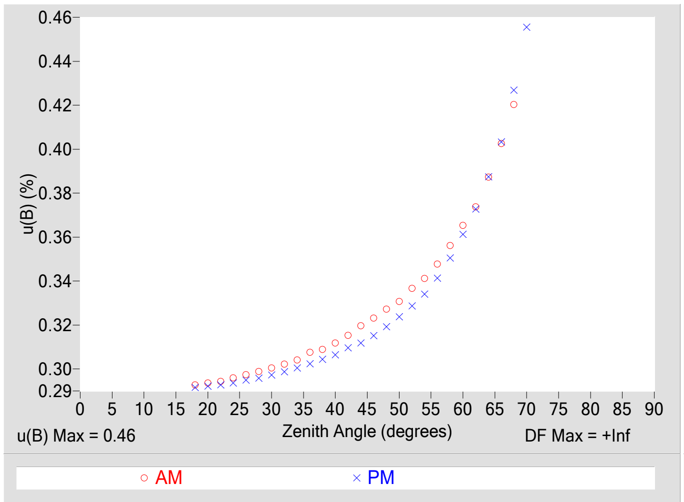


Figure 4. Residuals from Spline Interpolation

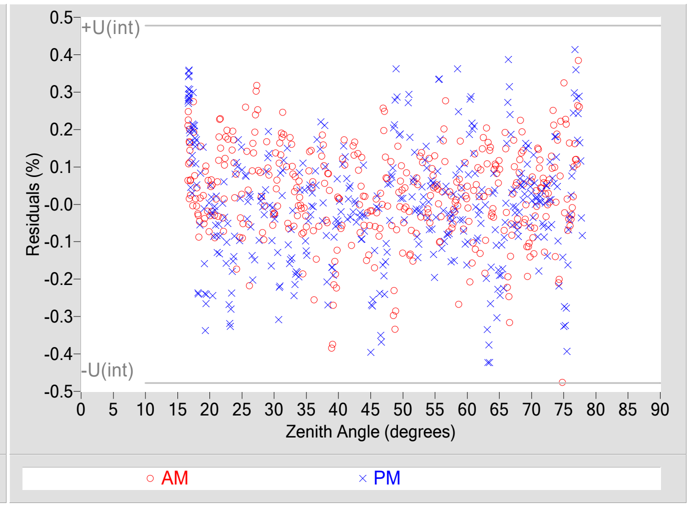


Table 3. Uncertainty using Spline Interpolation ‡

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)	15038
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

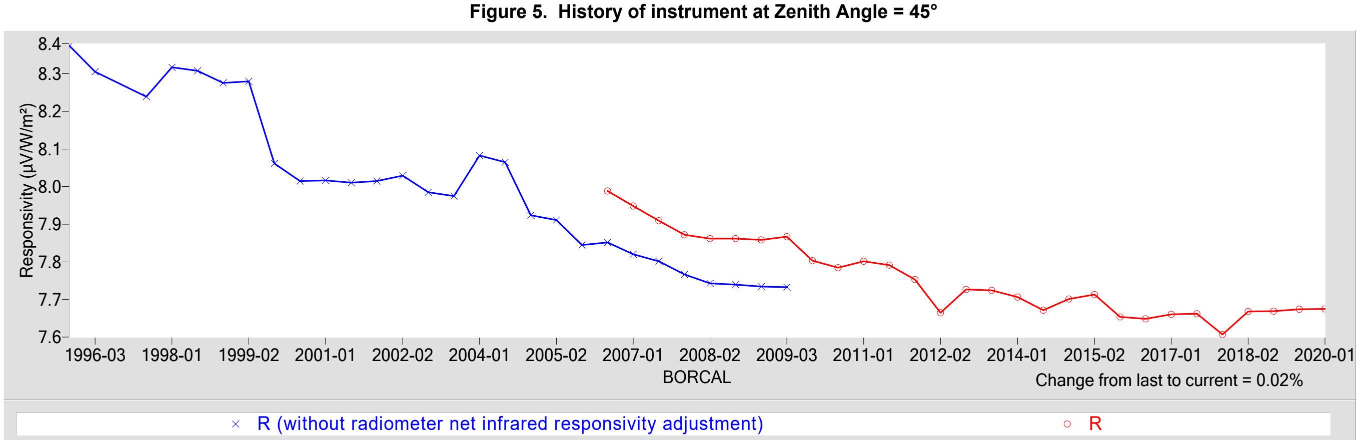
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6748	0.64729

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+1.6 / -1.6
Expanded Uncertainty, U (%)	+2.3 / -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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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:

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

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

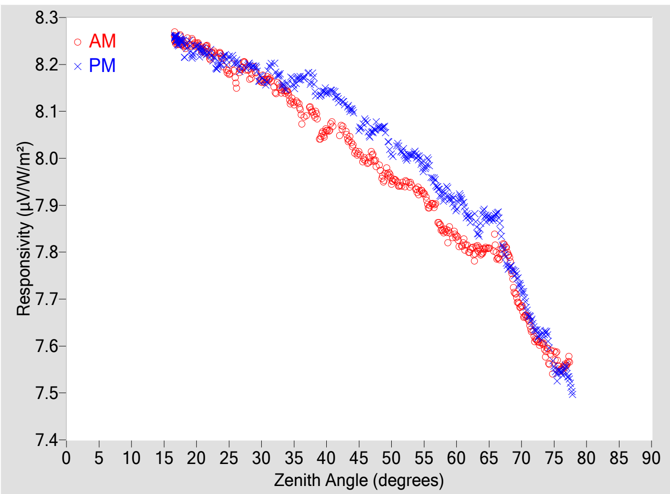


Figure 2. Responsivity vs Local Standard Time

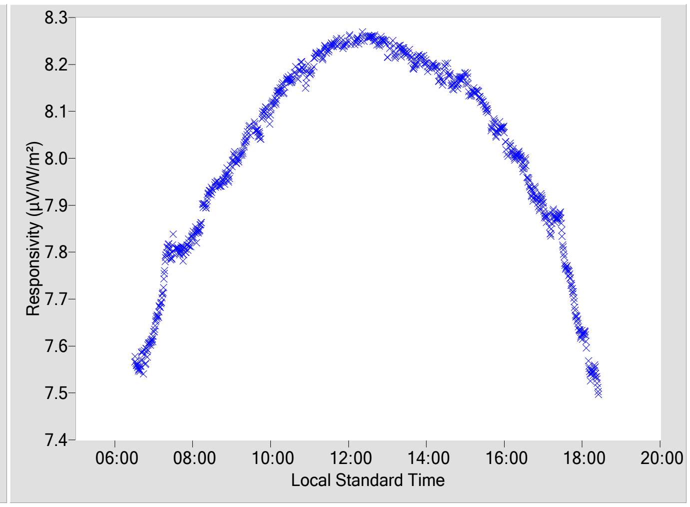


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.9980	0.32	97.40	8.0797	0.32	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9801	0.33	95.37	8.0654	0.32	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9545	0.33	93.93	8.0064	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9472	0.34	92.20	8.0083	0.33	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9314	0.34	90.84	8.0033	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9003	0.35	89.29	7.9673	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8458	0.36	87.85	7.9211	0.35	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8327	0.37	86.43	7.9002	0.36	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8020	0.37	85.04	7.8732	0.37	275.06
18	8.2428	0.29	155.25	8.2367	0.29	204.43	64	7.7990	0.39	83.66	7.8806	0.39	276.47
20	8.2434	0.29	142.77	8.2385	0.29	217.82	66	7.8082	0.40	82.27	7.8791	0.40	277.85
22	8.2160	0.29	134.07	8.2247	0.29	225.95	68	7.7910	0.42	80.85	7.7675	0.43	279.26
24	8.2098	0.30	128.59	8.2106	0.29	231.33	70	7.6820	N/A	79.52	7.7195	0.46	280.61
26	8.1669	0.30	123.57	8.2042	0.30	236.63	72	7.6180	N/A	78.11	7.6376	N/A	281.97
28	8.1817	0.30	119.37	8.1999	0.30	240.77	74	7.5803	N/A	76.70	7.6178	N/A	283.37
30	8.1670	0.30	115.85	8.1739	0.30	244.10	76	7.5508	N/A	75.34	7.5463	N/A	284.78
32	8.1432	0.30	112.56	8.1930	0.30	247.52	78	N/A	N/A	N/A	7.4999	N/A	286.07
34	8.1409	0.30	109.94	8.1546	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0988	0.31	107.40	8.1699	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0941	0.31	105.08	8.1638	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0590	0.31	102.96	8.1423	0.31	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0592	0.32	100.76	8.1231	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0287	0.32	99.06	8.1020	0.31	260.99	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

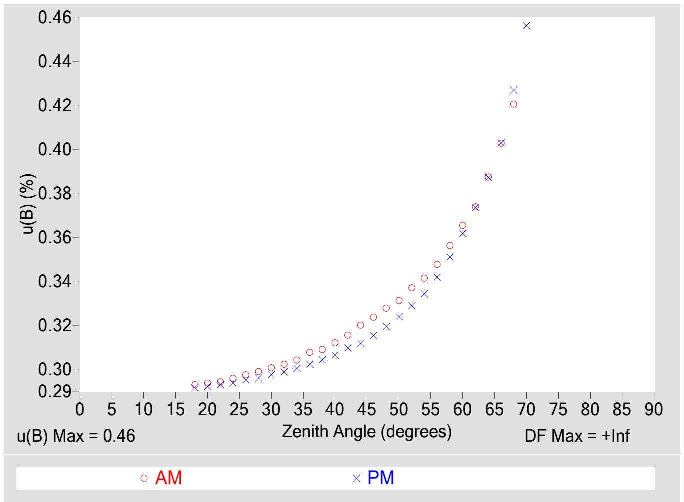


Figure 4. Residuals from Spline Interpolation

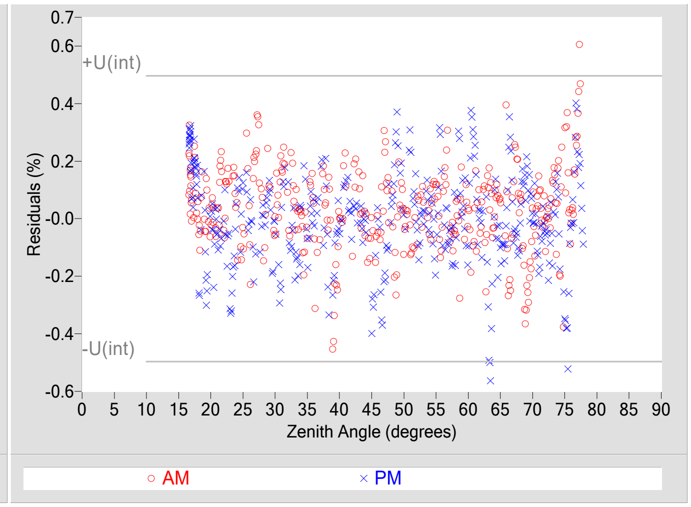


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.46
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	13395
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

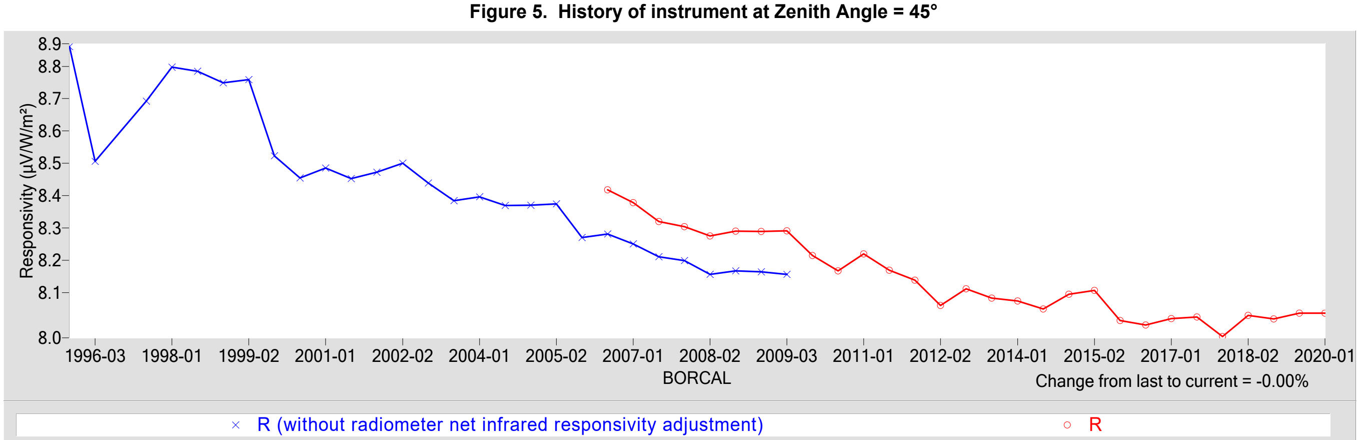
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0362	0.64834

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+2.0 / -2.5
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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31120E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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:

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

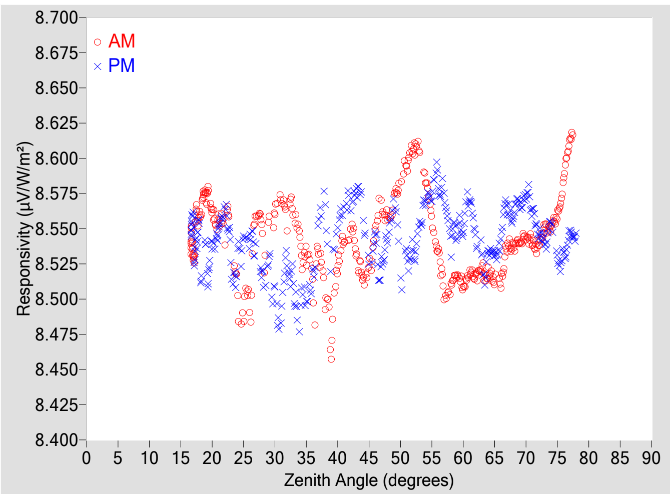


Figure 2. Responsivity vs Local Standard Time

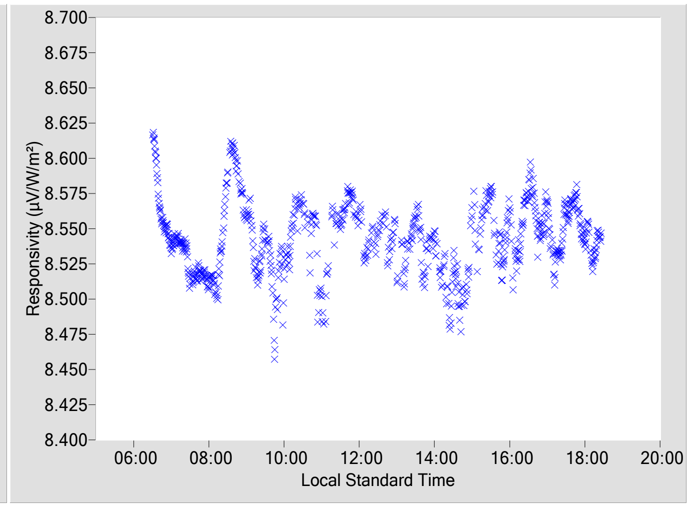


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5476	0.29	97.31	8.5437	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5595	0.29	95.57	8.5460	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5828	0.29	93.95	8.5108	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6069	0.29	92.37	8.5333	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5854	0.29	90.82	8.5689	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5349	0.30	89.36	8.5832	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5094	0.30	87.79	8.5423	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5083	0.30	86.41	8.5505	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5163	0.30	85.02	8.5421	0.29	275.08
18	8.5579	0.28	155.76	8.5363	0.28	204.65	64	8.5168	0.30	83.64	8.5330	0.30	276.47
20	8.5630	0.28	142.83	8.5394	0.28	217.28	66	8.5135	0.30	82.26	8.5431	0.30	277.83
22	8.5461	0.28	135.05	8.5637	0.28	225.38	68	8.5370	0.30	80.92	8.5598	0.30	279.24
24	8.5056	0.29	128.53	8.5253	0.28	231.54	70	8.5438	N/A	79.48	8.5733	0.30	280.64
26	8.4959	0.29	123.40	8.5418	0.28	236.40	72	8.5393	N/A	78.10	8.5476	N/A	281.96
28	8.5520	0.29	119.60	8.5171	0.28	240.63	74	8.5511	N/A	76.77	8.5530	N/A	283.36
30	8.5598	0.29	115.90	8.5050	0.28	244.31	76	8.5855	N/A	75.32	8.5317	N/A	284.76
32	8.5560	0.29	112.97	8.5237	0.28	247.40	78	N/A	N/A	N/A	8.5441	N/A	286.09
34	8.5402	0.29	109.83	8.4934	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5110	0.29	107.37	8.5152	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5029	0.29	105.10	8.5578	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5241	0.29	102.87	8.5511	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5467	0.29	100.92	8.5682	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5149	0.29	99.03	8.5591	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

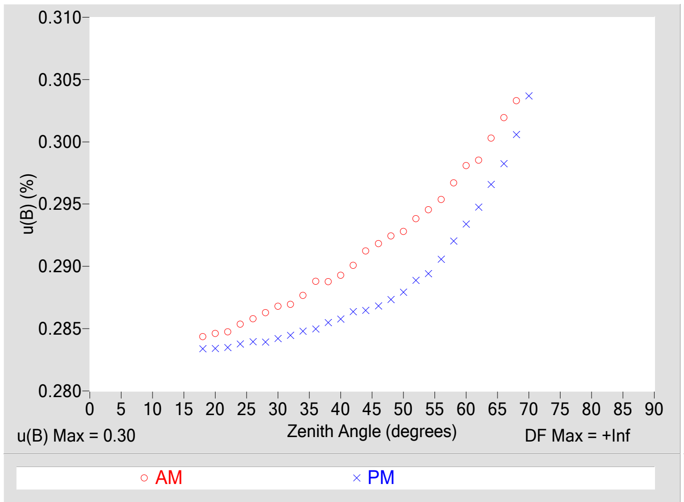


Figure 4. Residuals from Spline Interpolation

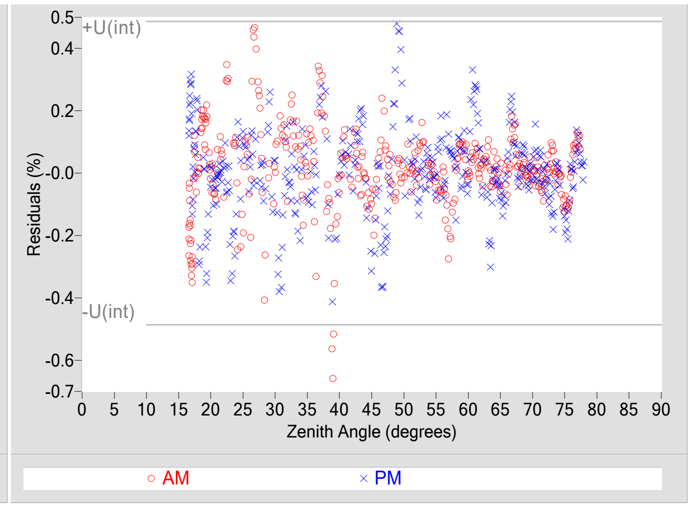


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	4677
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.76
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

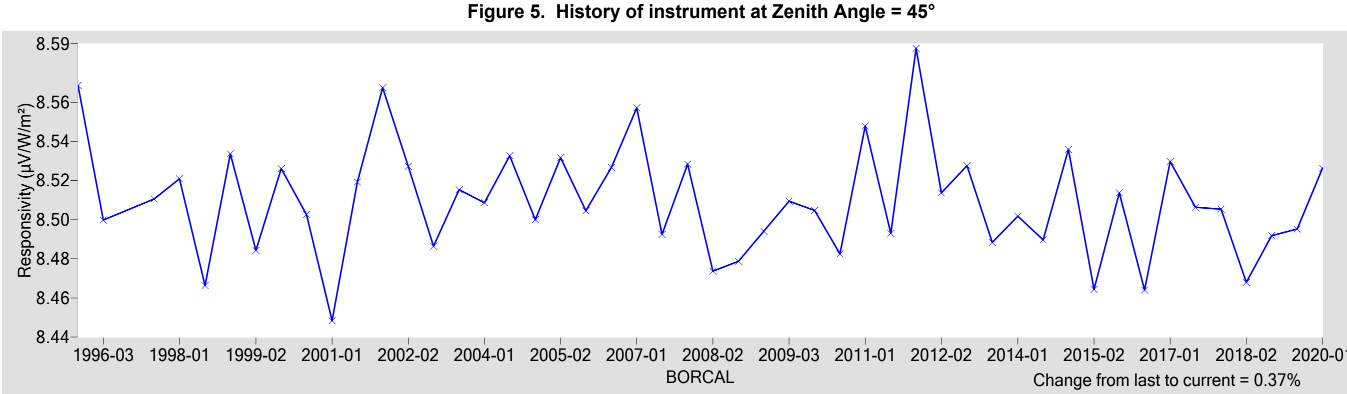
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5263	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.95 / -0.39
Expanded Uncertainty, U (%)	+1.5 / -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.

[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:**	31121E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

31121E6 Eppley NIP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

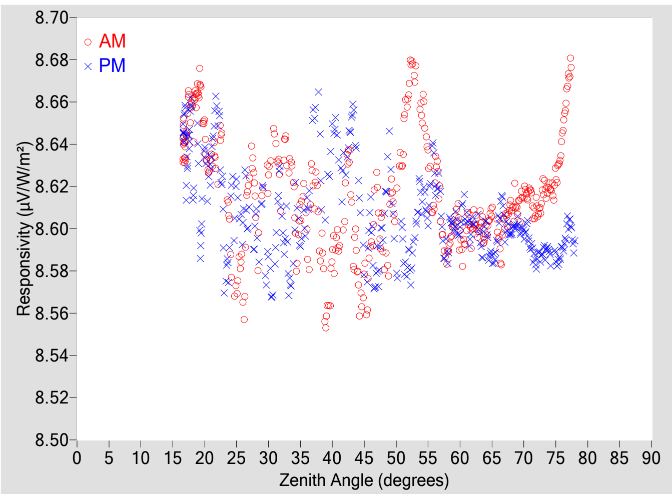


Figure 2. Responsivity vs Local Standard Time

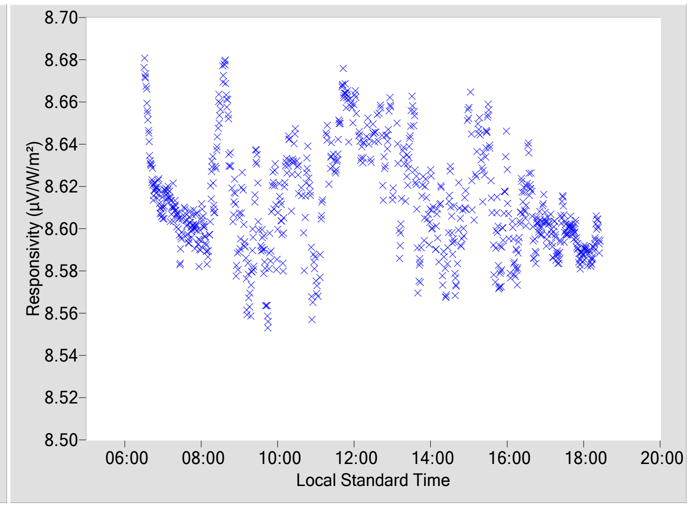


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5904	0.29	97.31	8.6042	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5923	0.29	95.57	8.6049	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6113	0.29	93.95	8.5778	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6662	0.29	92.37	8.5831	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6567	0.29	90.82	8.6123	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6168	0.30	89.36	8.6278	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5885	0.30	87.79	8.5891	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5958	0.30	86.41	8.6018	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6003	0.30	85.02	8.6032	0.29	275.08
18	8.6573	0.28	155.76	8.6404	0.28	204.65	64	8.5970	0.30	83.64	8.6013	0.30	276.47
20	8.6446	0.28	142.83	8.6350	0.28	217.28	66	8.5969	0.30	82.26	8.6004	0.30	277.83
22	8.6247	0.28	135.05	8.6563	0.28	225.38	68	8.6103	0.30	80.92	8.5982	0.30	279.24
24	8.5939	0.29	128.53	8.6004	0.28	231.54	70	8.6170	N/A	79.48	8.5982	0.30	280.64
26	8.5695	0.29	123.40	8.6029	0.28	236.40	72	8.6088	N/A	78.10	8.5848	N/A	281.96
28	8.6142	0.29	119.60	8.6007	0.28	240.63	74	8.6191	N/A	76.77	8.5882	N/A	283.36
30	8.6254	0.29	115.90	8.5858	0.28	244.31	76	8.6438	N/A	75.32	8.5899	N/A	284.76
32	8.6170	0.29	112.97	8.6110	0.28	247.40	78	N/A	N/A	N/A	8.5918	N/A	286.09
34	8.6111	0.29	109.83	8.6015	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5976	0.29	107.37	8.6076	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5940	0.29	105.10	8.6353	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5862	0.29	102.87	8.6438	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6149	0.29	100.92	8.6308	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5762	0.29	99.03	8.6252	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

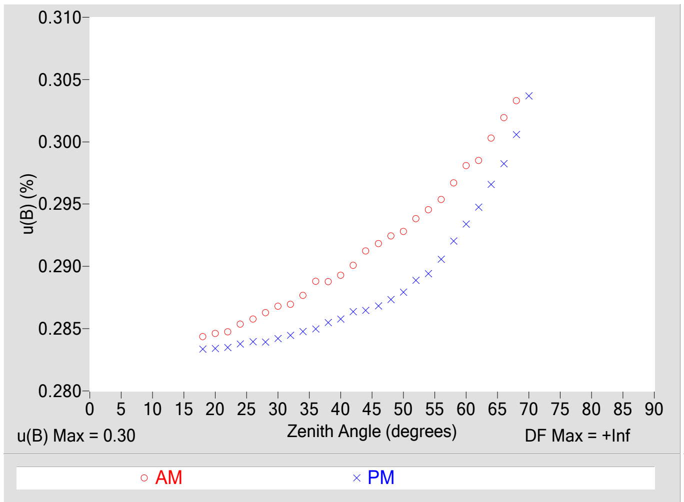


Figure 4. Residuals from Spline Interpolation

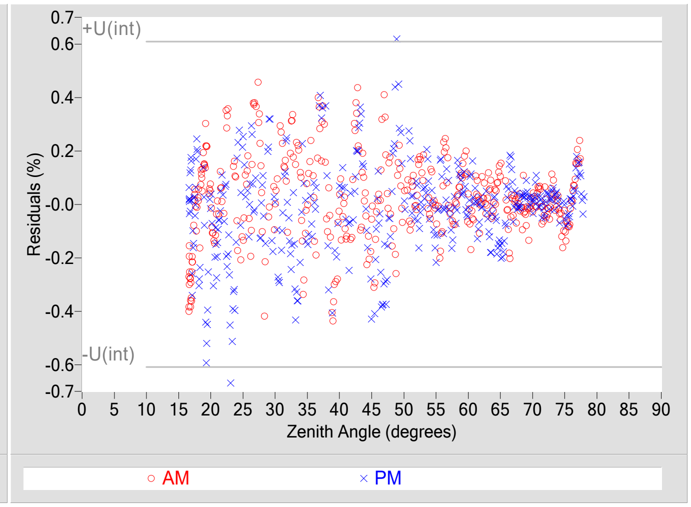


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.43
Effective degrees of freedom, DF(c)	2841
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.84
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

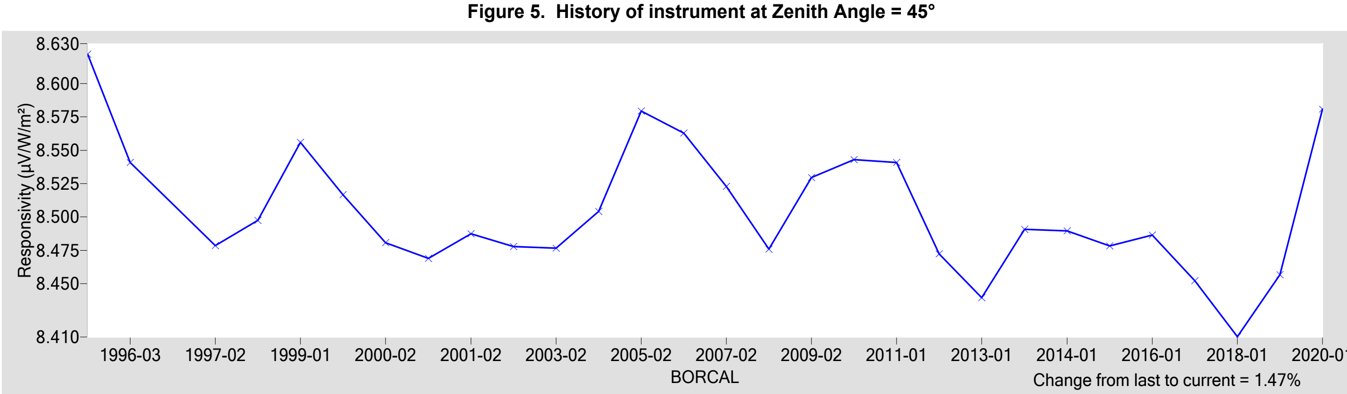
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5808	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.99 / -0.054
Expanded Uncertainty, U (%)	+1.6 / -0.64
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:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31146F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

31146F3 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

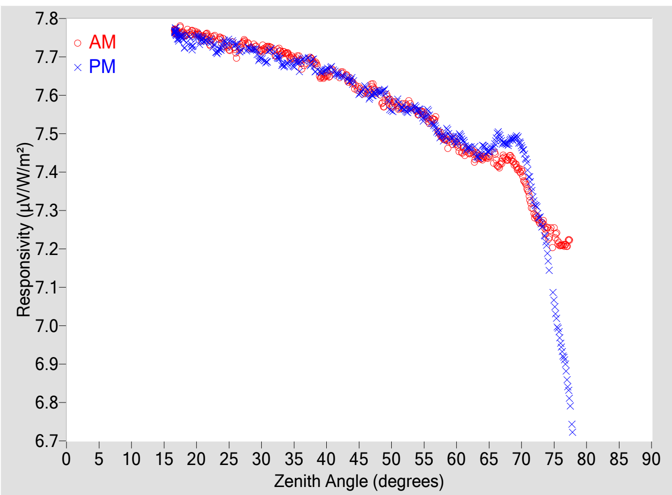


Figure 2. Responsivity vs Local Standard Time

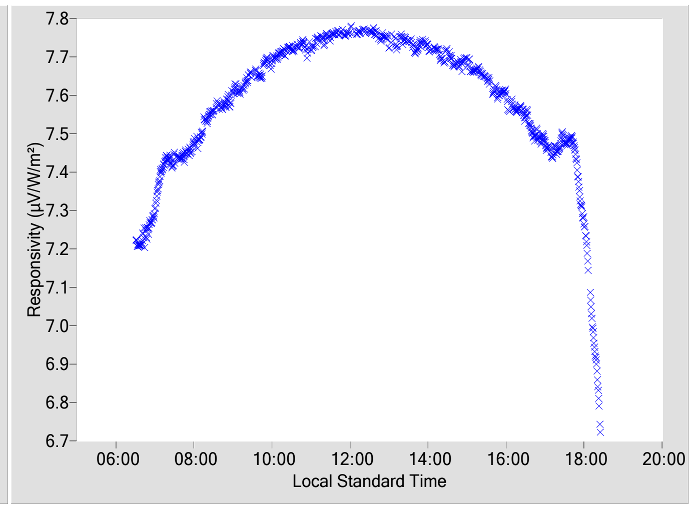


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.6104	0.32	97.40	7.6207	0.31	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6065	0.32	95.37	7.6085	0.31	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5767	0.33	93.93	7.5585	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5722	0.33	92.20	7.5651	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5556	0.34	90.84	7.5615	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5333	0.34	89.29	7.5339	0.33	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4869	0.35	87.85	7.4920	0.34	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4735	0.36	86.43	7.4818	0.35	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4490	0.37	85.04	7.4640	0.36	275.06
18	7.7593	0.29	155.25	7.7407	0.29	204.43	64	7.4357	0.38	83.66	7.4644	0.38	276.47
20	7.7618	0.29	142.77	7.7541	0.29	217.82	66	7.4342	0.40	82.27	7.4827	0.39	277.85
22	7.7387	0.29	134.07	7.7416	0.29	225.95	68	7.4375	0.42	80.85	7.4773	0.41	279.26
24	7.7395	0.29	128.59	7.7272	0.29	231.33	70	7.3990	N/A	79.52	7.4661	0.44	280.61
26	7.7127	0.30	123.57	7.7314	0.29	236.63	72	7.2897	N/A	78.11	7.3204	N/A	281.97
28	7.7314	0.30	119.37	7.7235	0.29	240.77	74	7.2436	N/A	76.70	7.1857	N/A	283.37
30	7.7189	0.30	115.85	7.6973	0.29	244.10	76	7.2105	N/A	75.34	6.9566	N/A	284.78
32	7.7069	0.30	112.56	7.7085	0.30	247.52	78	N/A	N/A	N/A	6.7330	N/A	286.07
34	7.7090	0.30	109.94	7.6830	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6872	0.31	107.40	7.6792	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6879	0.31	105.08	7.6812	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6523	0.31	102.96	7.6673	0.30	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6536	0.31	100.76	7.6521	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6331	0.32	99.06	7.6382	0.31	260.99	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

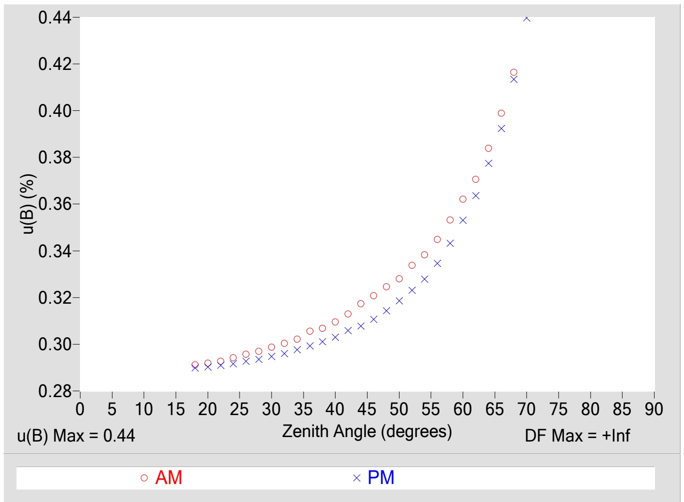


Figure 4. Residuals from Spline Interpolation

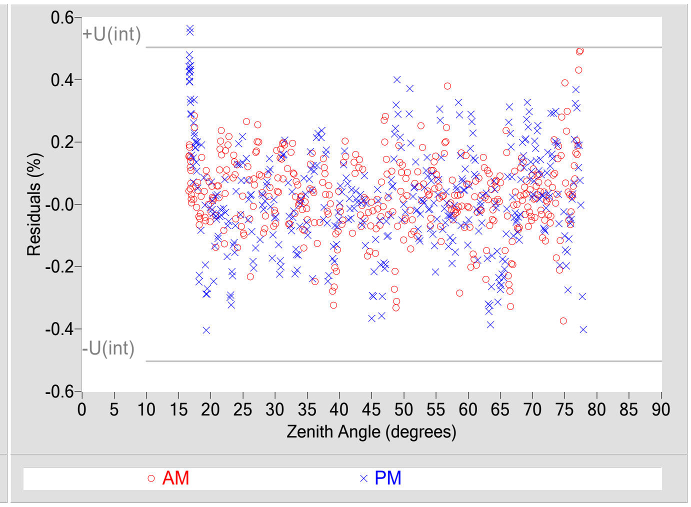


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	11512
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

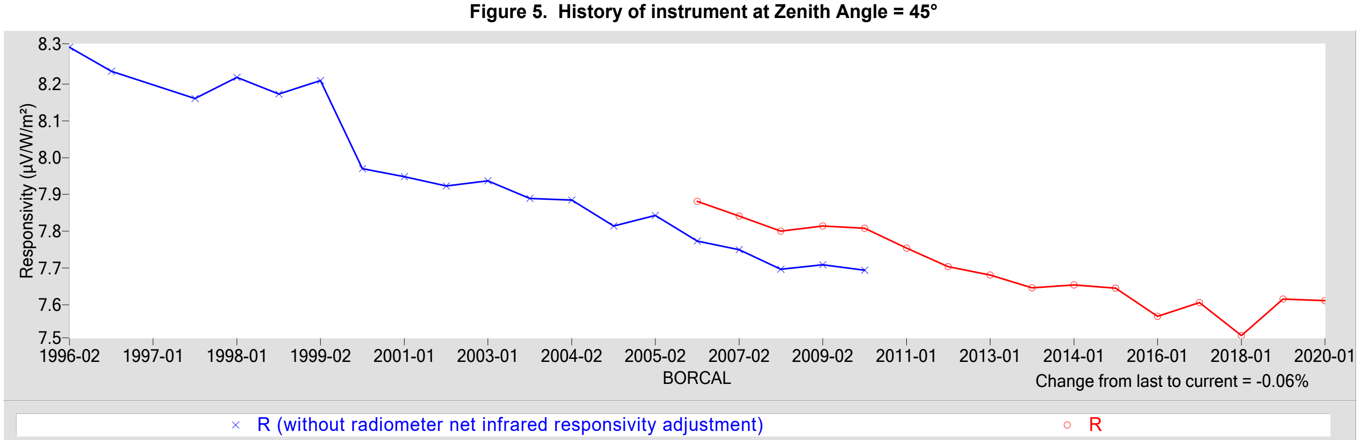
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6111	0.54900

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.4 / -1.8
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:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31147F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

31147F3 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

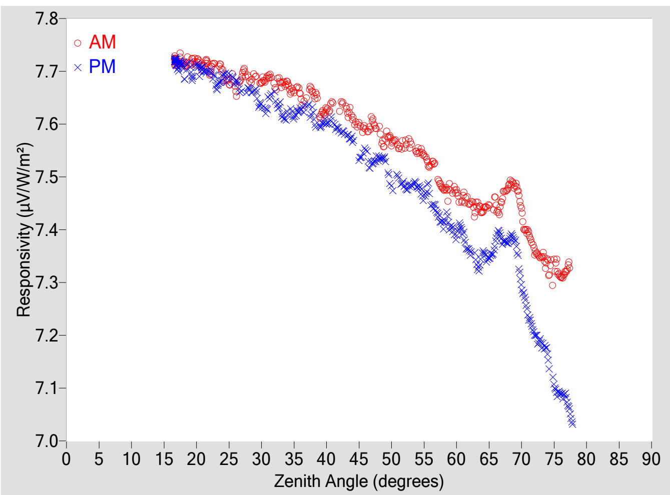


Figure 2. Responsivity vs Local Standard Time

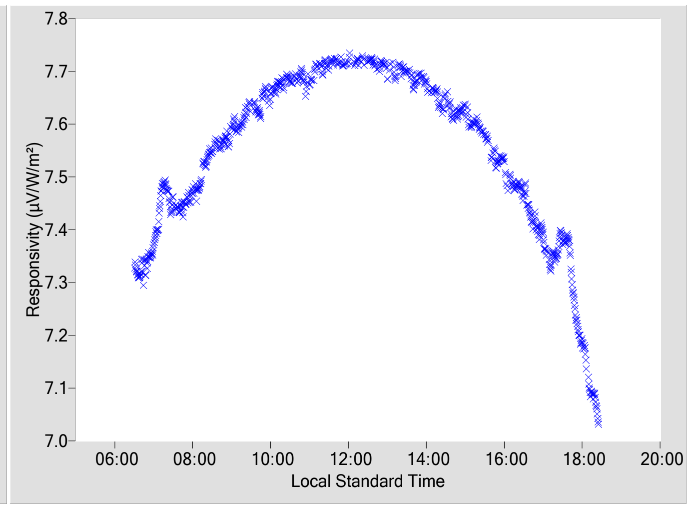


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5935	0.32	97.40	7.5514	0.31	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5886	0.33	95.37	7.5348	0.32	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5684	0.33	93.93	7.4784	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5621	0.33	92.20	7.4835	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5484	0.34	90.84	7.4822	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5229	0.35	89.29	7.4542	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4772	0.35	87.85	7.4130	0.34	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4708	0.36	86.43	7.3920	0.35	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4486	0.37	85.04	7.3592	0.37	275.06
18	7.7140	0.29	155.25	7.7025	0.29	204.43	64	7.4347	0.39	83.66	7.3541	0.38	276.47
20	7.7204	0.29	142.77	7.7112	0.29	217.82	66	7.4482	0.40	82.27	7.3771	0.39	277.85
22	7.6988	0.29	134.07	7.6997	0.29	225.95	68	7.4837	0.42	80.85	7.3794	0.42	279.26
24	7.6973	0.29	128.59	7.6880	0.29	231.33	70	7.4373	N/A	79.52	7.2916	0.44	280.61
26	7.6663	0.30	123.57	7.6799	0.29	236.63	72	7.3607	N/A	78.11	7.2033	N/A	281.97
28	7.6874	0.30	119.37	7.6674	0.29	240.77	74	7.3304	N/A	76.70	7.1611	N/A	283.37
30	7.6805	0.30	115.85	7.6368	0.30	244.10	76	7.3118	N/A	75.34	7.0904	N/A	284.78
32	7.6705	0.30	112.56	7.6522	0.30	247.52	78	N/A	N/A	N/A	7.0336	N/A	286.07
34	7.6771	0.30	109.94	7.6164	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6533	0.31	107.40	7.6274	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6561	0.31	105.08	7.6154	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6274	0.31	102.96	7.6030	0.30	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6334	0.31	100.76	7.5875	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6128	0.32	99.06	7.5713	0.31	260.99	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

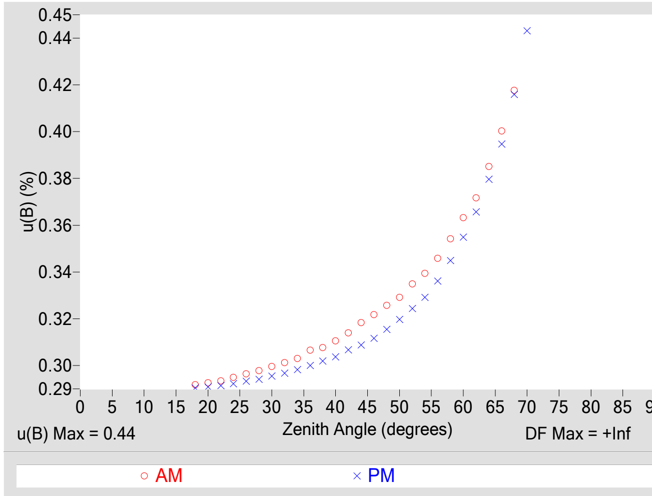


Figure 4. Residuals from Spline Interpolation

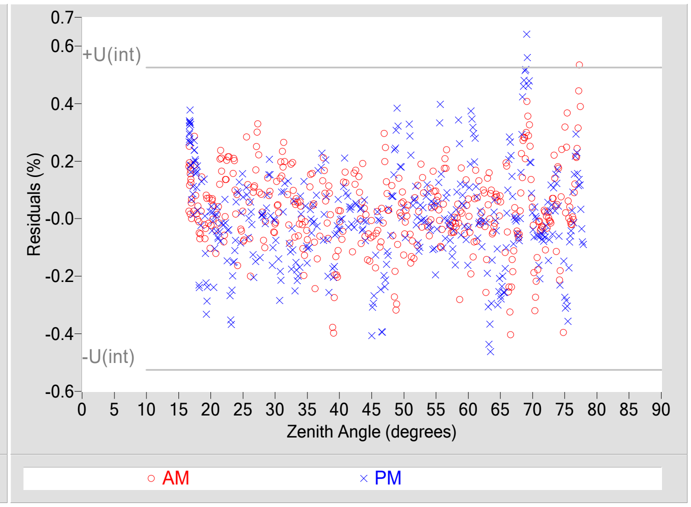


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	10310
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

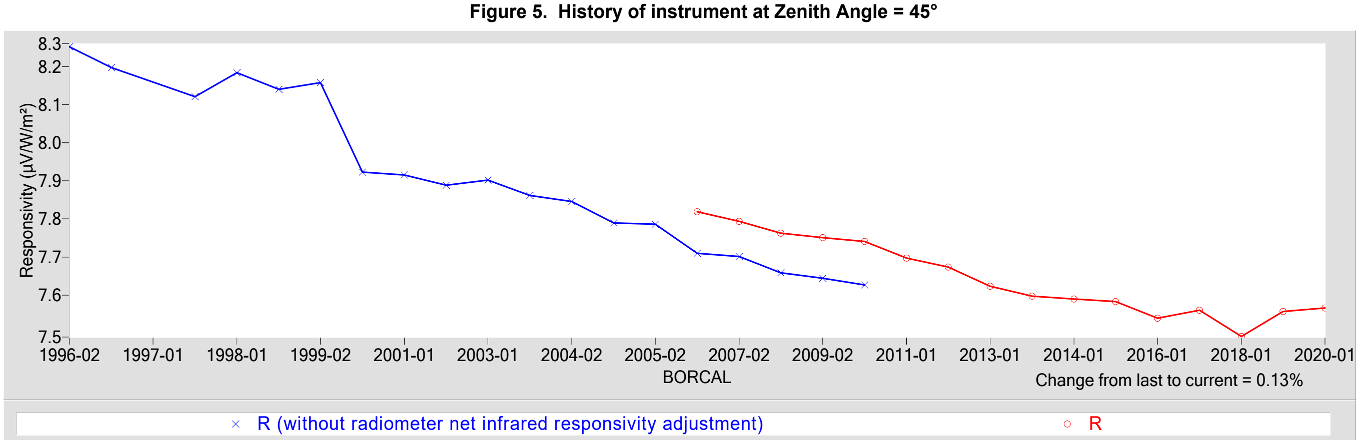
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5666	0.55100

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.5 / -2.3
Expanded Uncertainty, U (%)	+2.2 / -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 (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31148F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

31148F3 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

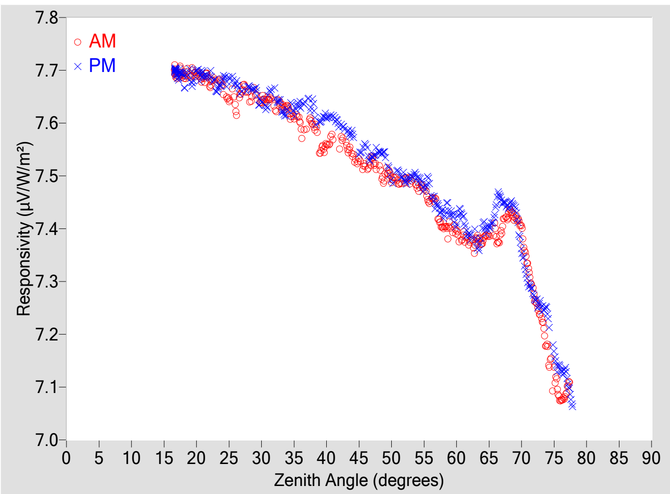


Figure 2. Responsivity vs Local Standard Time

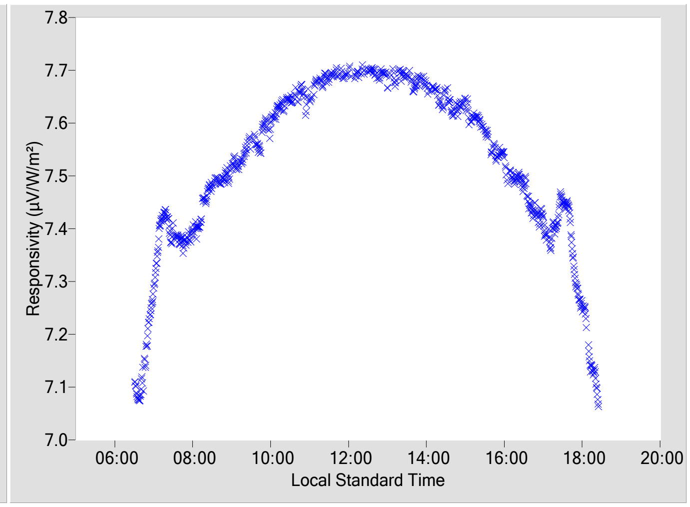


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5201	0.32	97.40	7.5578	0.31	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5150	0.33	95.37	7.5450	0.31	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4958	0.33	93.93	7.4890	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4930	0.33	92.20	7.4950	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4801	0.34	90.84	7.4961	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4542	0.35	89.29	7.4696	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4025	0.35	87.85	7.4298	0.34	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3940	0.36	86.43	7.4154	0.35	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3737	0.37	85.04	7.3868	0.36	275.06
18	7.6899	0.29	155.25	7.6842	0.29	204.43	64	7.3746	0.38	83.66	7.4019	0.38	276.47
20	7.6934	0.29	142.77	7.6989	0.29	217.82	66	7.3909	0.40	82.27	7.4388	0.39	277.85
22	7.6720	0.29	134.07	7.6919	0.29	225.95	68	7.4276	0.42	80.85	7.4437	0.41	279.26
24	7.6684	0.29	128.59	7.6806	0.29	231.33	70	7.4000	N/A	79.52	7.3581	0.44	280.61
26	7.6304	0.30	123.57	7.6741	0.29	236.63	72	7.2704	N/A	78.11	7.2693	N/A	281.97
28	7.6528	0.30	119.37	7.6691	0.29	240.77	74	7.1631	N/A	76.70	7.2368	N/A	283.37
30	7.6425	0.30	115.85	7.6422	0.30	244.10	76	7.0767	N/A	75.34	7.1349	N/A	284.78
32	7.6263	0.30	112.56	7.6571	0.30	247.52	78	N/A	N/A	N/A	7.0656	N/A	286.07
34	7.6310	0.30	109.94	7.6218	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5950	0.31	107.40	7.6338	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5940	0.31	105.08	7.6291	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5586	0.31	102.96	7.6121	0.30	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5627	0.31	100.76	7.5962	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5403	0.32	99.06	7.5797	0.31	260.99	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

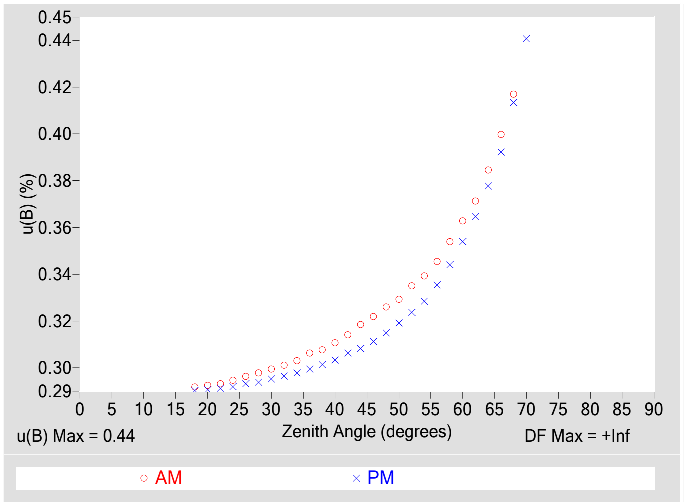


Figure 4. Residuals from Spline Interpolation

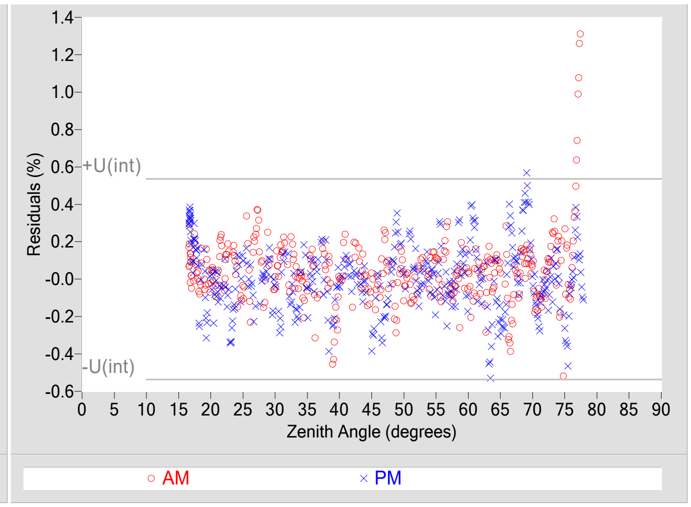


Table 3. Uncertainty using Spline Interpolation ‡

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)	9579
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

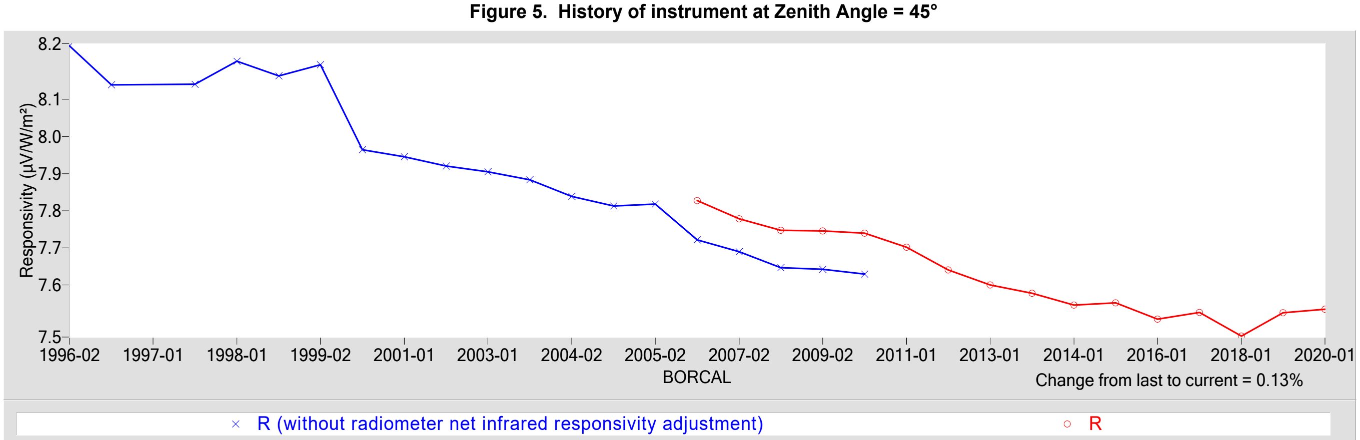
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5352	0.53300

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.6 / -1.9
Expanded Uncertainty, U (%)	+2.3 / -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:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31152F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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:

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

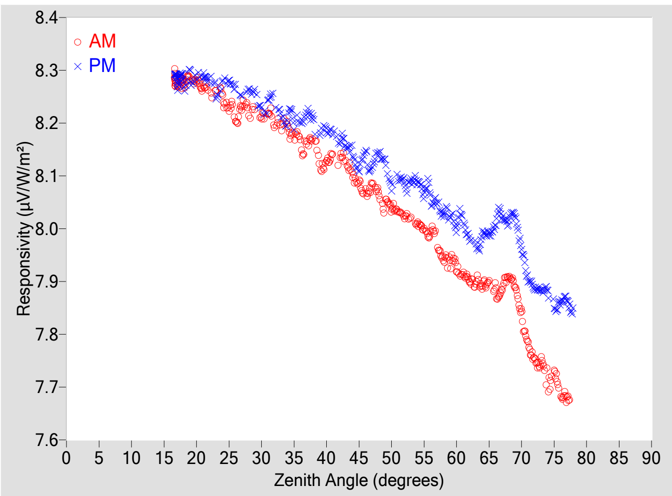


Figure 2. Responsivity vs Local Standard Time

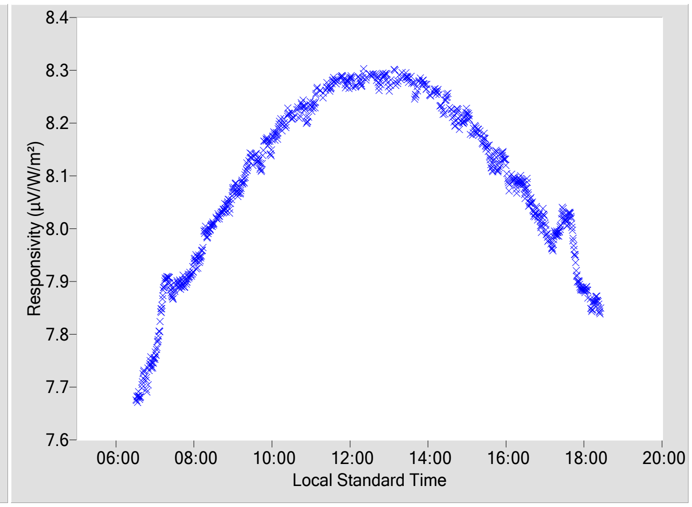


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0682	0.32	97.12	8.1462	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0680	0.33	95.56	8.1430	0.32	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0410	0.33	93.91	8.0830	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0228	0.34	92.28	8.0864	0.33	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0087	0.34	90.78	8.0882	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9919	0.35	89.35	8.0612	0.34	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9429	0.36	87.89	8.0284	0.35	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9288	0.36	86.46	8.0037	0.36	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9012	0.37	85.06	7.9820	0.37	275.04
18	8.2751	0.29	155.82	8.2791	0.29	204.36	64	7.8943	0.39	83.61	7.9888	0.38	276.48
20	8.2820	0.29	142.89	8.2896	0.29	217.44	66	7.8843	0.40	82.26	8.0117	0.40	277.88
22	8.2597	0.29	134.62	8.2829	0.29	225.85	68	7.9076	0.42	80.88	8.0127	0.42	279.21
24	8.2489	0.30	128.47	8.2797	0.29	231.63	70	7.8351	N/A	79.51	7.9625	0.45	280.60
26	8.2046	0.30	123.40	8.2672	0.29	236.25	72	7.7526	N/A	78.14	7.8869	N/A	282.00
28	8.2227	0.30	119.46	8.2619	0.29	240.69	74	7.7124	N/A	76.73	7.8814	N/A	283.36
30	8.2138	0.30	115.76	8.2308	0.30	244.01	76	7.6868	N/A	75.34	7.8613	N/A	284.81
32	8.1938	0.30	112.81	8.2428	0.30	247.32	78	N/A	N/A	N/A	7.8444	N/A	286.10
34	8.1934	0.30	109.84	8.2080	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1611	0.31	107.40	8.2006	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1673	0.31	105.13	8.2021	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1290	0.31	102.88	8.1864	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1322	0.31	100.89	8.1647	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0983	0.32	98.93	8.1399	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

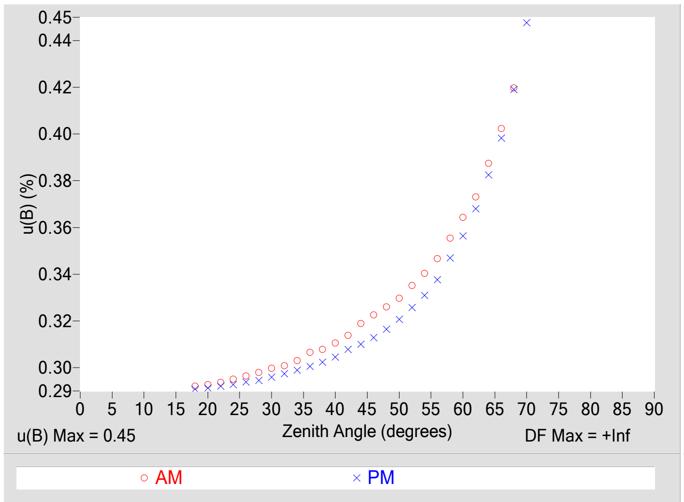


Figure 4. Residuals from Spline Interpolation

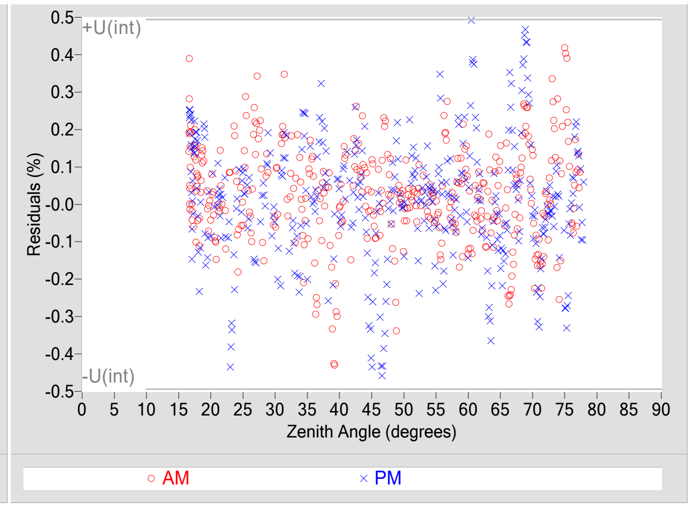


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	12993
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

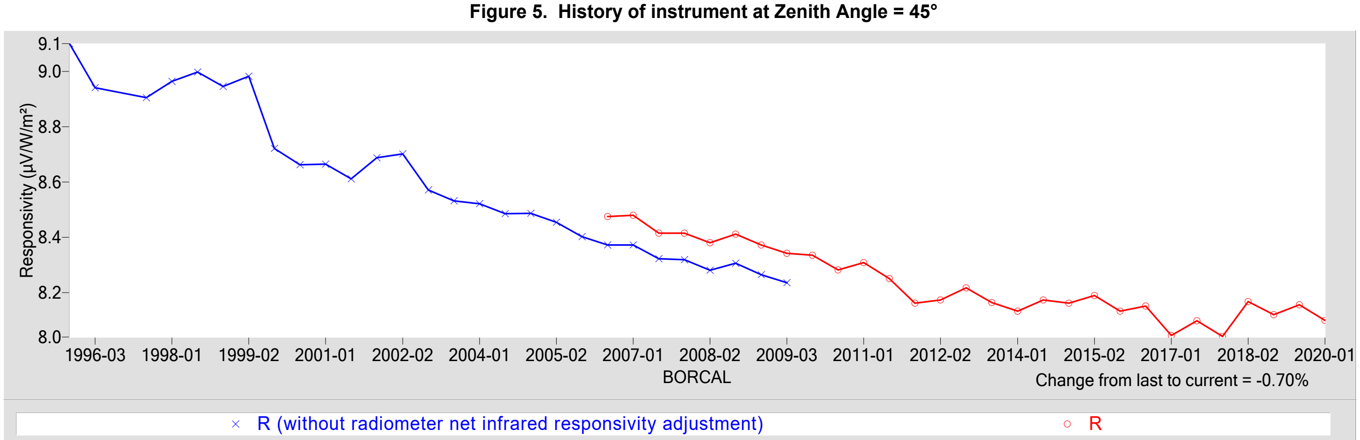
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0999	0.63390

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.8 / -2.1
Expanded Uncertainty, U (%)	+2.5 / -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:**	31153F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

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

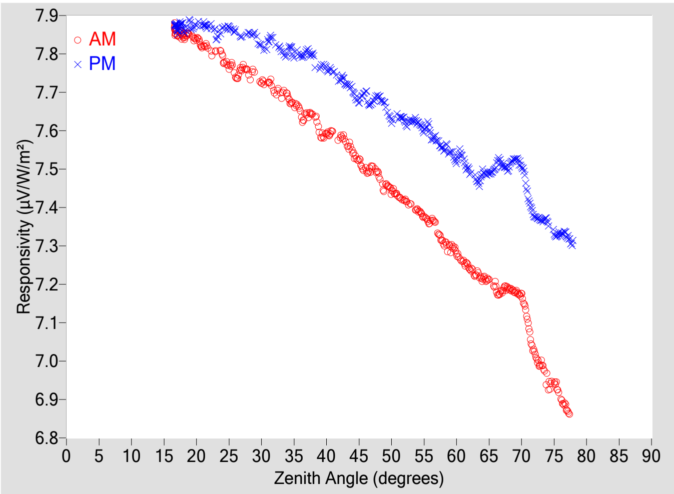


Figure 2. Responsivity vs Local Standard Time

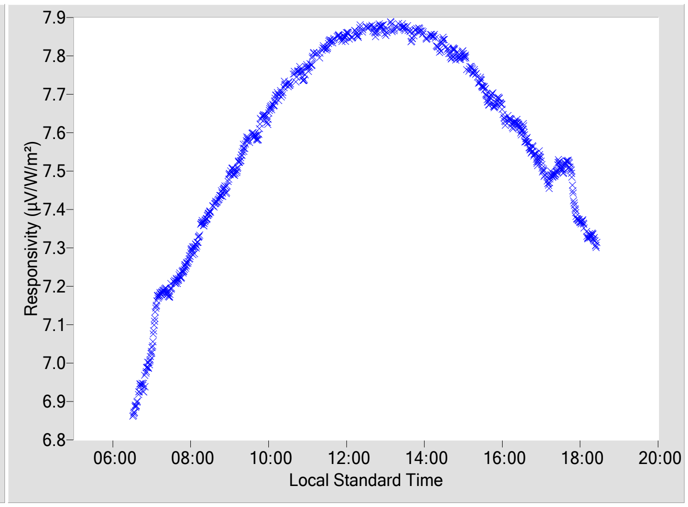


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.4960	0.32	97.12	7.7013	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4860	0.33	95.56	7.6898	0.32	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4457	0.33	93.91	7.6287	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4186	0.34	92.28	7.6259	0.33	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3927	0.34	90.78	7.6210	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3636	0.35	89.35	7.5928	0.34	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3089	0.36	87.89	7.5519	0.35	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2829	0.37	86.46	7.5227	0.36	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2419	0.38	85.06	7.4950	0.37	275.04
18	7.8455	0.29	155.82	7.8678	0.29	204.36	64	7.2151	0.39	83.61	7.4888	0.39	276.48
20	7.8397	0.29	142.89	7.8784	0.29	217.44	66	7.1936	0.41	82.26	7.5086	0.40	277.88
22	7.8116	0.29	134.62	7.8727	0.29	225.85	68	7.1894	0.43	80.88	7.5029	0.42	279.21
24	7.7907	0.30	128.47	7.8683	0.29	231.63	70	7.1682	N/A	79.51	7.5078	0.45	280.60
26	7.7409	0.30	123.40	7.8584	0.29	236.25	72	7.0218	N/A	78.14	7.3766	N/A	282.00
28	7.7490	0.30	119.46	7.8533	0.30	240.69	74	6.9446	N/A	76.73	7.3626	N/A	283.36
30	7.7274	0.30	115.76	7.8239	0.30	244.01	76	6.9057	N/A	75.34	7.3313	N/A	284.81
32	7.7018	0.30	112.81	7.8326	0.30	247.32	78	N/A	N/A	N/A	7.3076	N/A	286.10
34	7.6899	0.30	109.84	7.8050	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6461	0.31	107.40	7.7941	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6404	0.31	105.13	7.7896	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5931	0.31	102.88	7.7611	0.31	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5817	0.32	100.89	7.7322	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5402	0.32	98.93	7.7026	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

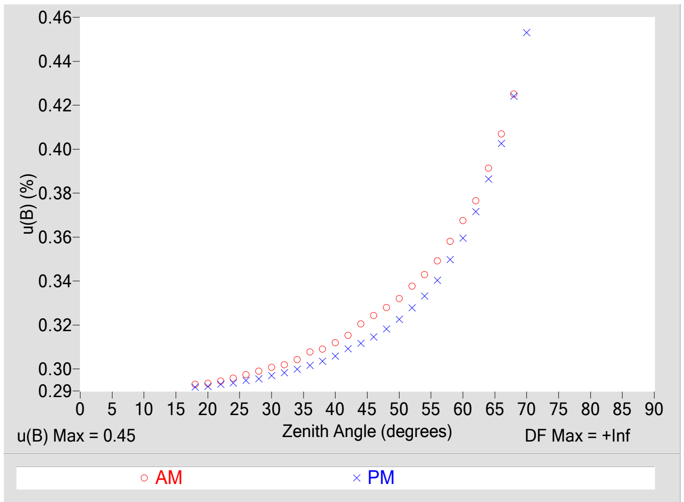


Figure 4. Residuals from Spline Interpolation

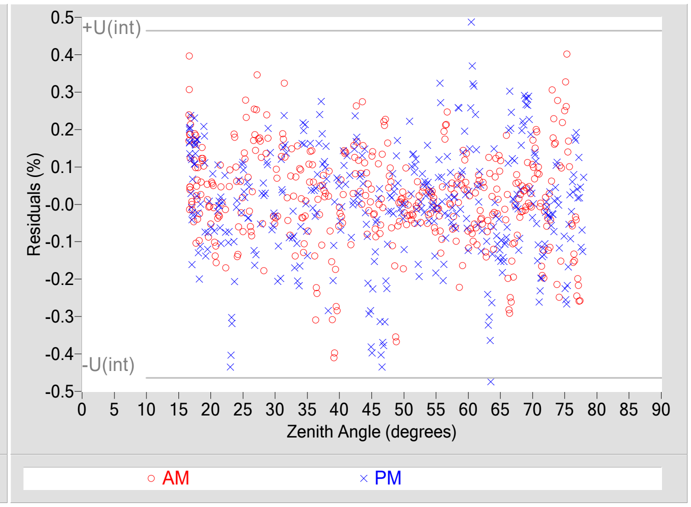


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	16421
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.00
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

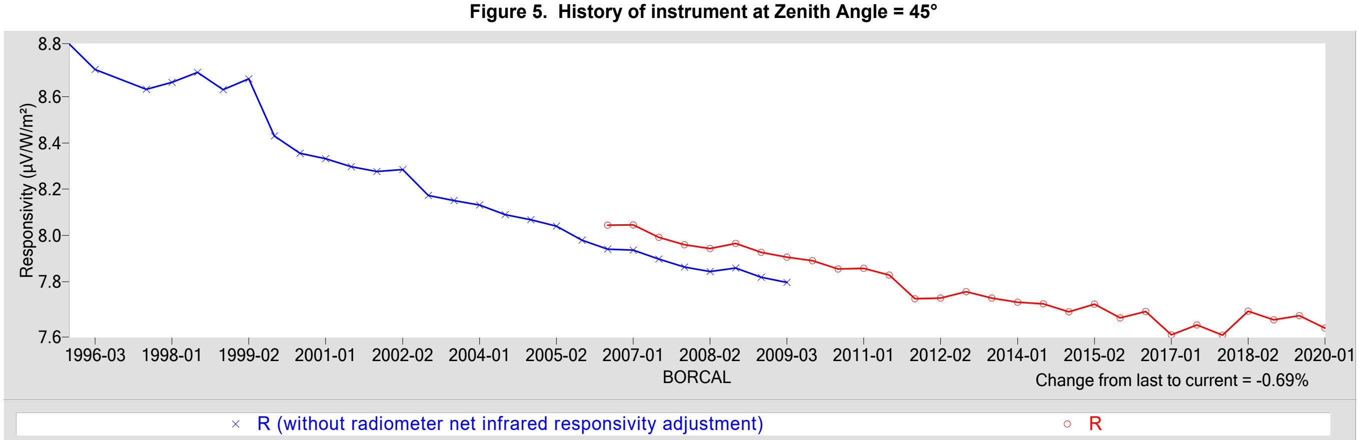
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5993	0.64286

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.72
Offset Uncertainty, U(off) (%)	+3.1 / -4.2
Expanded Uncertainty, U (%)	+3.8 / -4.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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 - 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

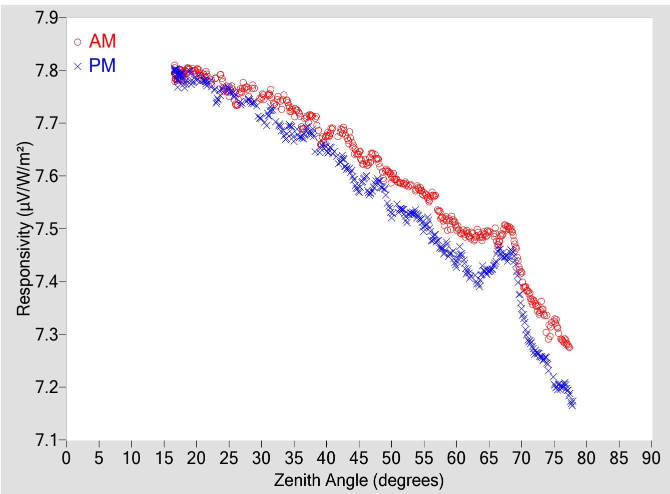


Figure 2. Responsivity vs Local Standard Time

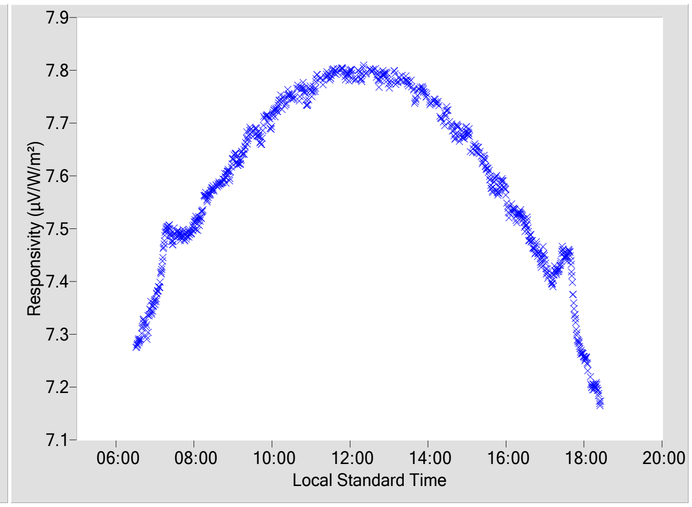


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6250	0.32	97.12	7.5986	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6276	0.33	95.56	7.5916	0.32	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5996	0.33	93.91	7.5300	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5853	0.33	92.28	7.5279	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5763	0.34	90.78	7.5237	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5590	0.35	89.35	7.4935	0.34	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5168	0.35	87.89	7.4583	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5047	0.36	86.46	7.4350	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4856	0.37	85.06	7.4138	0.37	275.04
18	7.7896	0.29	155.82	7.7829	0.29	204.36	64	7.4860	0.39	83.61	7.4194	0.38	276.48
20	7.7996	0.29	142.89	7.7861	0.29	217.44	66	7.4882	0.40	82.26	7.4428	0.40	277.88
22	7.7849	0.29	134.62	7.7756	0.29	225.85	68	7.5019	0.42	80.88	7.4465	0.42	279.21
24	7.7762	0.29	128.47	7.7647	0.29	231.63	70	7.4100	N/A	79.51	7.3513	0.44	280.60
26	7.7369	0.30	123.40	7.7516	0.29	236.25	72	7.3592	N/A	78.14	7.2670	N/A	282.00
28	7.7563	0.30	119.46	7.7429	0.29	240.69	74	7.3120	N/A	76.73	7.2438	N/A	283.36
30	7.7503	0.30	115.76	7.7092	0.30	244.01	76	7.2944	N/A	75.34	7.2010	N/A	284.81
32	7.7367	0.30	112.81	7.7138	0.30	247.32	78	N/A	N/A	N/A	7.1690	N/A	286.10
34	7.7378	0.30	109.84	7.6821	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7064	0.31	107.40	7.6729	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7121	0.31	105.13	7.6725	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6770	0.31	102.88	7.6505	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6821	0.31	100.89	7.6271	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6540	0.32	98.93	7.5987	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

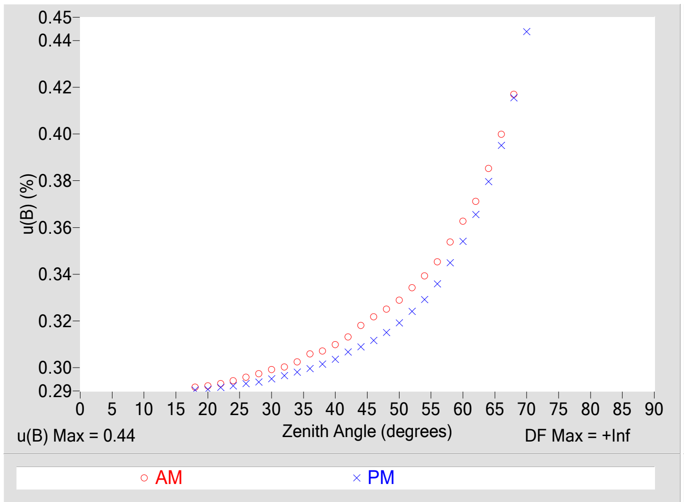


Figure 4. Residuals from Spline Interpolation

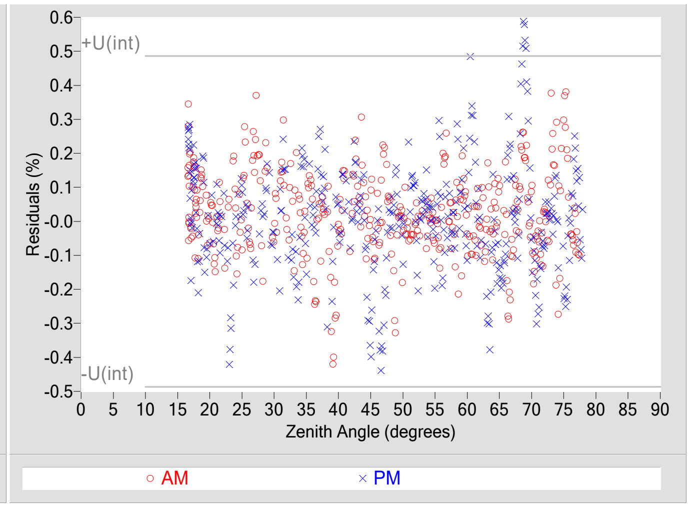


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	13247
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

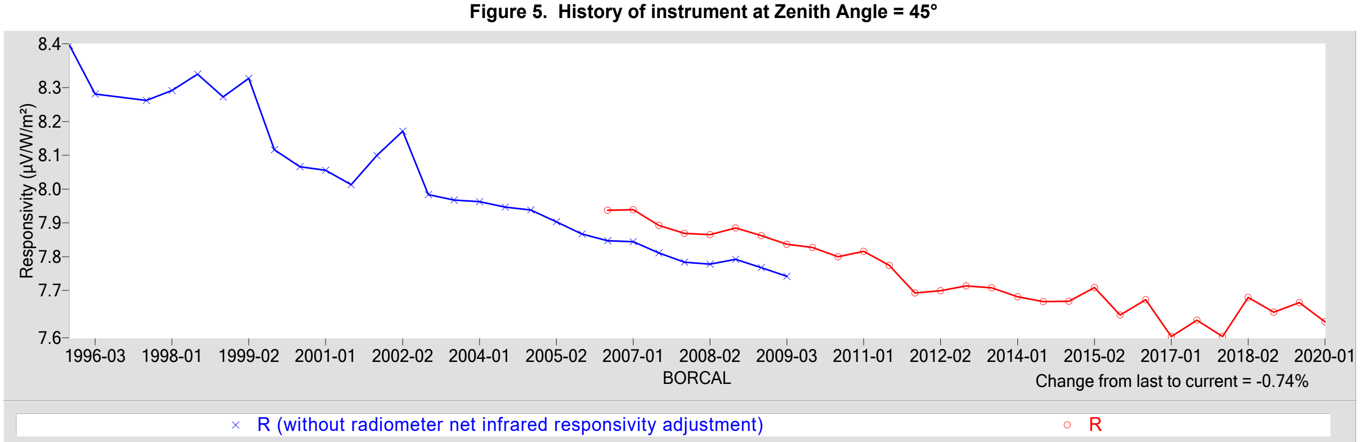
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6075	0.56158

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.9 / -2.3
Expanded Uncertainty, U (%)	+2.6 / -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:**	31155F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

31155F3 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

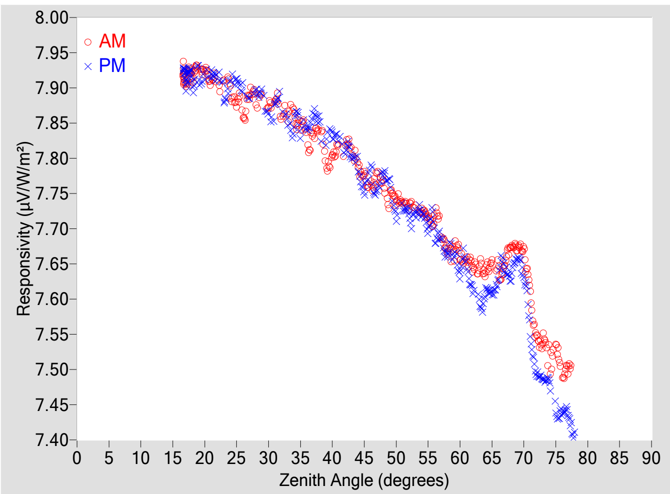


Figure 2. Responsivity vs Local Standard Time

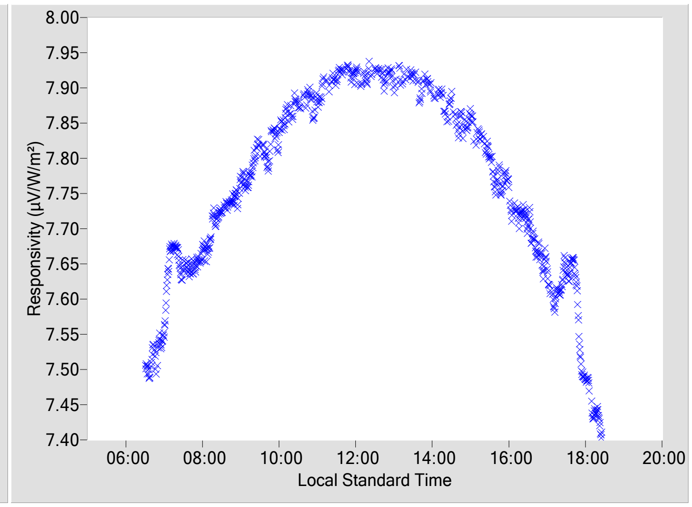


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.7610	0.32	97.12	7.7869	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7634	0.32	95.56	7.7790	0.31	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7423	0.33	93.91	7.7203	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7326	0.33	92.28	7.7201	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7249	0.34	90.78	7.7216	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7145	0.34	89.35	7.6986	0.33	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6699	0.35	87.89	7.6652	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6648	0.36	86.46	7.6389	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6456	0.37	85.06	7.6148	0.36	275.04
18	7.9157	0.29	155.82	7.9120	0.29	204.36	64	7.6416	0.38	83.61	7.6098	0.38	276.48
20	7.9259	0.29	142.89	7.9192	0.29	217.44	66	7.6432	0.40	82.26	7.6319	0.39	277.88
22	7.9060	0.29	134.62	7.9171	0.29	225.85	68	7.6742	0.42	80.88	7.6329	0.41	279.21
24	7.8974	0.29	128.47	7.9099	0.29	231.63	70	7.6627	N/A	79.51	7.6307	0.44	280.60
26	7.8601	0.30	123.40	7.8992	0.29	236.25	72	7.5473	N/A	78.14	7.4934	N/A	282.00
28	7.8842	0.30	119.46	7.8946	0.29	240.69	74	7.5146	N/A	76.73	7.4808	N/A	283.36
30	7.8752	0.30	115.76	7.8649	0.29	244.01	76	7.4939	N/A	75.34	7.4393	N/A	284.81
32	7.8575	0.30	112.81	7.8804	0.30	247.32	78	N/A	N/A	N/A	7.4068	N/A	286.10
34	7.8626	0.30	109.84	7.8468	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8294	0.31	107.40	7.8415	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8386	0.31	105.13	7.8467	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8049	0.31	102.88	7.8329	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8156	0.31	100.89	7.8108	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7862	0.32	98.93	7.7849	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

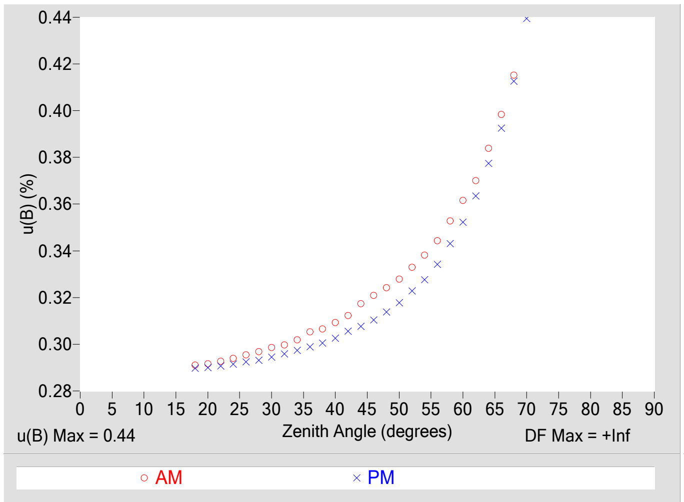


Figure 4. Residuals from Spline Interpolation

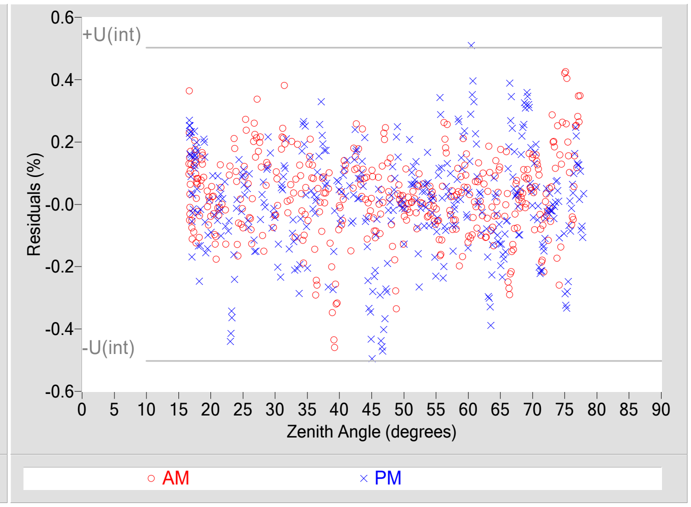


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	11673
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

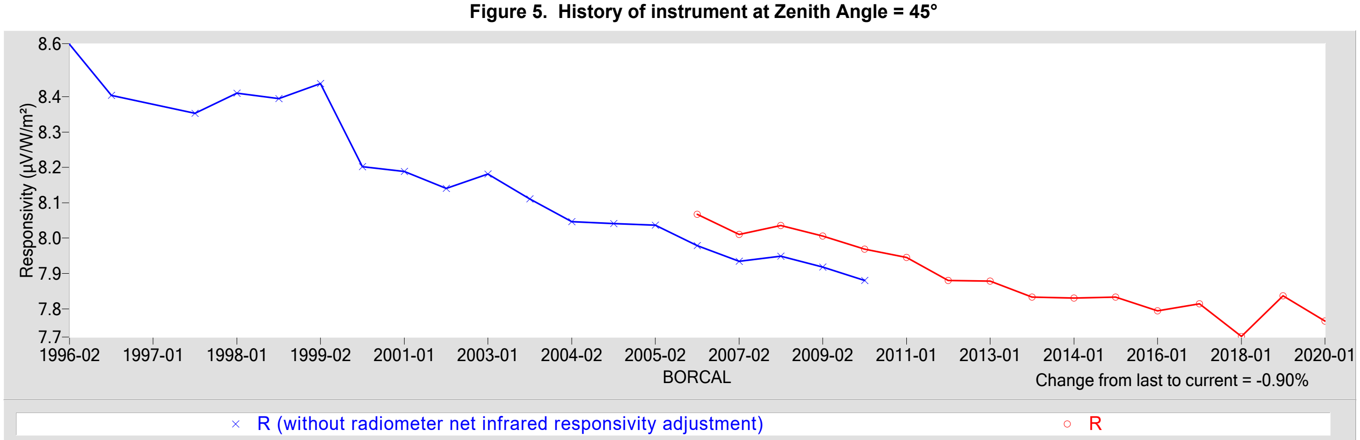
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.7656	0.52400

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.5 / -1.6
Expanded Uncertainty, U (%)	+2.2 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	31156F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

31156F3 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

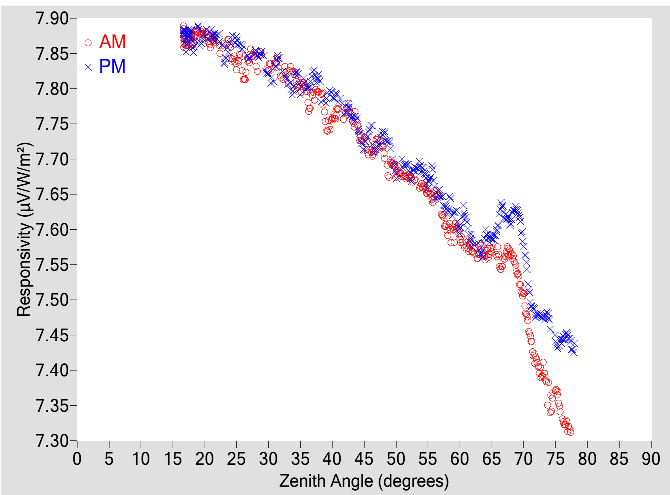


Figure 2. Responsivity vs Local Standard Time

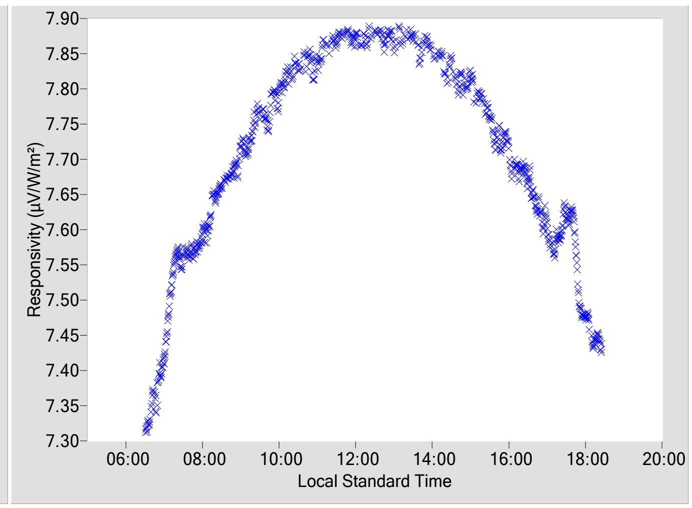


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.7103	0.32	97.12	7.7457	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7129	0.32	95.56	7.7370	0.31	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6851	0.33	93.91	7.6812	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6742	0.33	92.28	7.6843	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6626	0.34	90.78	7.6857	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6461	0.34	89.35	7.6608	0.33	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6008	0.35	87.89	7.6279	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5909	0.36	86.46	7.6020	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5699	0.37	85.06	7.5826	0.36	275.04
18	7.8691	0.29	155.82	7.8688	0.29	204.36	64	7.5650	0.38	83.61	7.5907	0.38	276.48
20	7.8779	0.29	142.89	7.8786	0.29	217.44	66	7.5622	0.40	82.26	7.6122	0.39	277.88
22	7.8633	0.29	134.62	7.8738	0.29	225.85	68	7.5655	0.42	80.88	7.6133	0.41	279.21
24	7.8545	0.29	128.47	7.8662	0.29	231.63	70	7.5010	N/A	79.51	7.5764	0.44	280.60
26	7.8162	0.30	123.40	7.8574	0.29	236.25	72	7.4119	N/A	78.14	7.4780	N/A	282.00
28	7.8385	0.30	119.46	7.8505	0.29	240.69	74	7.3595	N/A	76.73	7.4708	N/A	283.36
30	7.8303	0.30	115.76	7.8220	0.29	244.01	76	7.3329	N/A	75.34	7.4437	N/A	284.81
32	7.8167	0.30	112.81	7.8340	0.30	247.32	78	N/A	N/A	N/A	7.4318	N/A	286.10
34	7.8186	0.30	109.84	7.8072	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7900	0.31	107.40	7.8009	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7941	0.31	105.13	7.8065	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7590	0.31	102.88	7.7909	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7653	0.31	100.89	7.7671	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7383	0.32	98.93	7.7439	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

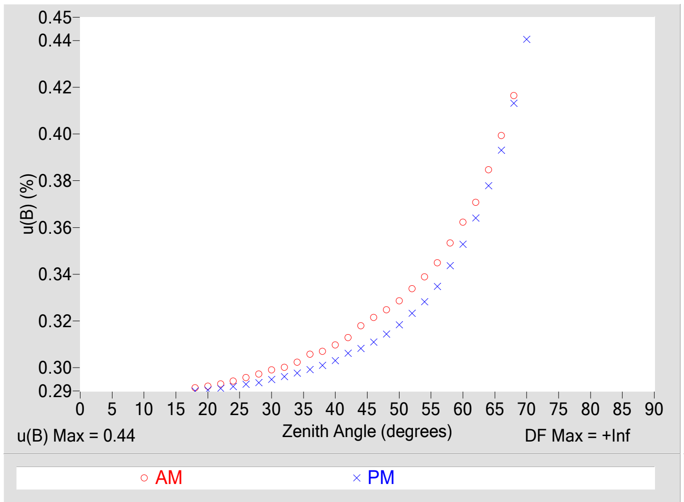


Figure 4. Residuals from Spline Interpolation

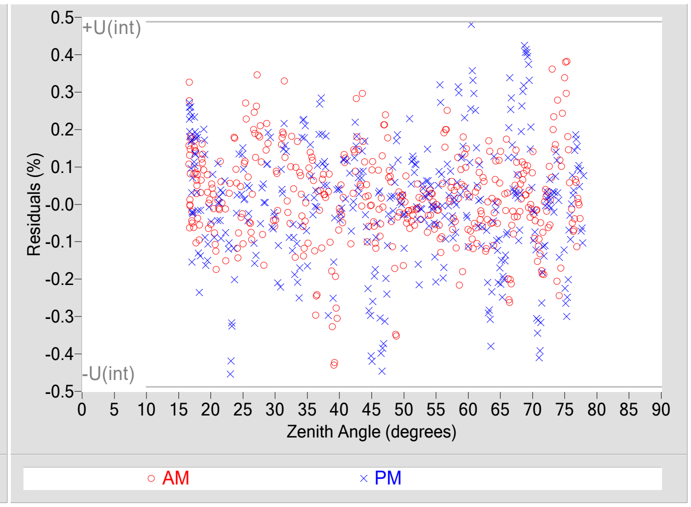


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	12812
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

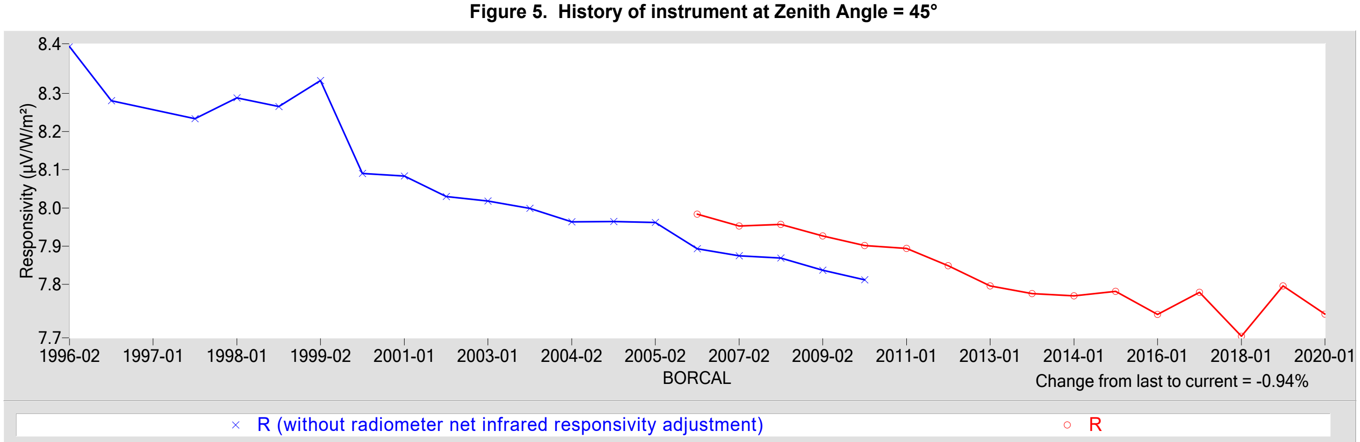
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.7221	0.53200

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.4 / -1.7
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

[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:**	31157F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

31157F3 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

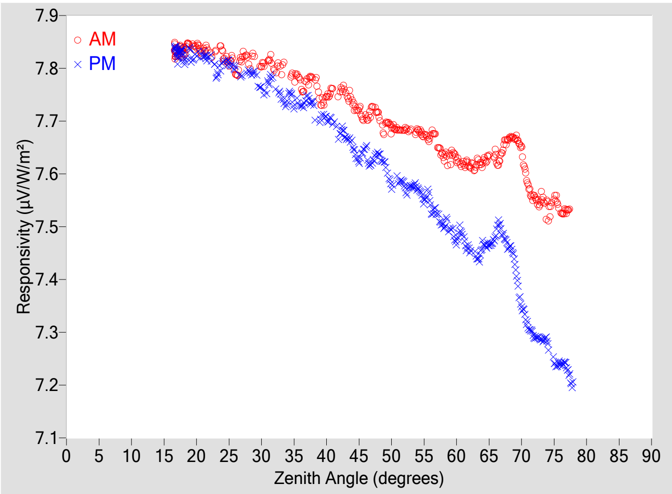


Figure 2. Responsivity vs Local Standard Time

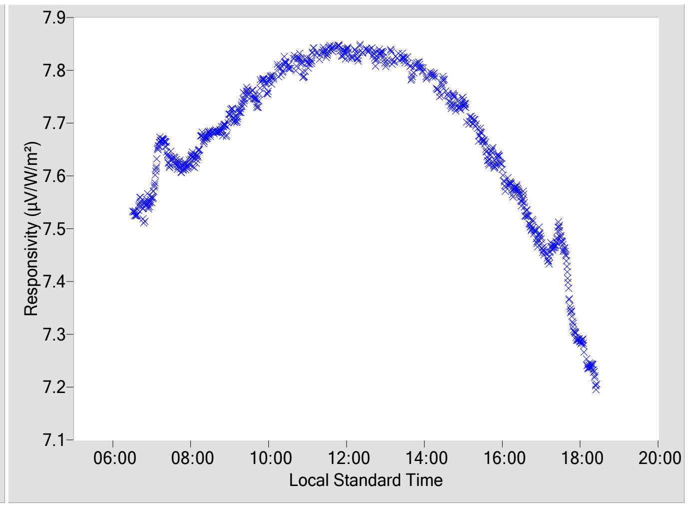


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.7066	0.32	97.12	7.6506	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7117	0.32	95.56	7.6383	0.31	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6887	0.33	93.91	7.5797	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6843	0.33	92.28	7.5773	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6819	0.34	90.78	7.5717	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6712	0.34	89.35	7.5405	0.33	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6341	0.35	87.89	7.5018	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6293	0.36	86.46	7.4736	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6149	0.37	85.06	7.4575	0.36	275.04
18	7.8310	0.29	155.82	7.8225	0.29	204.36	64	7.6216	0.38	83.61	7.4638	0.38	276.48
20	7.8428	0.29	142.89	7.8273	0.29	217.44	66	7.6335	0.40	82.26	7.4871	0.39	277.88
22	7.8318	0.29	134.62	7.8203	0.29	225.85	68	7.6661	0.41	80.88	7.4622	0.41	279.21
24	7.8282	0.29	128.47	7.8109	0.29	231.63	70	7.6433	N/A	79.51	7.3509	0.44	280.60
26	7.7907	0.30	123.40	7.8000	0.29	236.25	72	7.5550	N/A	78.14	7.2906	N/A	282.00
28	7.8133	0.30	119.46	7.7935	0.29	240.69	74	7.5321	N/A	76.73	7.2795	N/A	283.36
30	7.8061	0.30	115.76	7.7642	0.29	244.01	76	7.5289	N/A	75.34	7.2403	N/A	284.81
32	7.7975	0.30	112.81	7.7719	0.30	247.32	78	N/A	N/A	N/A	7.2005	N/A	286.10
34	N/A	N/A	N/A	7.7412	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7718	0.30	107.40	7.7286	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7814	0.31	105.13	7.7260	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7475	0.31	102.88	7.7039	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7548	0.31	100.89	7.6756	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7313	0.32	98.93	7.6512	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

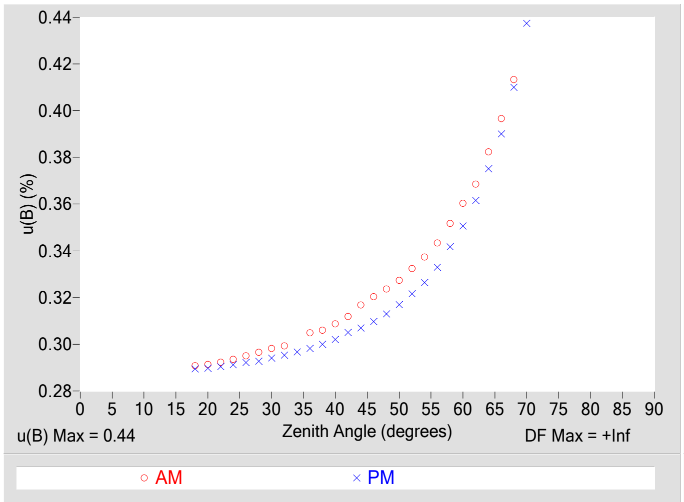


Figure 4. Residuals from Spline Interpolation

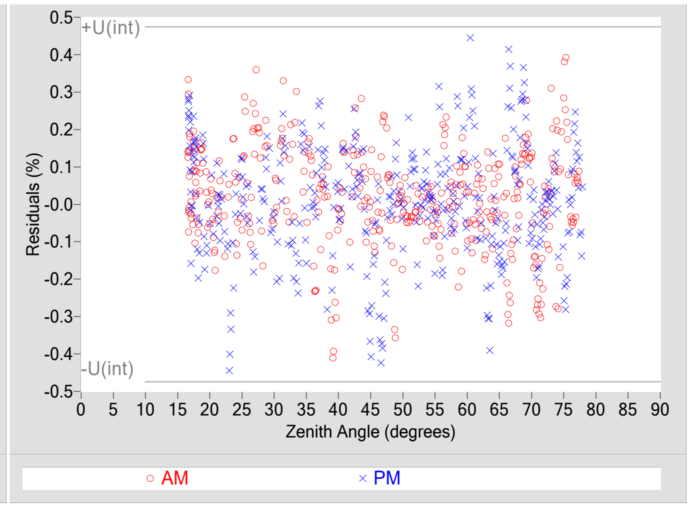


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	13618
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

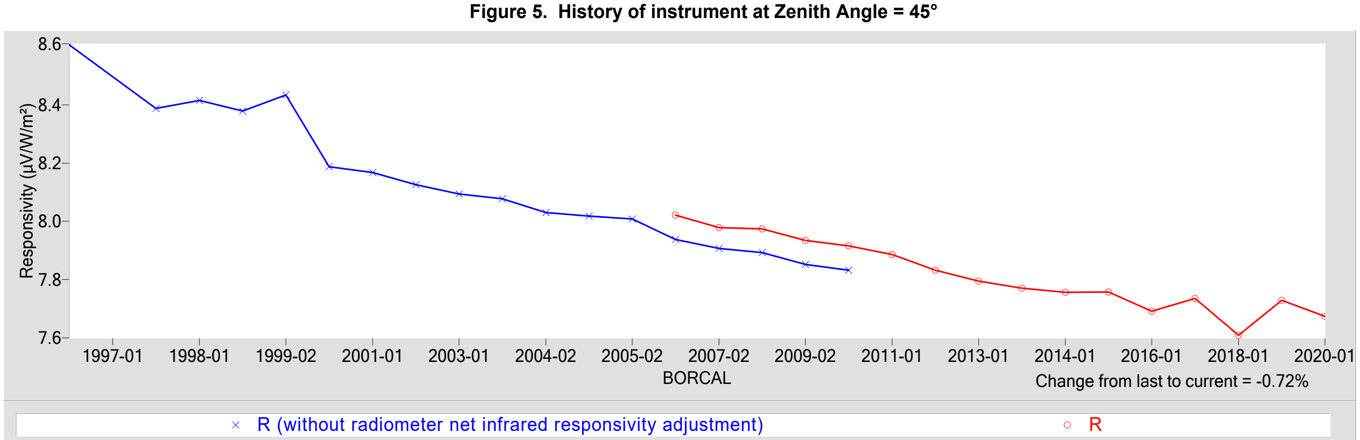
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6733	0.49000

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -2.6
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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31278F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

31278F3 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

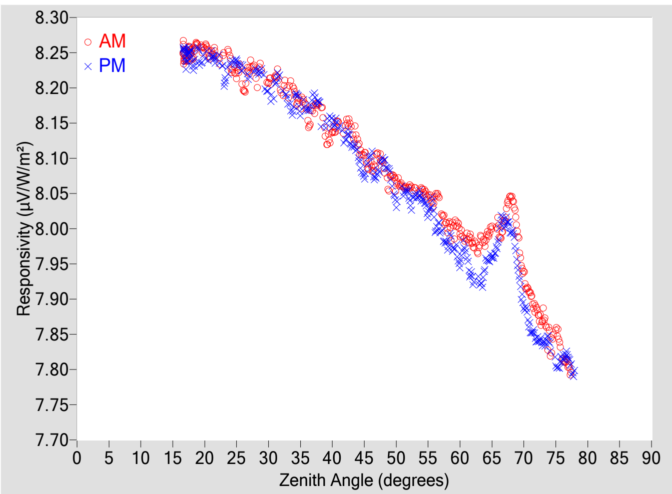


Figure 2. Responsivity vs Local Standard Time

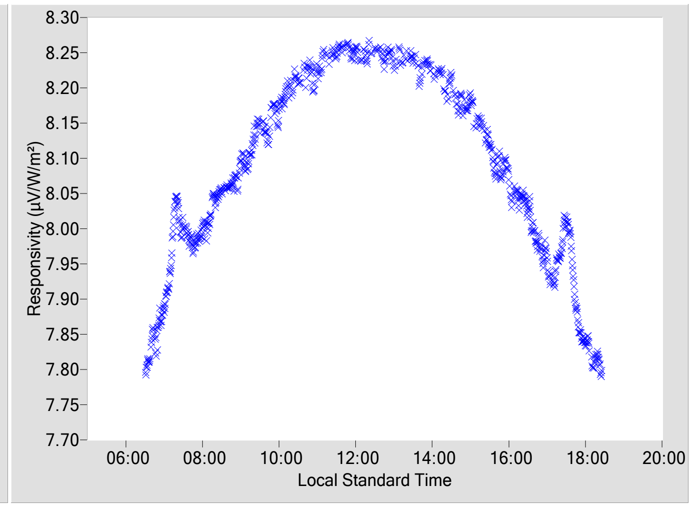


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0881	0.32	97.12	8.1055	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0905	0.32	95.56	8.0982	0.31	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0667	0.33	93.91	8.0390	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0594	0.33	92.28	8.0445	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0550	0.34	90.78	8.0425	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0404	0.34	89.35	8.0147	0.33	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0037	0.35	87.89	7.9774	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9975	0.36	86.46	7.9531	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9784	0.37	85.06	7.9290	0.36	275.04
18	8.2469	0.29	155.82	8.2407	0.29	204.36	64	7.9854	0.38	83.61	7.9501	0.38	276.48
20	8.2587	0.29	142.89	8.2466	0.29	217.44	66	8.0023	0.40	82.26	7.9890	0.39	277.88
22	8.2445	0.29	134.62	8.2415	0.29	225.85	68	8.0441	0.41	80.88	7.9976	0.41	279.21
24	8.2376	0.29	128.47	8.2351	0.29	231.63	70	7.9324	N/A	79.51	7.8924	0.44	280.60
26	8.1985	0.30	123.40	8.2270	0.29	236.25	72	7.8843	N/A	78.14	7.8419	N/A	282.00
28	8.2178	0.30	119.46	8.2244	0.29	240.69	74	7.8416	N/A	76.73	7.8377	N/A	283.36
30	8.2098	0.30	115.76	8.1957	0.29	244.01	76	7.8202	N/A	75.34	7.8158	N/A	284.81
32	8.1952	0.30	112.81	8.2073	0.30	247.32	78	N/A	N/A	N/A	7.7943	N/A	286.10
34	8.1948	0.30	109.84	8.1768	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1643	0.31	107.40	8.1690	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1751	0.31	105.13	8.1717	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1390	0.31	102.88	8.1519	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1457	0.31	100.89	8.1271	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1177	0.32	98.93	8.1012	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

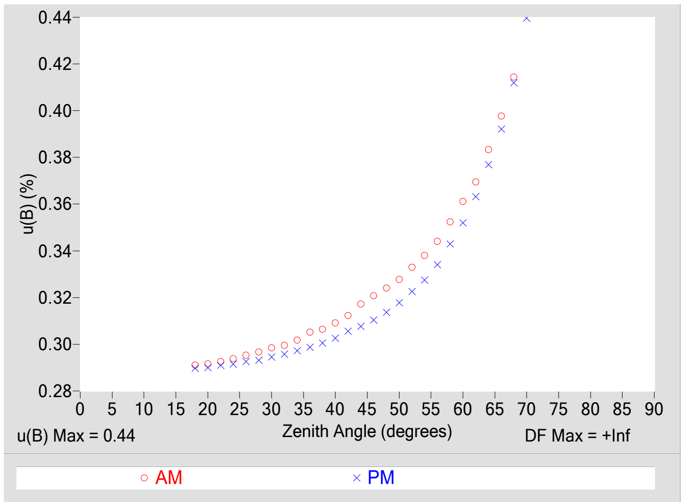


Figure 4. Residuals from Spline Interpolation

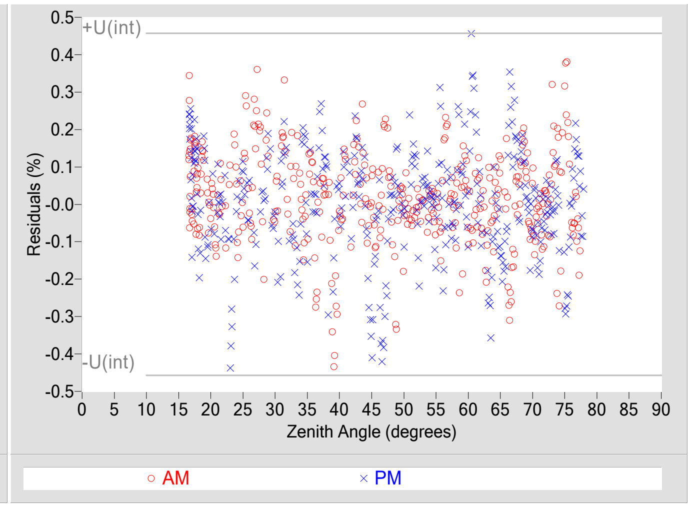


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	15599
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

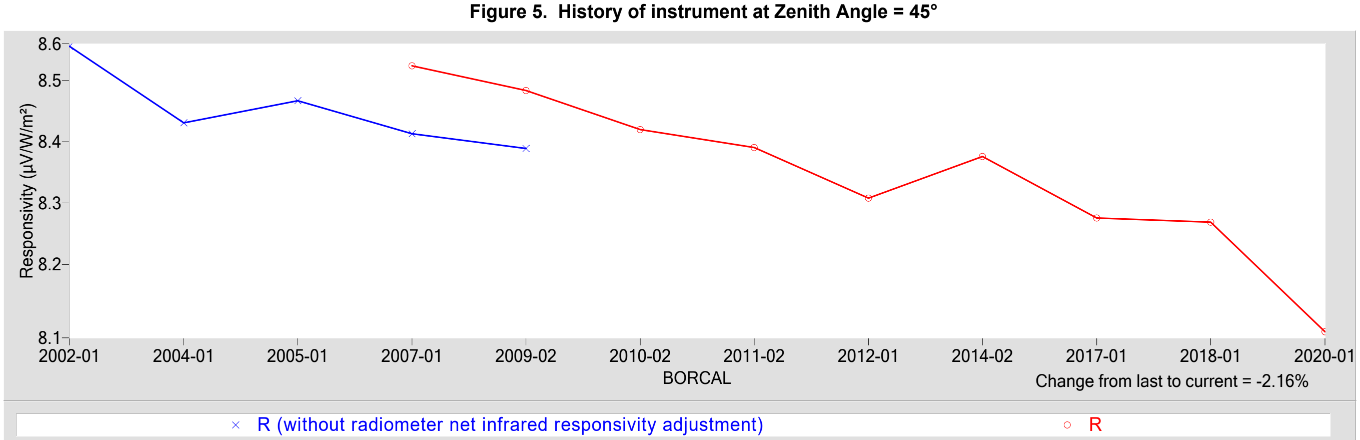
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0899	0.56100

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.5 / -1.7
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

[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:**	31281F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

31281F3 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),
= $Win - Wout$ = $Win - \sigma * Tc\text{^}4$
where, Win = incoming infrared (W/m²), σ = 5.6704e-8 W·m-2·K-4,
Tc = case temperature of pyrgeometer (K).

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

Figure 1. Responsivity vs Zenith Angle

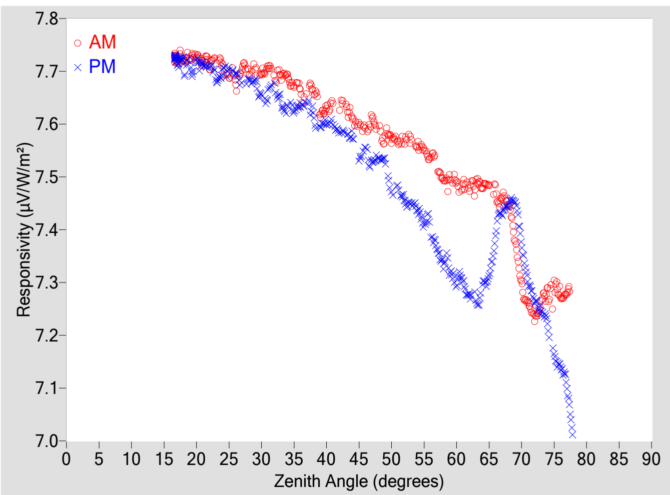


Figure 2. Responsivity vs Local Standard Time

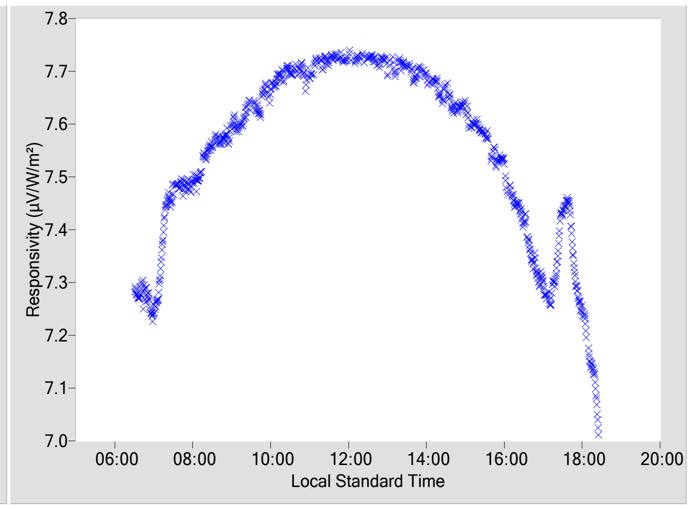


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.5948	0.32	97.40	7.5549	0.31	262.89
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5919	0.32	95.37	7.5346	0.31	264.64
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5734	0.33	93.93	7.4687	0.32	266.25
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5695	0.33	92.20	7.4562	0.32	267.76
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5578	0.34	90.84	7.4370	0.33	269.28
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5379	0.34	89.29	7.3955	0.34	270.81
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4946	0.35	87.85	7.3376	0.34	272.22
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4892	0.36	86.43	7.3007	0.35	273.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4788	0.37	85.04	7.2751	0.37	275.06
18	7.7208	0.29	155.25	7.7112	0.29	204.43	64	7.4802	0.38	83.66	7.2956	0.38	276.47
20	7.7286	0.29	142.77	7.7208	0.29	217.82	66	7.4717	0.40	82.27	7.3872	0.39	277.85
22	7.7088	0.29	134.07	7.7109	0.29	225.95	68	7.4441	0.41	80.85	7.4491	0.41	279.26
24	7.7087	0.29	128.59	7.6976	0.29	231.33	70	7.2999	N/A	79.52	7.3719	0.44	280.61
26	7.6782	0.30	123.57	7.6947	0.29	236.63	72	7.2361	N/A	78.11	7.2665	N/A	281.97
28	7.7011	0.30	119.37	7.6850	0.29	240.77	74	7.2779	N/A	76.70	7.2188	N/A	283.37
30	7.6964	0.30	115.85	7.6567	0.30	244.10	76	7.2762	N/A	75.34	7.1405	N/A	284.78
32	7.6848	0.30	112.56	7.6684	0.30	247.52	78	N/A	N/A	N/A	7.0184	N/A	286.07
34	7.6905	0.30	109.94	7.6297	0.30	250.05	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6615	0.31	107.40	7.6352	0.30	252.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6608	0.31	105.08	7.6160	0.30	255.06	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6314	0.31	102.96	7.6019	0.30	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6359	0.31	100.76	7.5848	0.31	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6121	0.32	99.06	7.5769	0.31	260.99	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

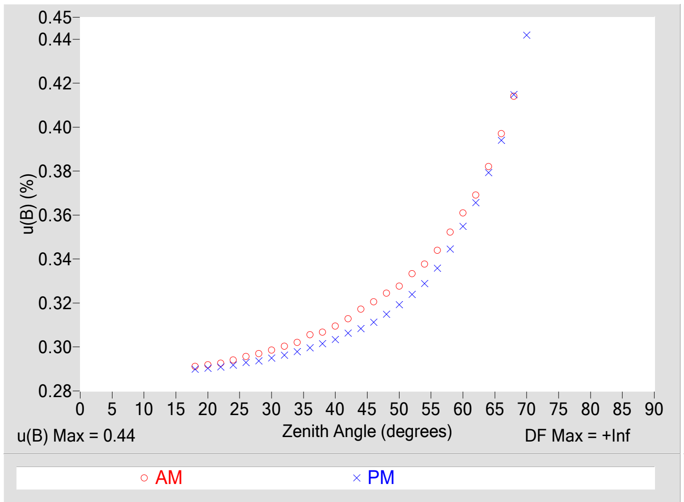


Figure 4. Residuals from Spline Interpolation

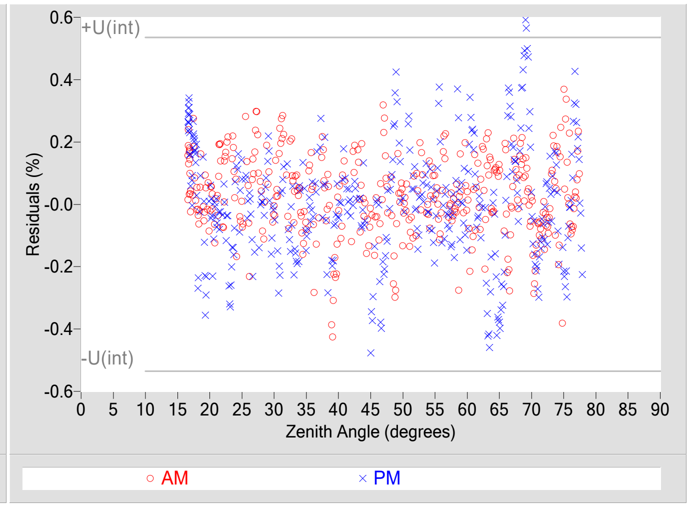


Table 3. Uncertainty using Spline Interpolation ‡

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)	9681
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

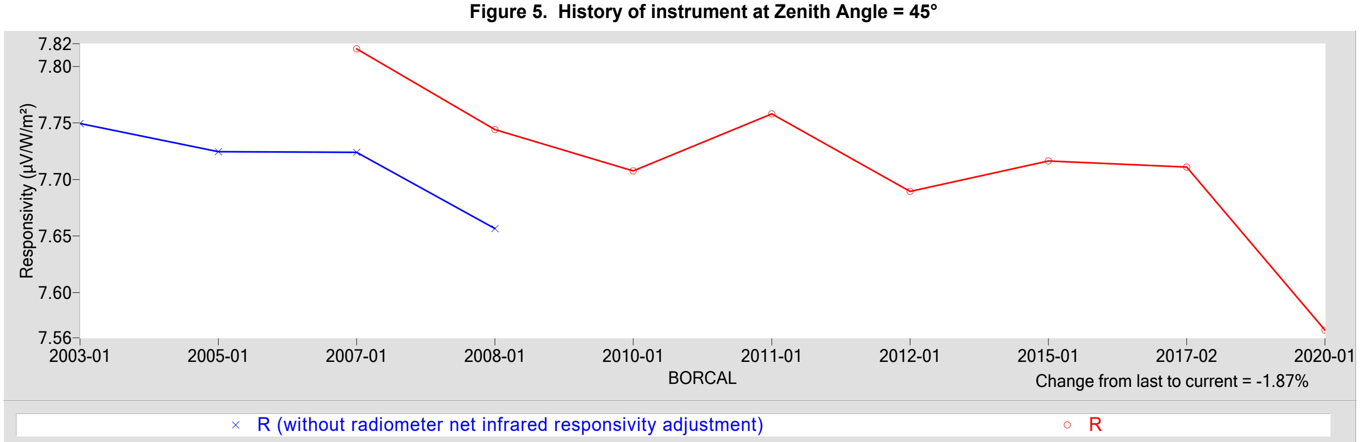
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5669	0.54100

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -3.5
Expanded Uncertainty, U (%)	+2.4 / -4.2
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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31284F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

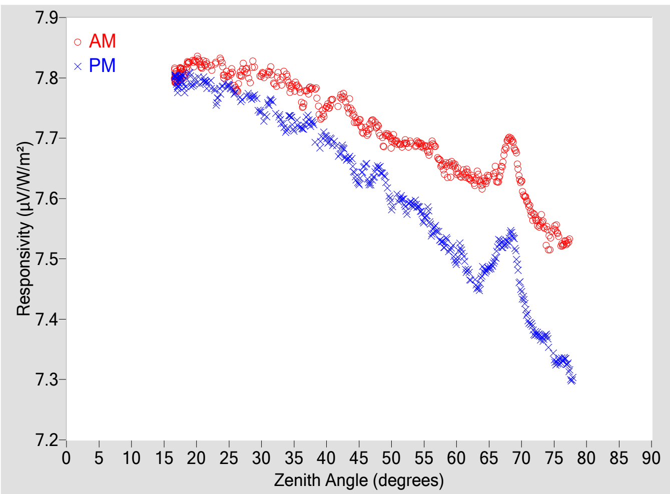


Figure 2. Responsivity vs Local Standard Time

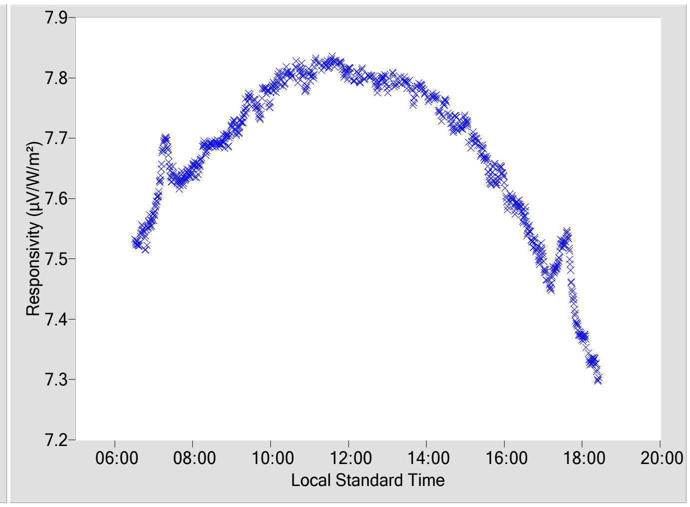


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.7113	0.32	97.12	7.6563	0.31	262.86
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7147	0.32	95.56	7.6526	0.31	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6977	0.33	93.91	7.5906	0.32	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6929	0.33	92.28	7.5907	0.32	267.75
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6918	0.34	90.78	7.5869	0.33	269.31
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6833	0.34	89.35	7.5556	0.33	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6510	0.35	87.89	7.5243	0.34	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6483	0.36	86.46	7.4967	0.35	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6348	0.37	85.06	7.4724	0.36	275.04
18	7.8071	0.29	155.82	7.7914	0.29	204.36	64	7.6248	0.38	83.61	7.4776	0.38	276.48
20	7.8300	0.29	142.89	7.7973	0.29	217.44	66	7.6404	0.40	82.26	7.5064	0.39	277.88
22	7.8195	0.29	134.62	7.7901	0.29	225.85	68	7.6985	0.41	80.88	7.5317	0.41	279.21
24	7.8155	0.29	128.47	7.7860	0.29	231.63	70	7.6220	N/A	79.51	7.4455	0.44	280.60
26	7.7826	0.30	123.40	7.7743	0.29	236.25	72	7.5689	N/A	78.14	7.3766	N/A	282.00
28	7.8038	0.30	119.46	7.7704	0.29	240.69	74	7.5356	N/A	76.73	7.3670	N/A	283.36
30	7.8055	0.30	115.76	7.7445	0.29	244.01	76	7.5278	N/A	75.34	7.3311	N/A	284.81
32	7.7905	0.30	112.81	7.7505	0.30	247.32	78	N/A	N/A	N/A	7.3015	N/A	286.10
34	7.7965	0.30	109.84	7.7226	0.30	250.16	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7705	0.31	107.40	7.7174	0.30	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7822	0.31	105.13	7.7174	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7527	0.31	102.88	7.6996	0.30	257.17	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7642	0.31	100.89	7.6755	0.31	259.26	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7374	0.32	98.93	7.6519	0.31	261.15	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

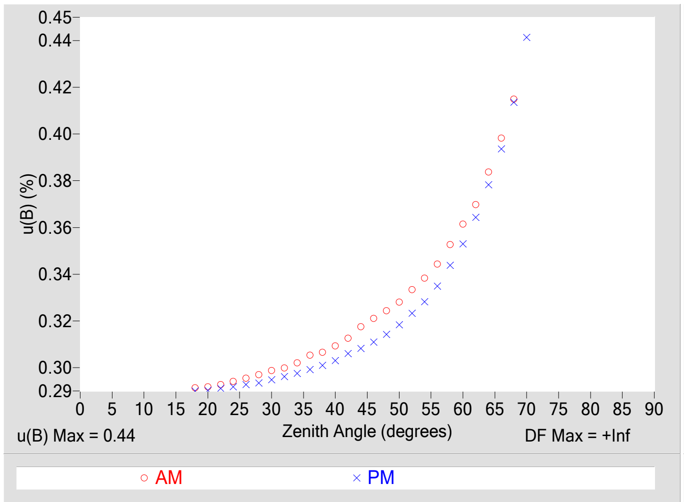


Figure 4. Residuals from Spline Interpolation

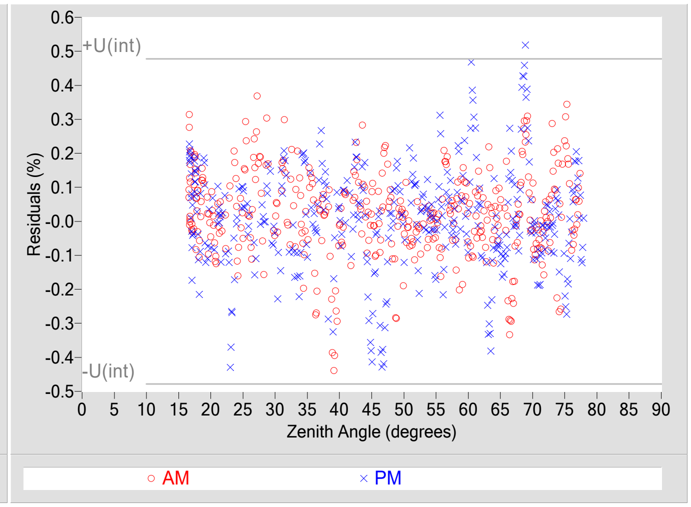


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.44
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	13783
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.98
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

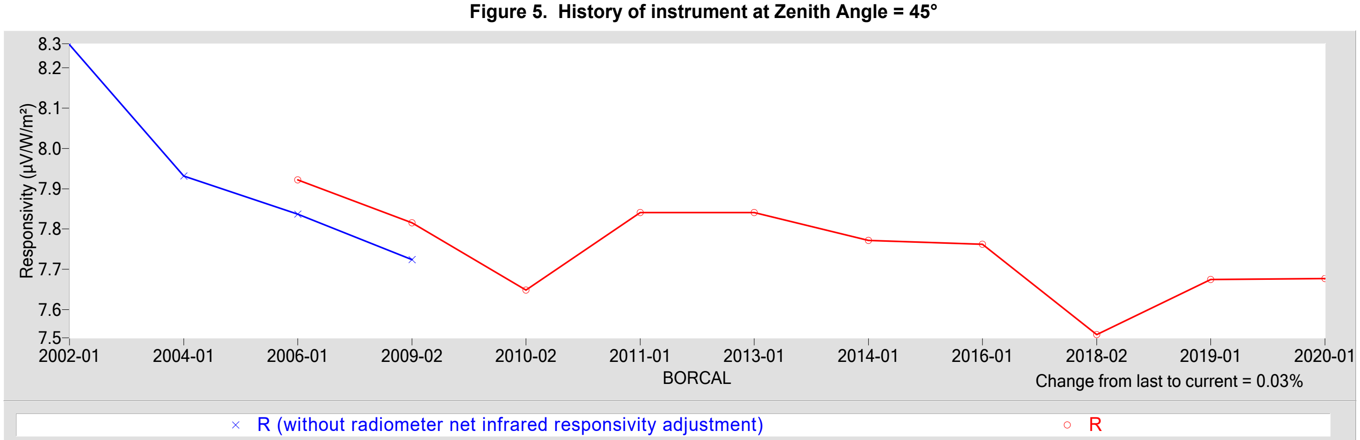
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6769	0.54600

† Rnet determination date: 03/31/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.7 / -2.3
Expanded Uncertainty, U (%)	+2.4 / -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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31291F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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:

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

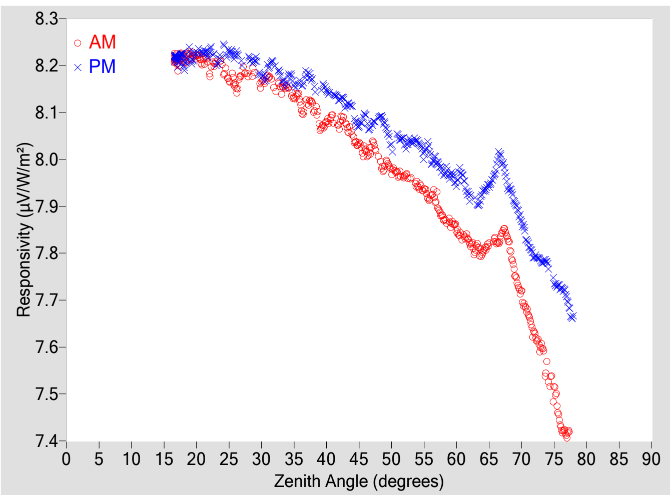


Figure 2. Responsivity vs Local Standard Time

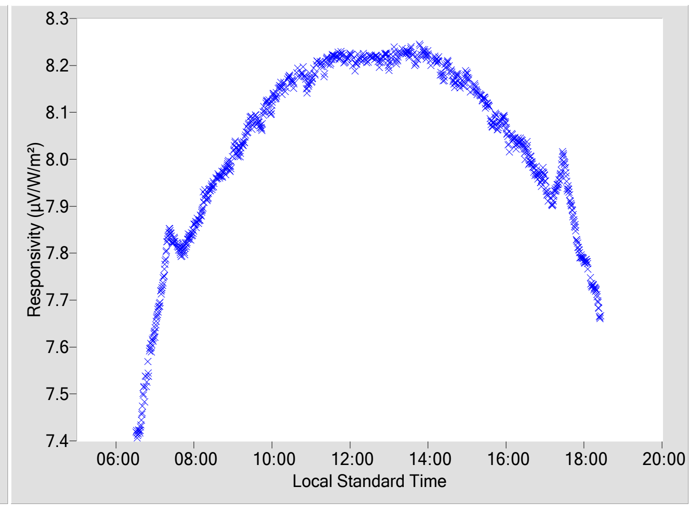


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0182	0.32	97.23	8.0958	0.31	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0060	0.33	95.57	8.0897	0.32	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9782	0.33	93.91	8.0262	0.32	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9642	0.33	92.33	8.0357	0.32	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9428	0.34	90.79	8.0372	0.33	269.35
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9187	0.35	89.35	8.0068	0.34	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8748	0.35	87.89	7.9712	0.35	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8527	0.36	86.46	7.9509	0.36	273.65
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8232	0.37	85.07	7.9226	0.37	275.04
18	8.2128	0.29	154.88	8.2121	0.29	204.05	64	7.8007	0.39	83.61	7.9296	0.38	276.48
20	8.2200	0.29	142.66	8.2298	0.29	217.84	66	7.8264	0.40	82.22	7.9764	0.40	277.85
22	8.1908	0.29	134.57	8.2300	0.29	225.45	68	7.8242	0.42	80.88	7.9405	0.42	279.21
24	8.1935	0.29	128.38	8.2436	0.29	232.17	70	7.7095	N/A	79.51	7.8674	0.45	280.60
26	8.1549	0.30	123.60	8.2223	0.29	236.58	72	7.6269	N/A	78.15	7.7918	N/A	282.01
28	8.1793	0.30	119.63	8.2148	0.29	240.96	74	7.5464	N/A	76.79	7.7770	N/A	283.37
30	8.1630	0.30	115.85	8.1810	0.30	244.18	76	7.4341	N/A	75.33	7.7264	N/A	284.82
32	8.1484	0.30	112.65	8.2032	0.30	247.26	78	N/A	N/A	N/A	7.6638	N/A	286.10
34	8.1532	0.30	110.04	8.1729	0.30	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1178	0.31	107.39	8.1622	0.30	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1081	0.31	105.05	8.1565	0.30	255.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0792	0.31	102.95	8.1475	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0764	0.31	100.93	8.1278	0.31	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0485	0.32	98.99	8.1046	0.31	261.06	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

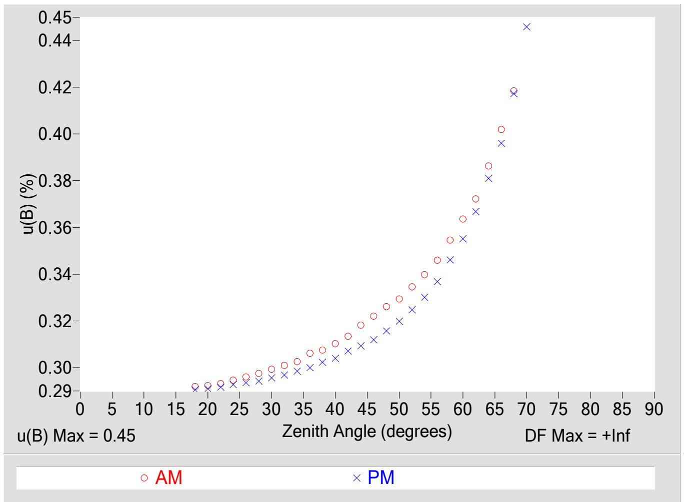


Figure 4. Residuals from Spline Interpolation

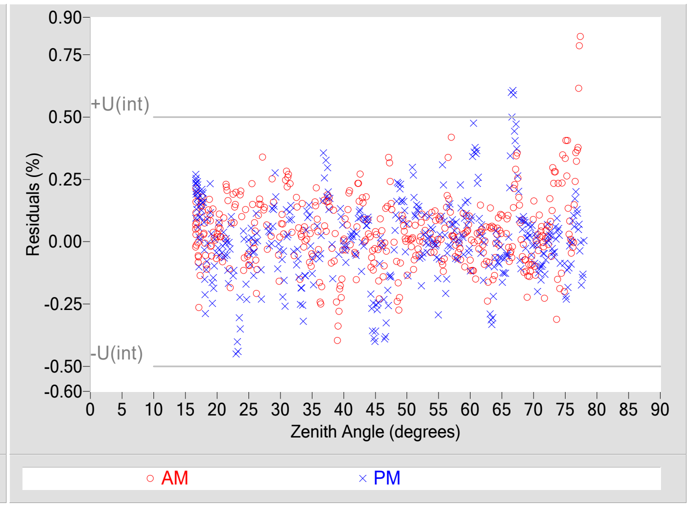


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	12874
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

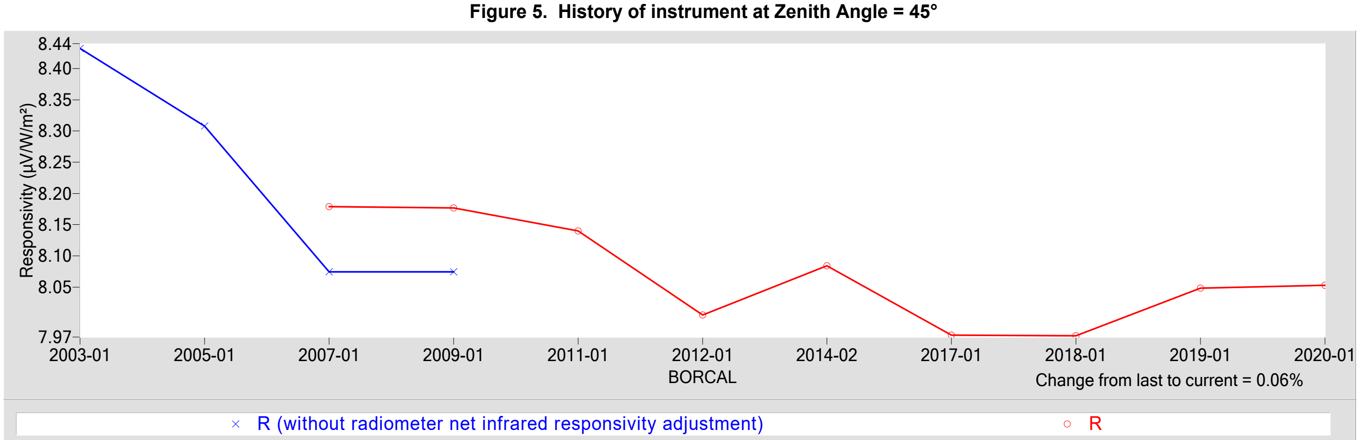
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0529	0.61842

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.9 / -2.5
Expanded Uncertainty, U (%)	+2.6 / -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:**	31293F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

31293F3 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

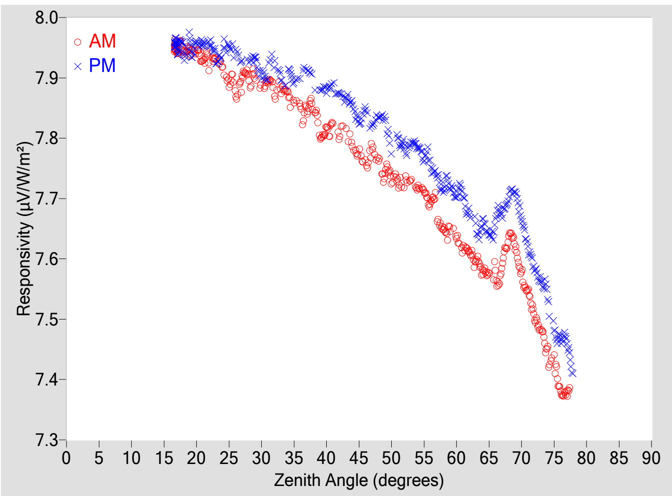


Figure 2. Responsivity vs Local Standard Time

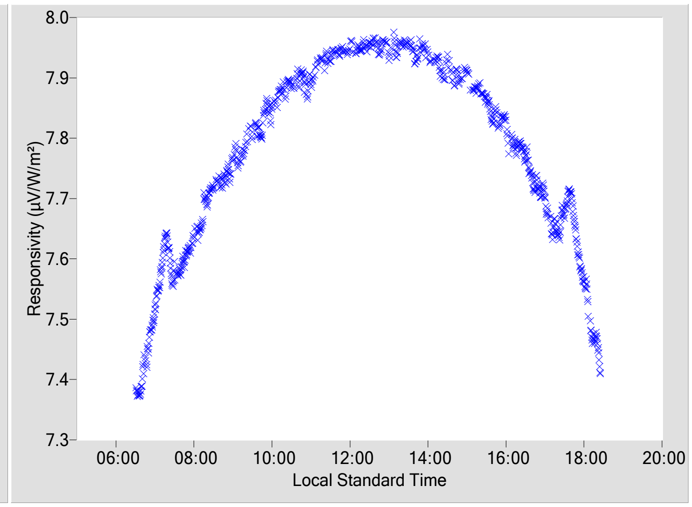


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.7563	0.32	97.13	7.8466	0.31	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7654	0.33	95.53	7.8344	0.32	264.60
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7335	0.33	93.96	7.7827	0.32	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7286	0.34	92.24	7.7859	0.33	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.7180	0.34	90.85	7.7854	0.33	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6943	0.35	89.30	7.7522	0.34	270.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6490	0.35	87.86	7.7168	0.35	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6340	0.36	86.39	7.7046	0.36	273.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6096	0.37	85.04	7.6752	0.37	275.01
18	7.9430	0.29	155.62	7.9462	0.29	204.78	64	7.5795	0.39	83.67	7.6596	0.38	276.45
20	7.9443	0.29	142.82	7.9583	0.29	217.24	66	7.5719	0.40	82.28	7.6639	0.40	277.86
22	7.9185	0.29	134.99	7.9565	0.29	225.71	68	7.6336	0.42	80.86	7.7009	0.42	279.22
24	7.9134	0.30	128.26	7.9488	0.29	231.68	70	7.5765	N/A	79.52	7.6684	0.45	280.57
26	7.8706	0.30	123.41	7.9410	0.29	236.56	72	7.5041	N/A	78.12	7.5838	N/A	281.98
28	7.8995	0.30	119.35	7.9282	0.29	240.58	74	7.4404	N/A	76.70	7.5349	N/A	283.38
30	7.8855	0.30	116.13	7.9081	0.30	244.30	76	7.3815	N/A	75.34	7.4686	N/A	284.79
32	7.8727	0.30	112.74	7.9225	0.30	247.36	78	N/A	N/A	N/A	7.4106	N/A	286.08
34	7.8751	0.30	109.91	7.9142	0.30	250.45	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8530	0.31	107.41	7.8988	0.30	252.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8490	0.31	105.14	7.8927	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8151	0.31	102.91	7.8806	0.31	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8076	0.31	100.92	7.8738	0.31	259.16	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7865	0.32	99.03	7.8564	0.31	261.01	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

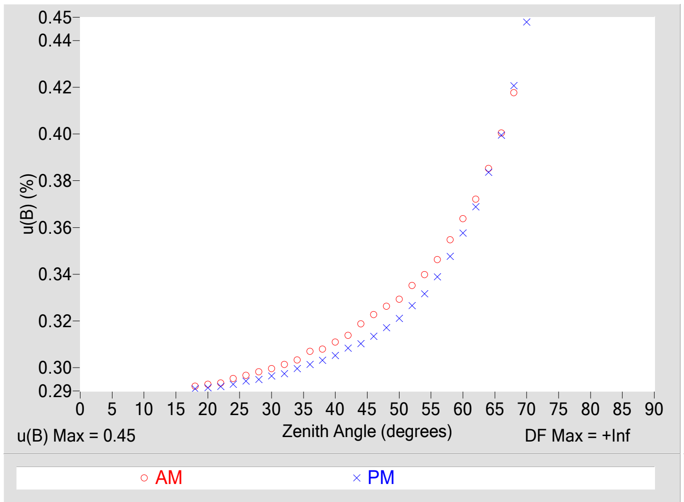


Figure 4. Residuals from Spline Interpolation

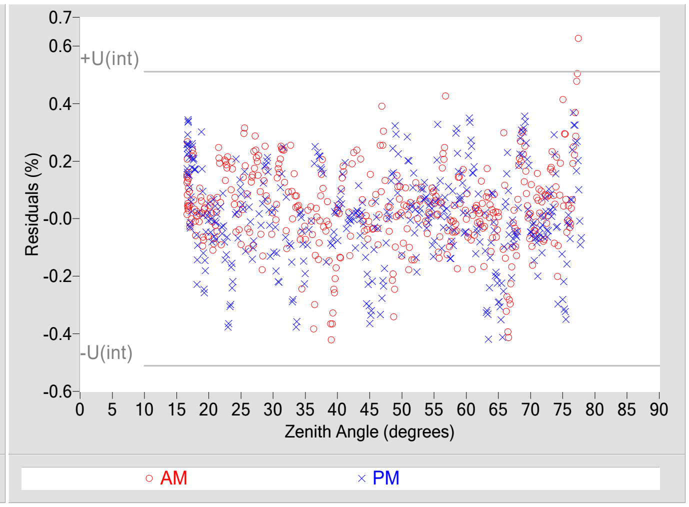


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	11871
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

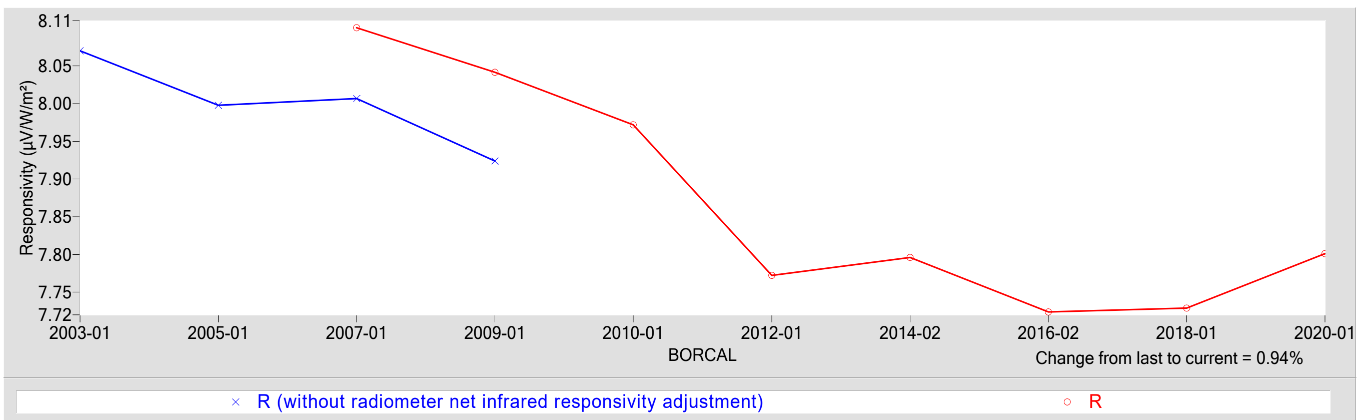
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8012	0.62546

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.6 / -2.1
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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31388E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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
31388E6 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

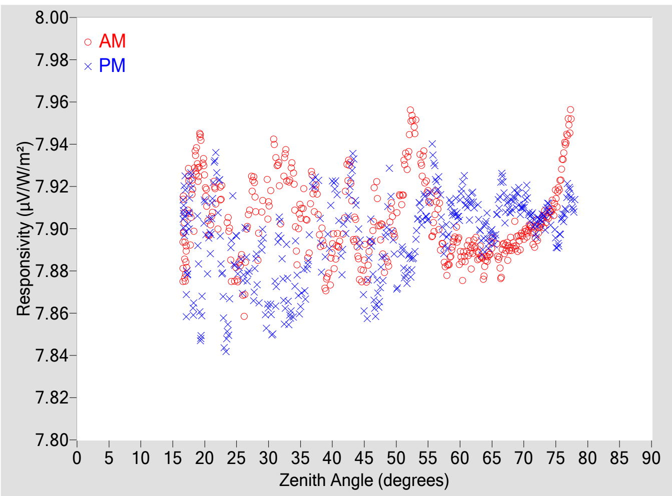


Figure 2. Responsivity vs Local Standard Time

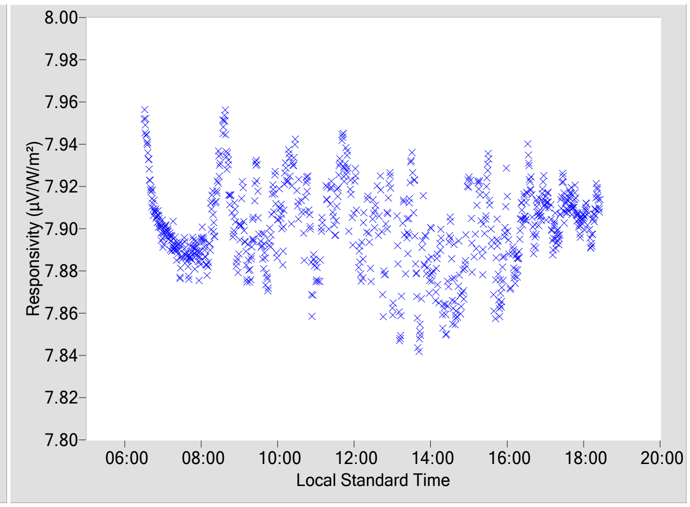


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8923	0.29	97.31	7.8943	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8897	0.29	95.57	7.8862	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9018	0.29	93.95	7.8716	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9399	0.29	92.37	7.8837	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9311	0.29	90.82	7.9050	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9045	0.30	89.36	7.9283	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8817	0.30	87.79	7.8965	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8878	0.30	86.41	7.9118	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8894	0.30	85.02	7.9141	0.29	275.08
18	7.9111	0.28	155.76	7.8969	0.28	204.65	64	7.8832	0.30	83.64	7.9036	0.30	276.47
20	7.9247	0.28	142.83	7.9065	0.28	217.28	66	7.8866	0.30	82.26	7.9104	0.30	277.83
22	7.9058	0.28	135.05	7.9233	0.28	225.38	68	7.8914	0.30	80.92	7.9105	0.30	279.24
24	7.8898	0.29	128.53	7.8754	0.28	231.54	70	7.8975	N/A	79.48	7.9123	0.30	280.64
26	7.8708	0.29	123.40	7.8771	0.28	236.40	72	7.8986	N/A	78.10	7.9004	N/A	281.96
28	7.9150	0.29	119.60	7.8797	0.28	240.63	74	7.9072	N/A	76.77	7.9082	N/A	283.36
30	7.9129	0.29	115.90	7.8637	0.28	244.31	76	7.9305	N/A	75.32	7.9034	N/A	284.76
32	7.9113	0.29	112.97	7.8902	0.28	247.40	78	N/A	N/A	N/A	7.9103	N/A	286.09
34	7.9143	0.29	109.83	7.8750	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8982	0.29	107.37	7.8789	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8984	0.29	105.10	7.9001	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8892	0.29	102.87	7.9185	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9127	0.29	100.92	7.8999	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8870	0.29	99.03	7.9009	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

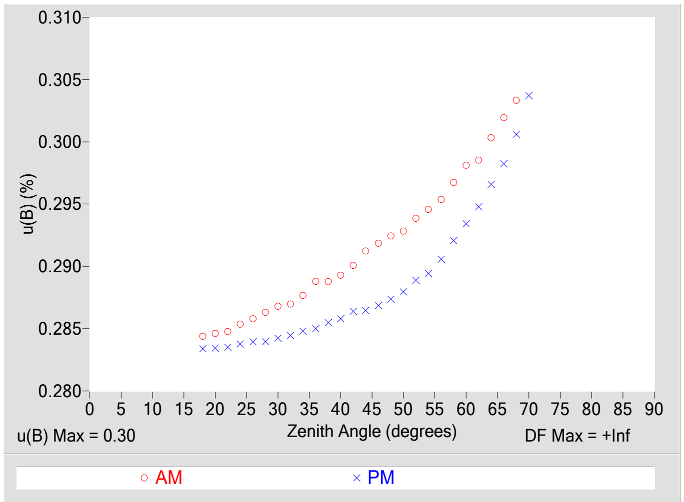


Figure 4. Residuals from Spline Interpolation

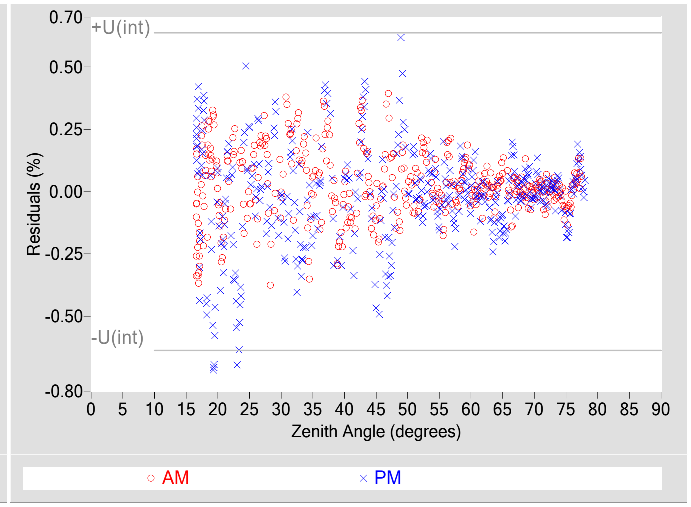


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.44
Effective degrees of freedom, DF(c)	2603
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.86
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

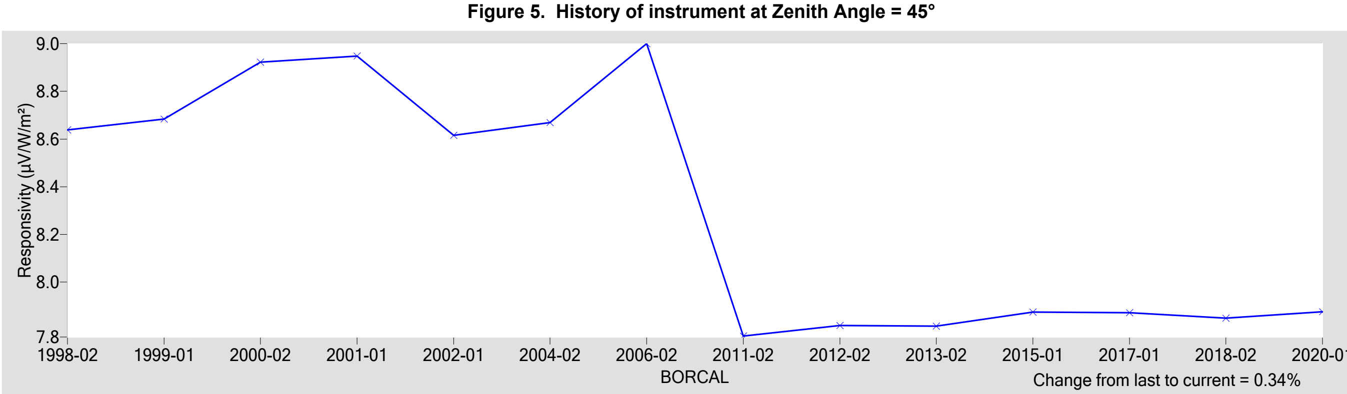
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8755	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.82 / -0.15
Expanded Uncertainty, U (%)	+1.4 / -0.73
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:**	31631F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

31631F3 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

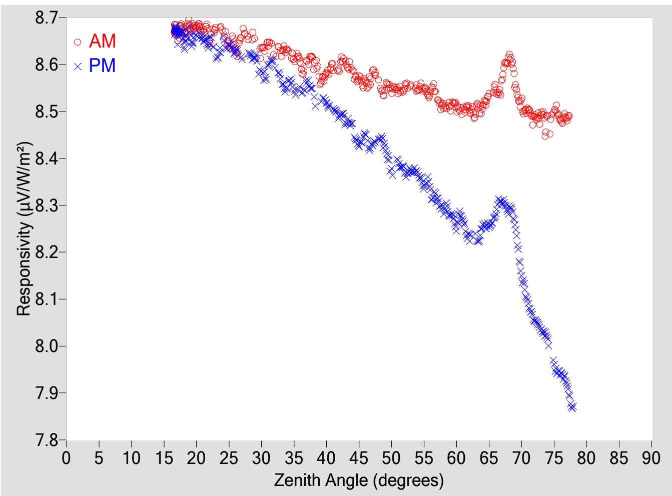


Figure 2. Responsivity vs Local Standard Time

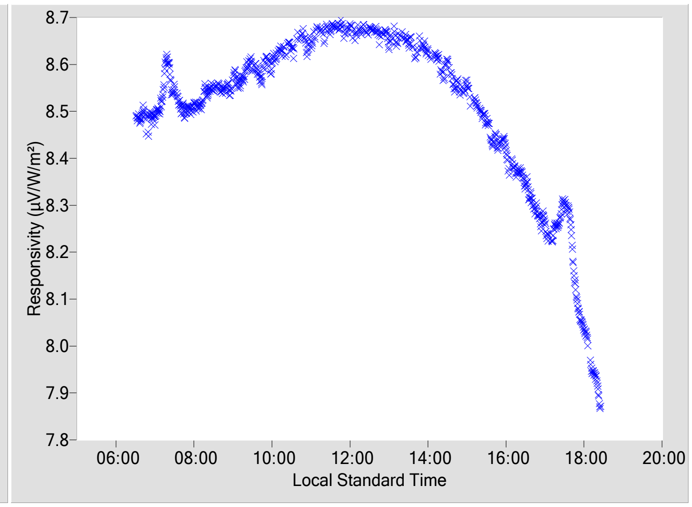


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5616	0.32	97.23	8.4517	0.31	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5667	0.33	95.57	8.4411	0.32	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5494	0.33	93.91	8.3715	0.32	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5497	0.33	92.33	8.3735	0.33	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5472	0.34	90.79	8.3666	0.33	269.35
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5392	0.35	89.35	8.3289	0.34	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5120	0.35	87.89	8.2908	0.35	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5107	0.36	86.46	8.2573	0.36	273.65
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5030	0.37	85.07	8.2346	0.37	275.04
18	8.6707	0.29	154.88	8.6571	0.29	204.05	64	8.5095	0.39	83.61	8.2559	0.38	276.48
20	8.6819	0.29	142.66	8.6640	0.29	217.84	66	8.5466	0.40	82.22	8.2809	0.40	277.85
22	8.6588	0.29	134.57	8.6504	0.29	225.45	68	8.6103	0.42	80.88	8.2903	0.42	279.21
24	8.6670	0.29	128.38	8.6557	0.29	232.17	70	8.5128	N/A	79.51	8.1527	0.45	280.60
26	8.6320	0.30	123.60	8.6282	0.29	236.58	72	8.4858	N/A	78.15	8.0541	N/A	282.01
28	8.6565	0.30	119.63	8.6218	0.29	240.96	74	8.4787	N/A	76.82	8.0141	N/A	283.37
30	8.6309	0.30	115.85	8.5856	0.30	244.18	76	8.4822	N/A	75.33	7.9416	N/A	284.82
32	8.6189	0.30	112.65	8.5997	0.30	247.26	78	N/A	N/A	N/A	7.8690	N/A	286.10
34	8.6297	0.30	110.04	8.5588	0.30	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6008	0.31	107.39	8.5456	0.30	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6027	0.31	105.05	8.5303	0.30	255.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5806	0.31	102.95	8.5177	0.30	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5944	0.31	100.93	8.4902	0.31	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5838	0.32	98.99	8.4646	0.31	261.06	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

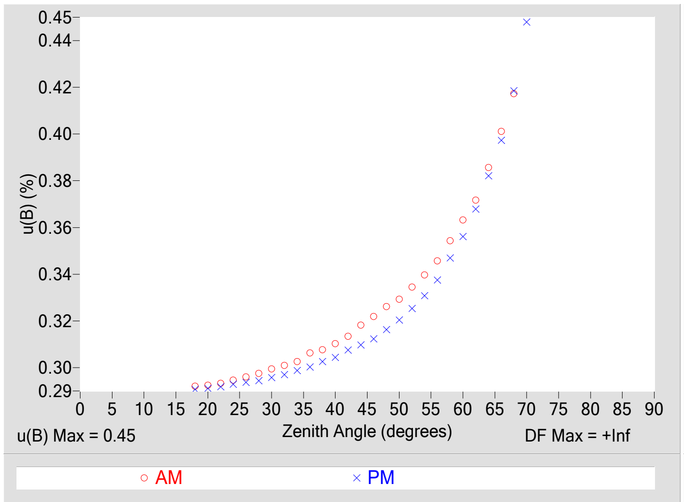


Figure 4. Residuals from Spline Interpolation

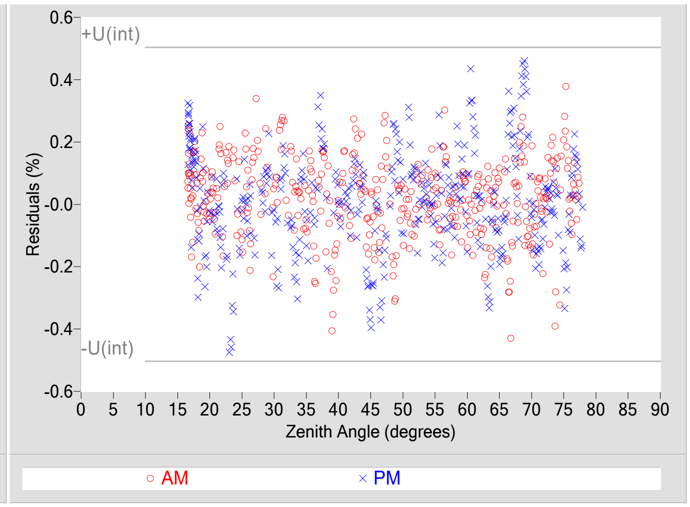


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.45
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	12775
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

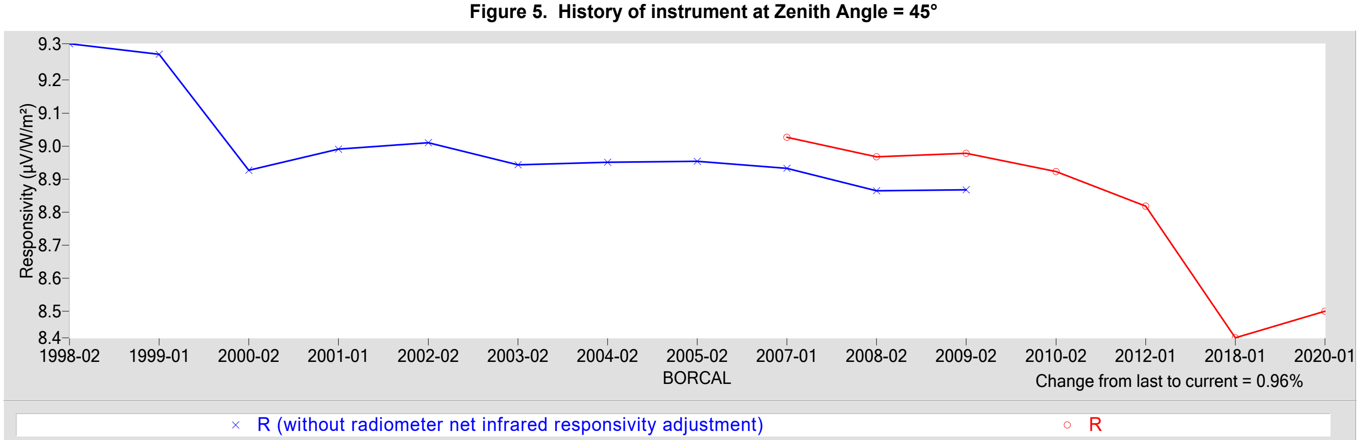
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5008	0.65987

† Rnet determination date: 04/25/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.5 / -2.9
Expanded Uncertainty, U (%)	+2.2 / -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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31827E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

31827E6 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

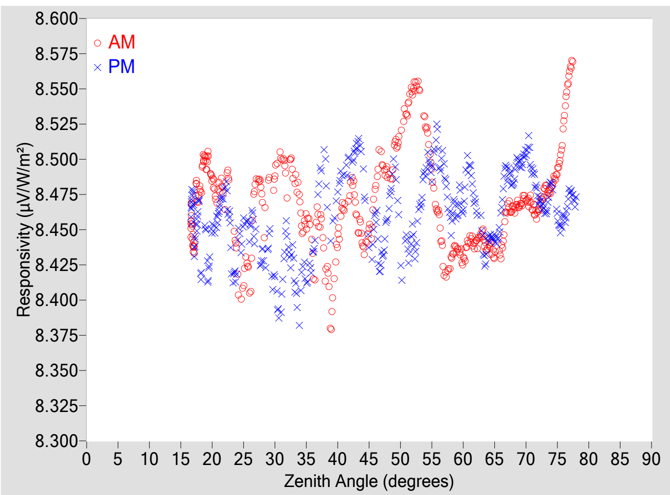


Figure 2. Responsivity vs Local Standard Time

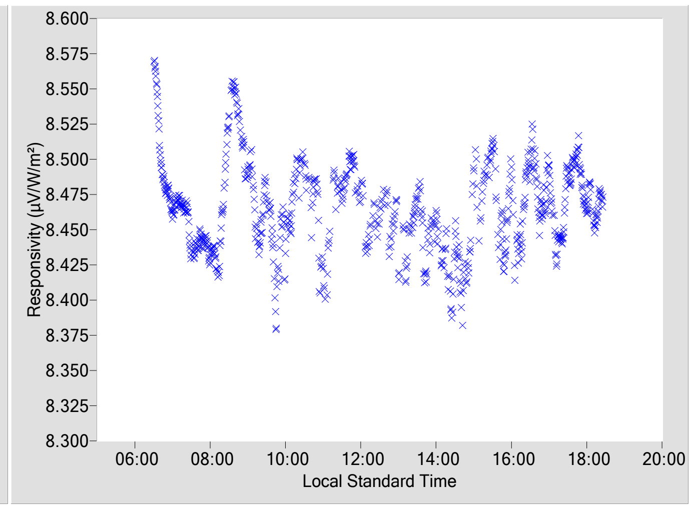


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4772	0.29	97.31	8.4582	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4904	0.29	95.57	8.4634	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5185	0.29	93.95	8.4193	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5500	0.29	92.37	8.4426	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5257	0.29	90.82	8.4912	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4630	0.30	89.36	8.5083	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4289	0.30	87.79	8.4556	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4279	0.30	86.41	8.4679	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4397	0.30	85.02	8.4662	0.29	275.08
18	8.4761	0.28	155.76	8.4468	0.28	204.65	64	8.4386	0.30	83.64	8.4437	0.30	276.47
20	8.4863	0.28	142.83	8.4513	0.28	217.28	66	8.4345	0.30	82.26	8.4598	0.30	277.83
22	8.4701	0.28	135.05	8.4789	0.28	225.38	68	8.4645	0.30	80.92	8.4853	0.30	279.24
24	8.4249	0.29	128.53	8.4313	0.28	231.54	70	8.4715	N/A	79.48	8.5053	0.30	280.64
26	8.4160	0.29	123.40	8.4511	0.28	236.40	72	8.4647	N/A	78.10	8.4730	N/A	281.96
28	8.4750	0.29	119.60	8.4308	0.28	240.63	74	8.4783	N/A	76.77	8.4821	N/A	283.36
30	8.4871	0.29	115.90	8.4137	0.28	244.31	76	8.5256	N/A	75.32	8.4574	N/A	284.76
32	8.4814	0.29	112.97	8.4434	0.28	247.40	78	N/A	N/A	N/A	8.4699	N/A	286.09
34	8.4648	0.29	109.83	8.4028	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4304	0.29	107.37	8.4311	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4241	0.29	105.10	8.4885	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4437	0.29	102.87	8.4767	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4789	0.29	100.92	8.4944	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4393	0.29	99.03	8.4906	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

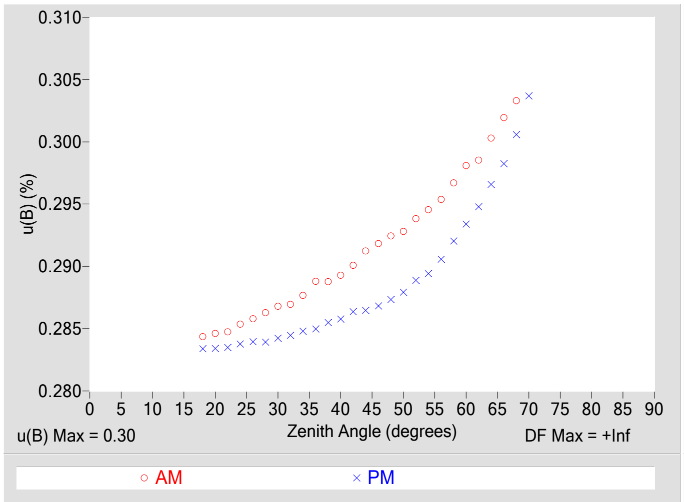


Figure 4. Residuals from Spline Interpolation

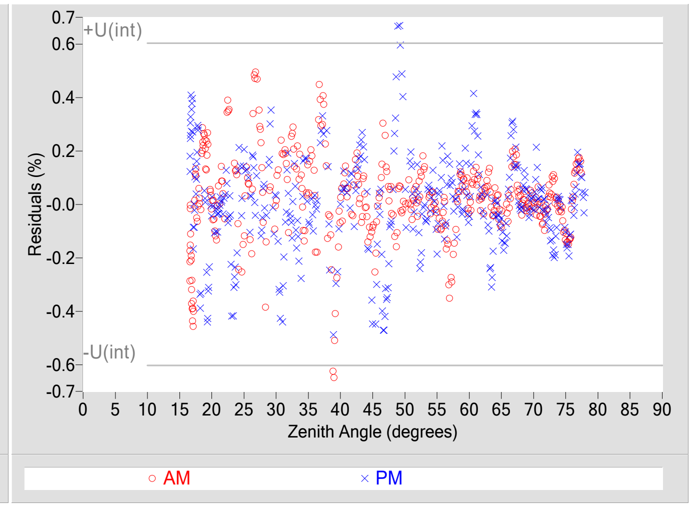


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.30
Combined Standard Uncertainty, u(c) (%)	±0.43
Effective degrees of freedom, DF(c)	2899
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.84
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

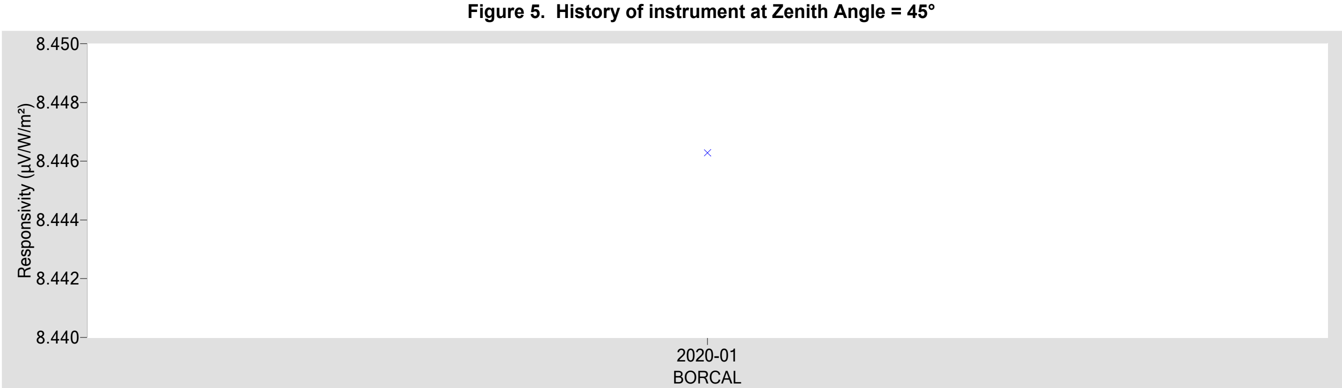
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4463	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+1.2 / -0.51
Expanded Uncertainty, U (%)	+1.8 / -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:**	31866E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

31866E6 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

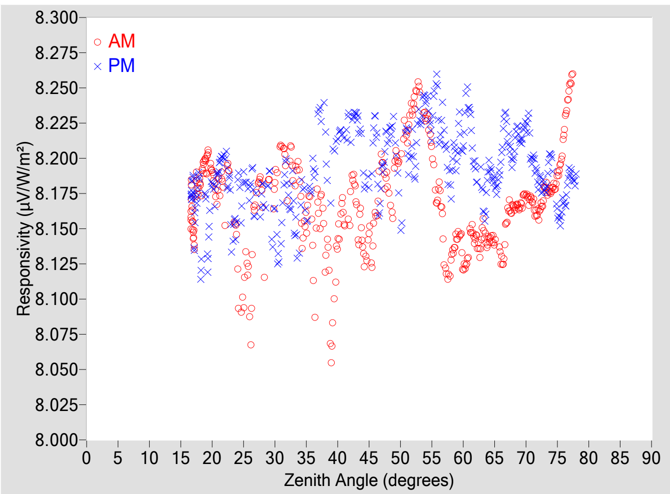


Figure 2. Responsivity vs Local Standard Time

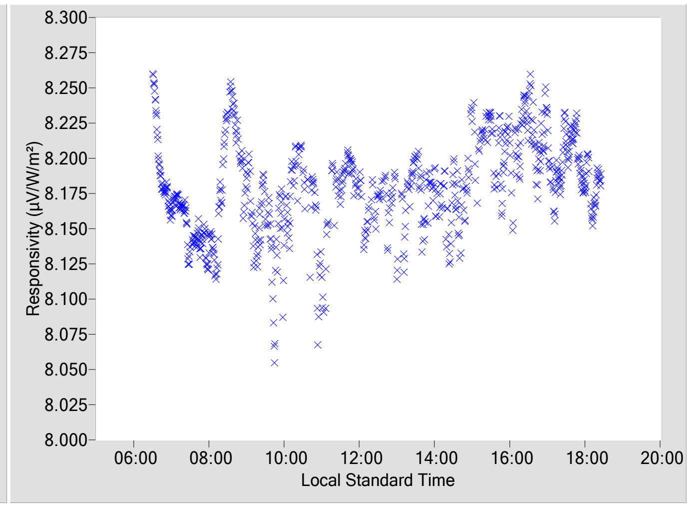


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1580	0.29	97.31	8.2229	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1817	0.29	95.57	8.2160	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2004	0.29	93.95	8.1514	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2371	0.29	92.37	8.2005	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2302	0.29	90.82	8.2415	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1736	0.30	89.36	8.2324	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1277	0.30	87.79	8.1837	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1243	0.30	86.41	8.2140	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1418	0.30	85.02	8.1892	0.29	275.08
18	8.1804	0.28	155.76	8.1542	0.28	205.06	64	8.1406	0.30	83.64	8.1909	0.30	276.47
20	8.1906	0.28	142.83	8.1808	0.28	217.28	66	8.1301	0.30	82.26	8.1978	0.30	277.83
22	8.1659	0.28	135.05	8.2018	0.28	225.38	68	8.1647	0.30	80.92	8.2025	0.30	279.24
24	8.1283	0.29	128.53	8.1678	0.28	231.54	70	8.1738	N/A	79.48	8.2239	0.30	280.64
26	8.0929	0.29	123.40	8.1777	0.28	236.40	72	8.1612	N/A	78.10	8.1843	N/A	281.96
28	8.1748	0.29	119.60	8.1742	0.28	240.63	74	8.1770	N/A	76.77	8.1999	N/A	283.36
30	8.1792	0.29	115.90	8.1582	0.28	244.31	76	8.2165	N/A	75.32	8.1675	N/A	284.76
32	8.1823	0.29	112.97	8.1804	0.28	247.40	78	N/A	N/A	N/A	8.1845	N/A	286.09
34	8.1755	0.29	109.83	8.1615	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1360	0.29	107.37	8.1885	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1346	0.29	105.10	8.2096	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1424	0.29	102.87	8.2149	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1683	0.29	100.92	8.2218	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1369	0.29	99.03	8.1952	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

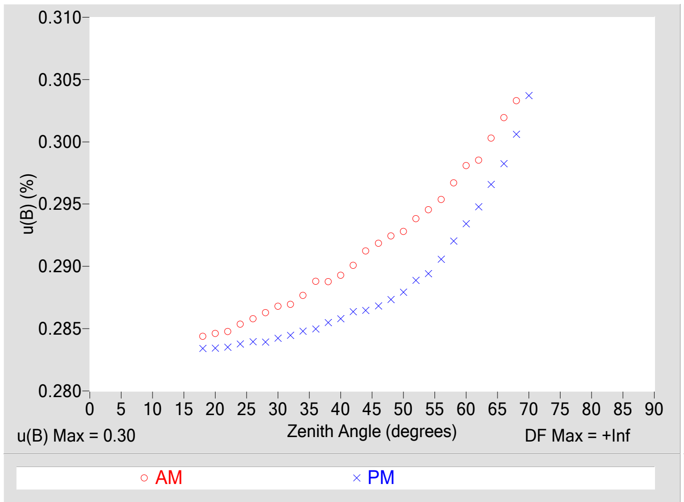


Figure 4. Residuals from Spline Interpolation

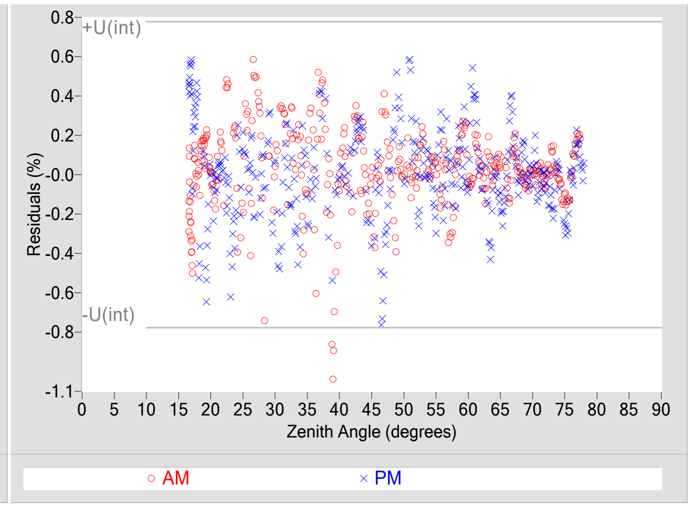


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.39
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	1852
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

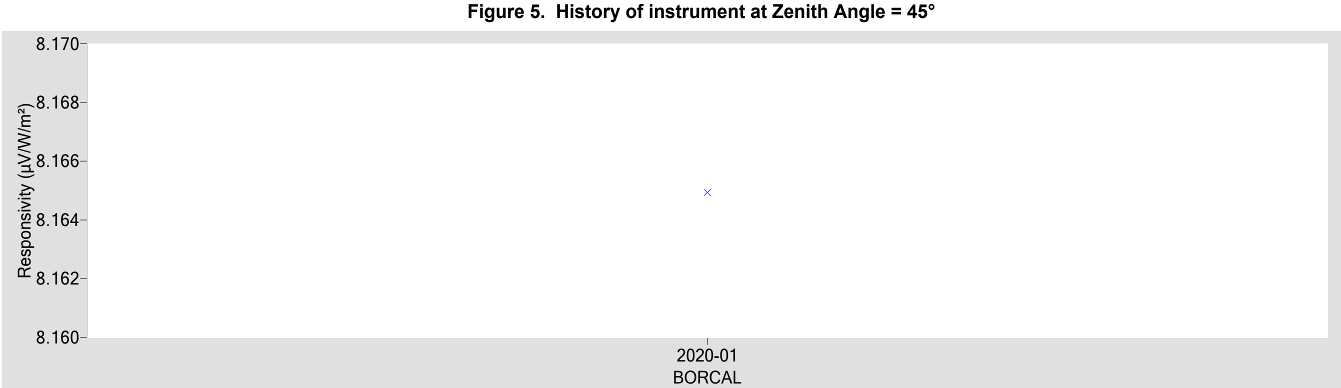
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1649	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.94 / -0.50
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:**	32016F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

32016F3 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

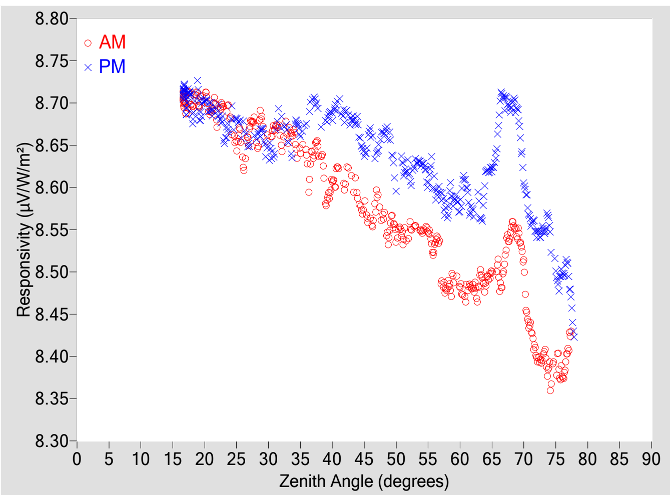


Figure 2. Responsivity vs Local Standard Time

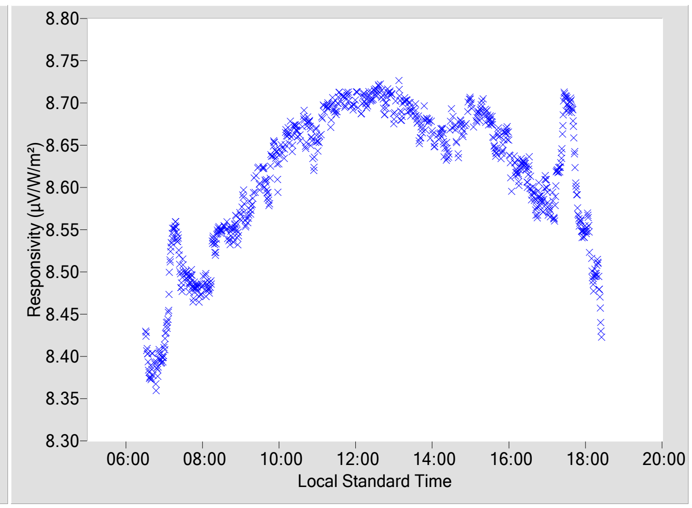


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5574	0.32	97.13	8.6644	0.31	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5671	0.33	95.53	8.6645	0.32	264.60
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5455	0.33	93.96	8.6034	0.32	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5497	0.33	92.24	8.6176	0.32	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5482	0.34	90.85	8.6284	0.33	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5298	0.34	89.30	8.5990	0.34	270.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4820	0.35	87.86	8.5738	0.34	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4811	0.36	86.39	8.5764	0.35	273.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4806	0.37	85.04	8.5729	0.37	275.01
18	8.6960	0.29	155.62	8.6945	0.29	204.78	64	8.4855	0.38	83.67	8.6097	0.38	276.45
20	8.7087	0.29	142.82	8.7031	0.29	217.24	66	8.4988	0.40	82.28	8.6741	0.39	277.86
22	8.6755	0.29	134.99	8.6904	0.29	225.71	68	8.5516	0.41	80.86	8.6944	0.42	279.22
24	8.6758	0.29	128.26	8.6809	0.29	231.68	70	8.5046	N/A	79.52	8.6141	0.44	280.57
26	8.6266	0.30	123.41	8.6679	0.29	236.56	72	8.4005	N/A	78.12	8.5467	N/A	281.98
28	8.6639	0.30	119.35	8.6594	0.29	240.58	74	8.3782	N/A	76.70	8.5513	N/A	283.38
30	8.6586	0.30	116.13	8.6439	0.30	244.30	76	8.3772	N/A	75.34	8.4979	N/A	284.79
32	8.6513	0.30	112.74	8.6772	0.30	247.36	78	N/A	N/A	N/A	8.4263	N/A	286.08
34	8.6615	0.30	109.91	8.6777	0.30	250.45	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6371	0.31	107.41	8.6753	0.30	252.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6411	0.31	105.14	8.6826	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6059	0.31	102.91	8.6864	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6075	0.31	100.92	8.6876	0.31	259.16	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5869	0.32	99.03	8.6739	0.31	261.01	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

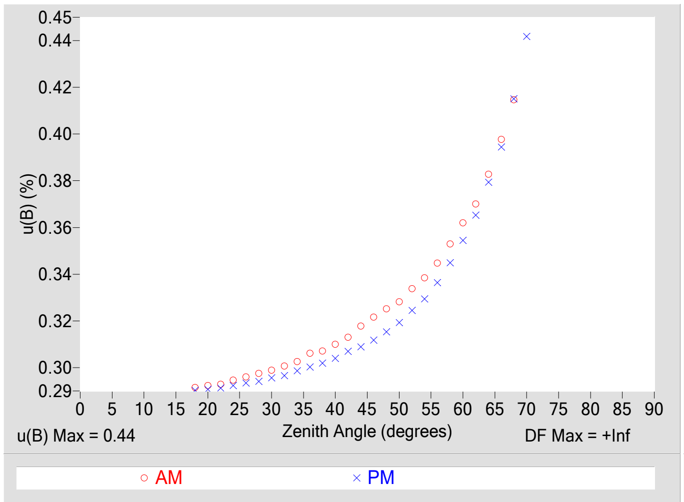


Figure 4. Residuals from Spline Interpolation

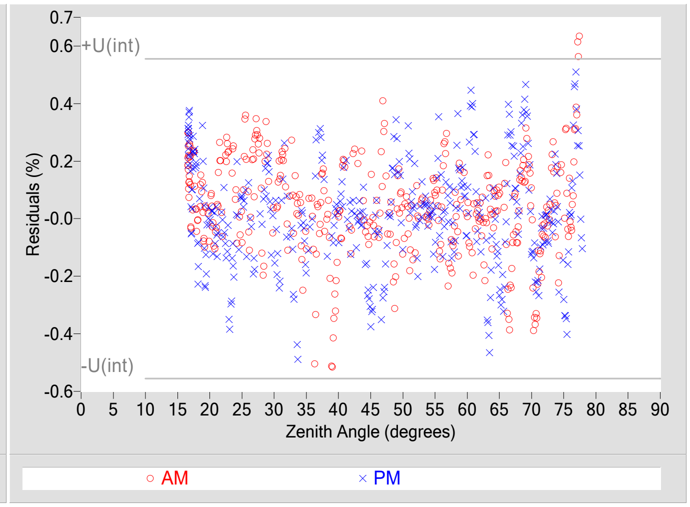


Table 3. Uncertainty using Spline Interpolation ‡

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)	8865
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

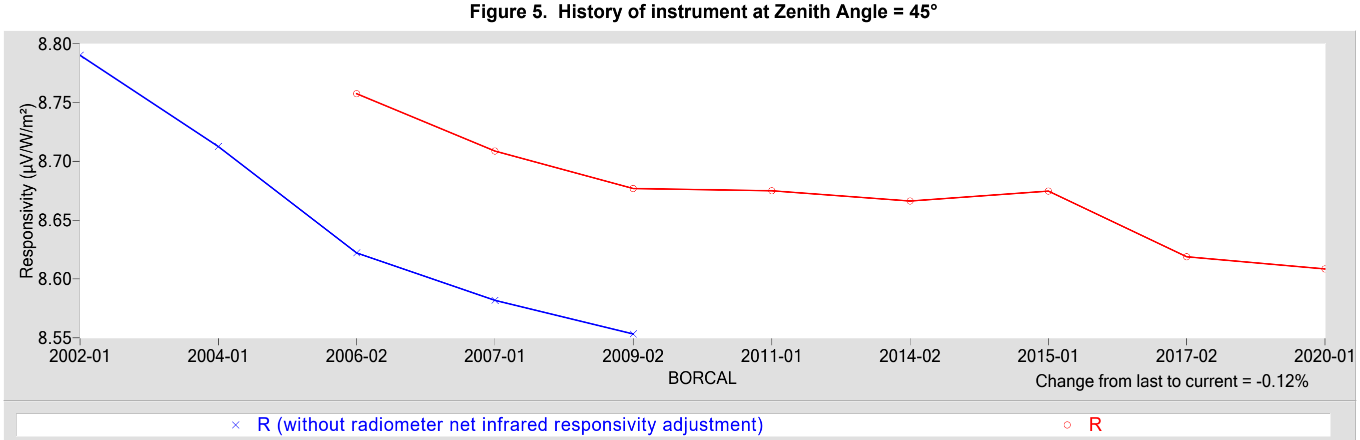
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6085	0.64054

† Rnet determination date: 06/13/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+0.92 / -1.5
Expanded Uncertainty, U (%)	+1.6 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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:**	32017F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

32017F3 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

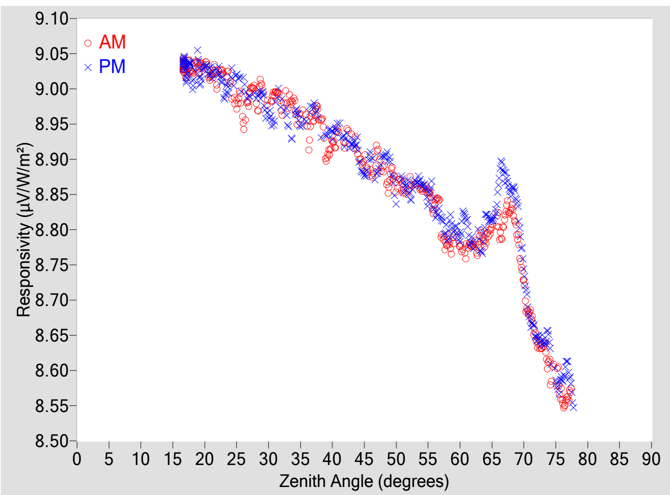


Figure 2. Responsivity vs Local Standard Time

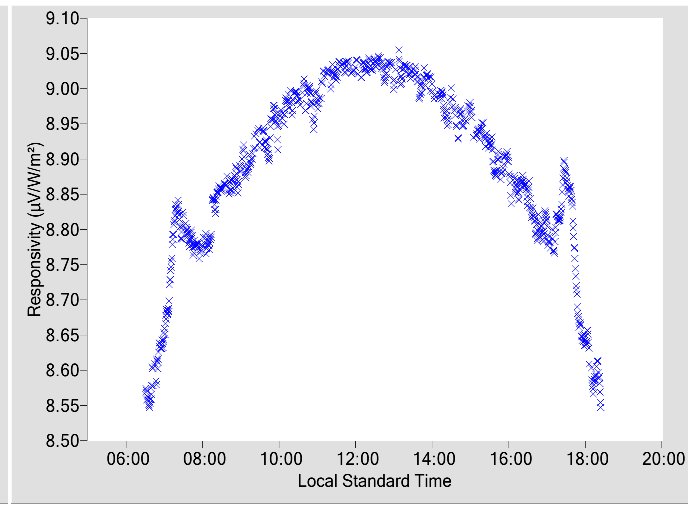


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.8788	0.32	97.13	8.9045	0.31	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8874	0.32	95.53	8.9038	0.31	264.60
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8640	0.33	93.96	8.8425	0.32	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8644	0.33	92.24	8.8545	0.32	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8573	0.34	90.85	8.8651	0.33	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8342	0.34	89.30	8.8305	0.33	270.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7802	0.35	87.86	8.7942	0.34	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7750	0.36	86.39	8.7899	0.35	273.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7769	0.37	85.04	8.7817	0.36	275.01
18	9.0243	0.29	155.62	9.0191	0.29	204.78	64	8.7838	0.38	83.67	8.8127	0.38	276.45
20	9.0357	0.29	142.82	9.0315	0.29	217.24	66	8.8079	0.40	82.28	8.8625	0.39	277.86
22	9.0025	0.29	134.99	9.0255	0.29	225.71	68	8.8292	0.41	80.86	8.8542	0.41	279.22
24	9.0012	0.29	128.26	9.0133	0.29	231.68	70	8.7238	N/A	79.52	8.7463	0.44	280.57
26	8.9514	0.30	123.41	9.0063	0.29	236.56	72	8.6420	N/A	78.12	8.6472	N/A	281.98
28	8.9867	0.30	119.35	8.9903	0.29	240.58	74	8.6010	N/A	76.70	8.6377	N/A	283.38
30	8.9804	0.30	116.13	8.9644	0.29	244.30	76	8.5584	N/A	75.34	8.5887	N/A	284.79
32	8.9719	0.30	112.74	8.9798	0.30	247.36	78	N/A	N/A	N/A	8.5473	N/A	286.03
34	8.9800	0.30	109.91	8.9670	0.30	250.45	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9554	0.31	107.41	8.9542	0.30	252.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.9609	0.31	105.14	8.9450	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9233	0.31	102.91	8.9352	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9269	0.31	100.92	8.9296	0.31	259.16	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9075	0.32	99.03	8.9151	0.31	261.01	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

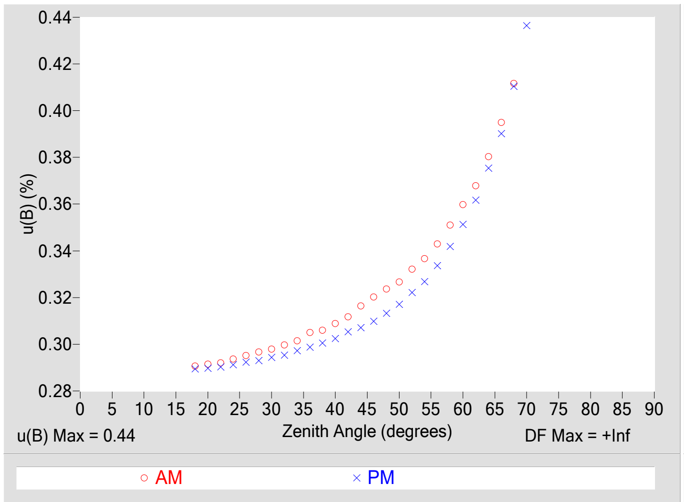


Figure 4. Residuals from Spline Interpolation

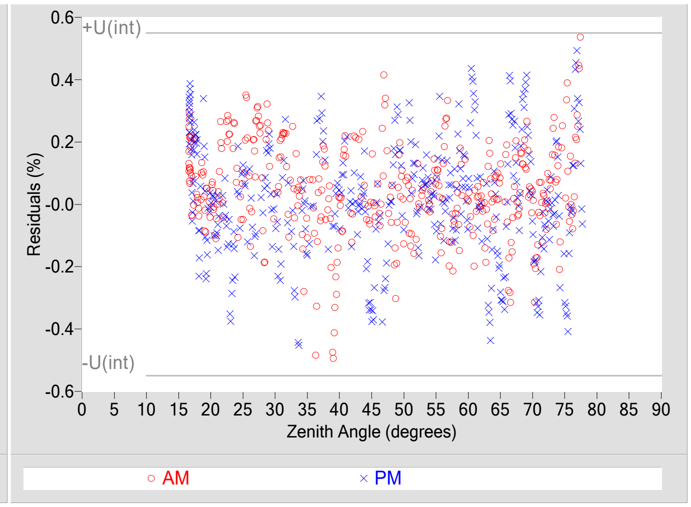


Table 3. Uncertainty using Spline Interpolation ‡

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)	8853
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

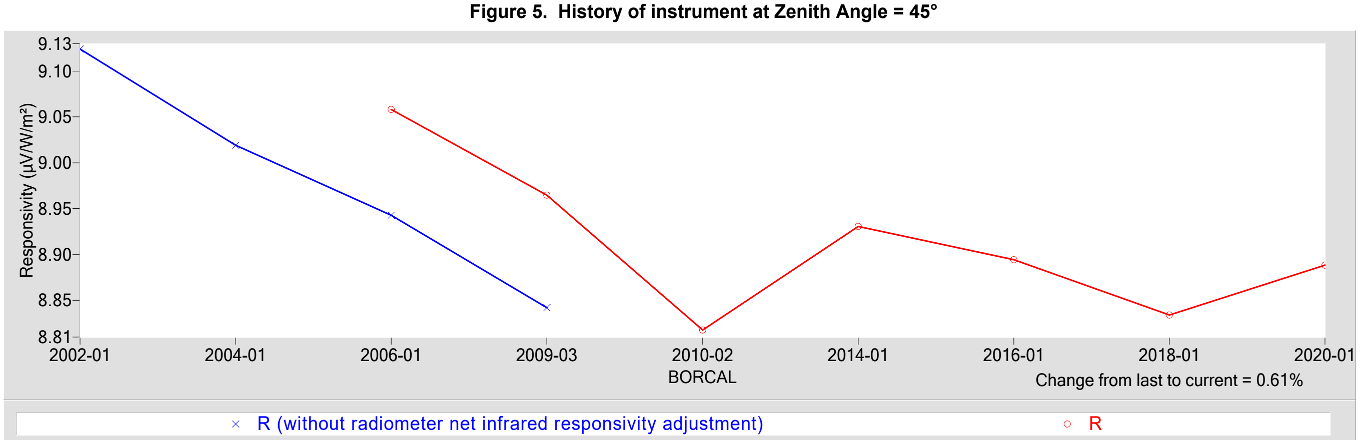
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.8885	0.59100

† Rnet determination date: 04/03/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.0 / -1.3
Expanded Uncertainty, U (%)	+1.7 / -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:**	32018F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

32018F3 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

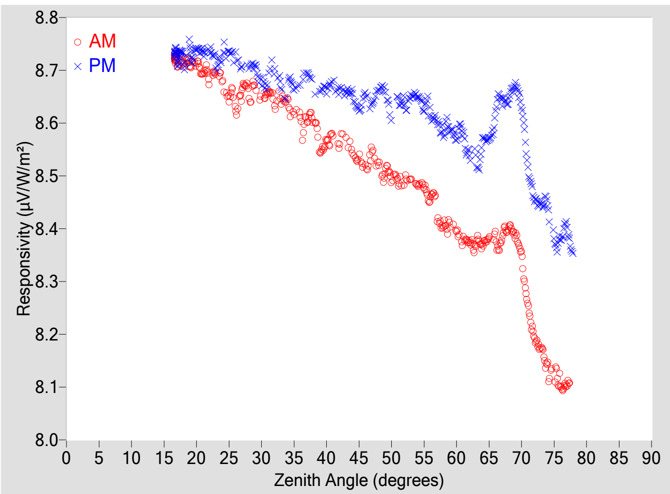


Figure 2. Responsivity vs Local Standard Time

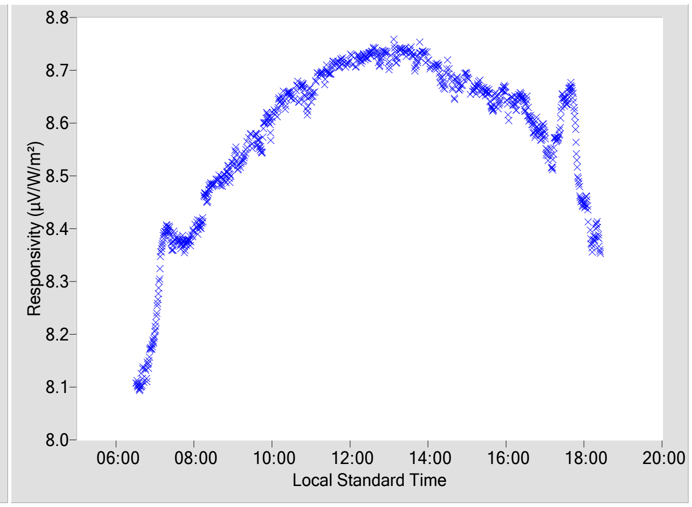


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5155	0.32	97.13	8.6535	0.31	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5240	0.32	95.53	8.6622	0.31	264.60
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4962	0.33	93.96	8.6102	0.32	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4927	0.33	92.24	8.6367	0.32	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4832	0.34	90.85	8.6501	0.33	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4582	0.34	89.30	8.6157	0.33	270.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4066	0.35	87.86	8.5828	0.34	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3934	0.36	86.39	8.5708	0.35	273.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3736	0.37	85.04	8.5418	0.36	275.01
18	8.7118	0.29	155.62	8.7197	0.29	204.78	64	8.3694	0.38	83.67	8.5619	0.38	276.45
20	8.7145	0.29	142.82	8.7401	0.29	217.24	66	8.3797	0.40	82.28	8.6200	0.39	277.86
22	8.6779	0.29	134.99	8.7374	0.29	225.71	68	8.4017	0.41	80.86	8.6424	0.41	279.22
24	8.6726	0.29	128.26	8.7337	0.29	231.68	70	8.3493	N/A	79.52	8.6323	0.44	280.57
26	8.6231	0.30	123.41	8.7225	0.29	236.56	72	8.1928	N/A	78.12	8.4569	N/A	281.98
28	8.6569	0.30	119.35	8.7067	0.29	240.58	74	8.1324	N/A	76.70	8.4412	N/A	283.38
30	8.6472	0.30	116.13	8.6810	0.29	244.30	76	8.1048	N/A	75.34	8.3815	N/A	284.79
32	8.6346	0.30	112.74	8.6978	0.30	247.36	78	N/A	N/A	N/A	8.3550	N/A	286.08
34	8.6403	0.30	109.91	8.6834	0.30	250.45	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6114	0.31	107.41	8.6721	0.30	252.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6041	0.31	105.14	8.6689	0.30	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5657	0.31	102.91	8.6634	0.30	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5633	0.31	100.92	8.6636	0.31	259.16	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5438	0.32	99.03	8.6542	0.31	261.01	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

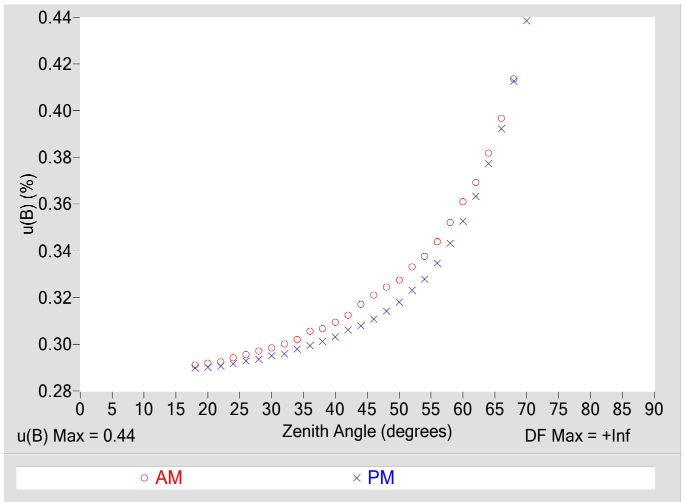


Figure 4. Residuals from Spline Interpolation

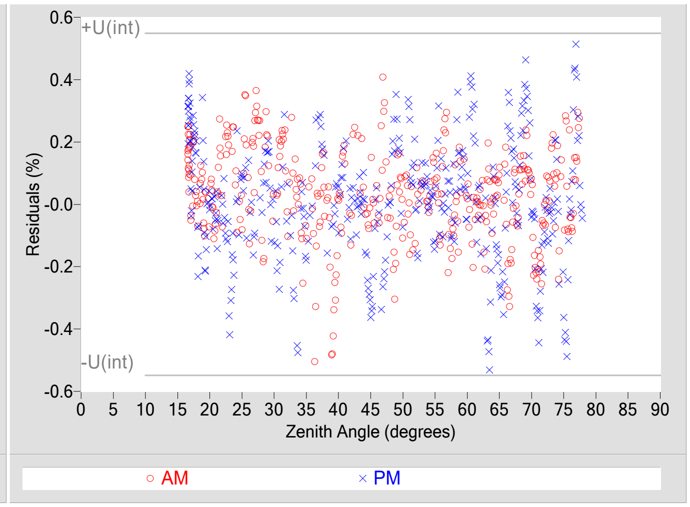


Table 3. Uncertainty using Spline Interpolation ‡

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)	8991
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

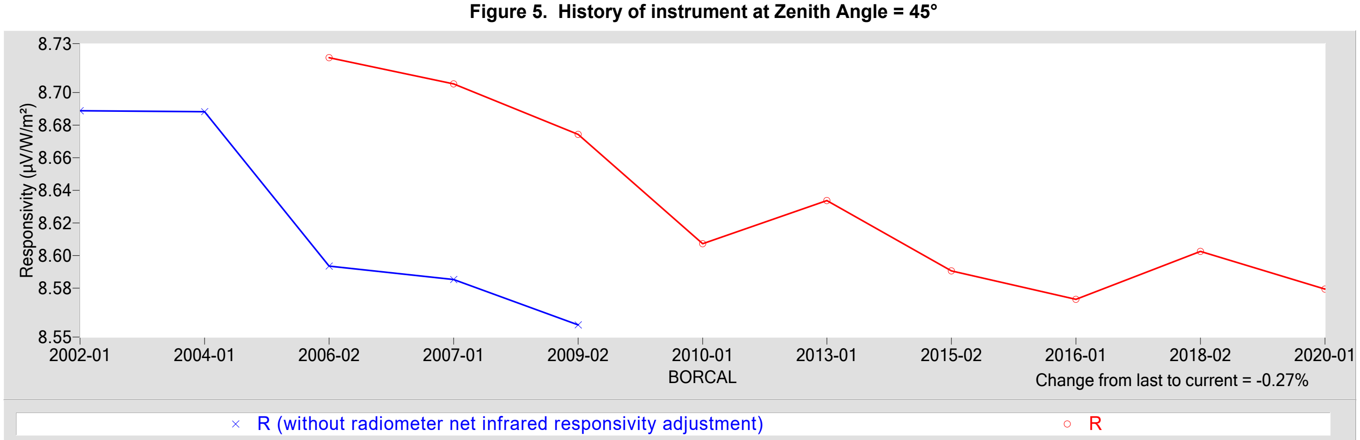
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.5795	0.60555

† Rnet determination date: 06/13/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.71
Offset Uncertainty, U(off) (%)	+1.4 / -2.2
Expanded Uncertainty, U (%)	+2.1 / -2.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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: 5/19/2020

Due Date: 5/19/2021

Customer: TWP

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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:

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

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

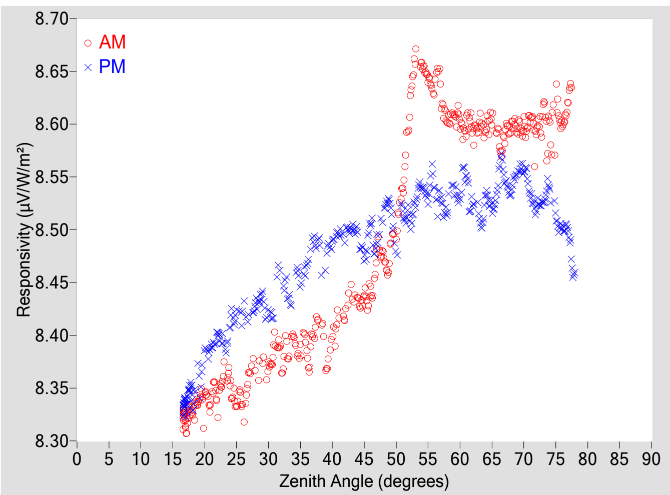


Figure 2. Responsivity vs Local Standard Time

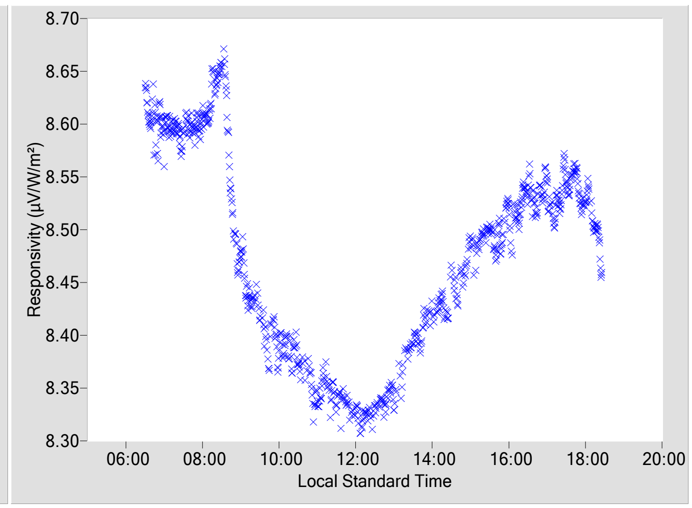


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4407	0.31	97.25	8.5048	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4754	0.32	95.59	8.5161	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5019	0.32	93.79	8.4778	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6052	0.33	92.31	8.5130	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6557	0.33	90.81	8.5399	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6331	0.34	89.35	8.5402	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6036	0.34	87.87	8.5212	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6056	0.35	86.48	8.5308	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5928	0.36	85.00	8.5255	0.35	275.07
18	8.3263	0.29	155.25	8.3423	0.29	204.66	64	8.5951	0.37	83.63	8.5316	0.36	276.50
20	8.3449	0.29	142.01	8.3869	0.29	217.31	66	8.5870	0.38	82.24	8.5462	0.37	277.82
22	8.3368	0.29	135.08	8.4001	0.29	225.48	68	8.5972	0.40	80.90	8.5356	0.39	279.23
24	8.3538	0.29	128.45	8.4148	0.29	231.70	70	8.5949	N/A	79.49	8.5567	0.41	280.62
26	8.3282	0.29	123.61	8.4214	0.29	236.47	72	8.5877	N/A	78.17	8.5217	N/A	282.03
28	8.3668	0.29	119.57	8.4284	0.29	240.60	74	8.5931	N/A	76.75	8.5365	N/A	283.38
30	8.3683	0.29	115.82	8.4212	0.29	244.22	76	8.5995	N/A	75.31	8.5023	N/A	284.79
32	8.3749	0.30	112.67	8.4616	0.29	247.03	78	N/A	N/A	N/A	8.4582	N/A	286.12
34	8.3961	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3814	0.30	107.32	8.4656	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4152	0.30	105.30	8.4811	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3972	0.30	102.98	8.4881	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4180	0.31	101.01	8.4951	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4334	0.31	98.96	8.5003	0.30	260.95	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

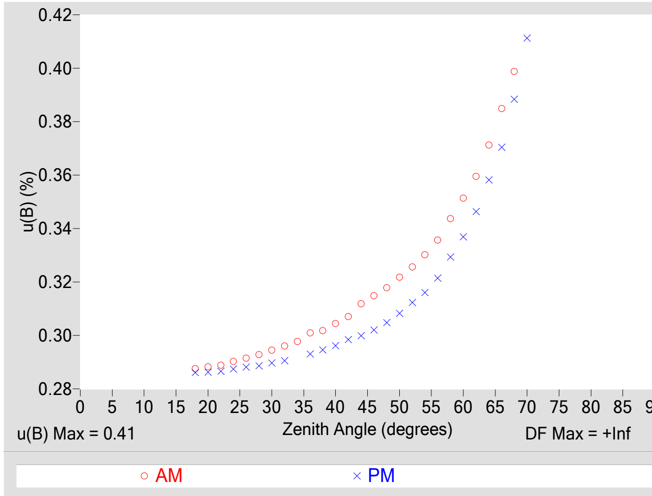


Figure 4. Residuals from Spline Interpolation

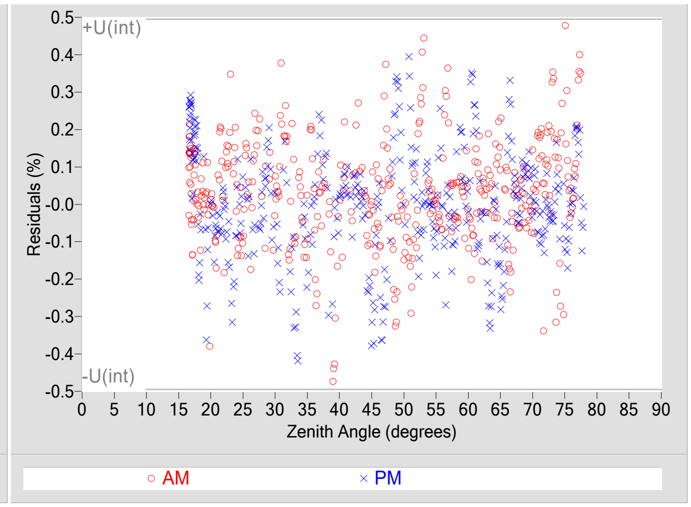


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	10446
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.94
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

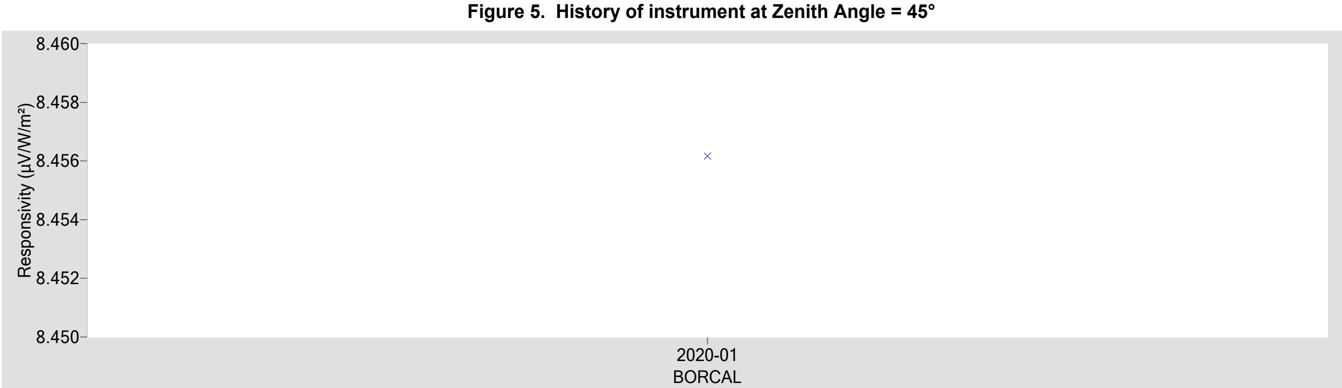
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4562	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+2.4 / -1.0
Expanded Uncertainty, U (%)	+3.0 / -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).

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:**	32989F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

32989F3 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

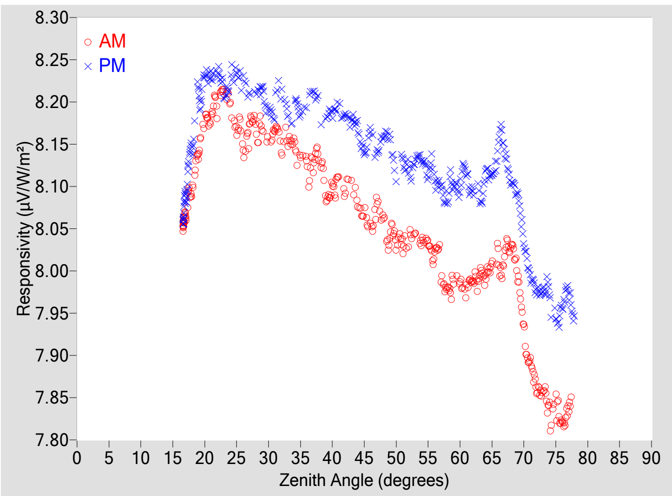


Figure 2. Responsivity vs Local Standard Time

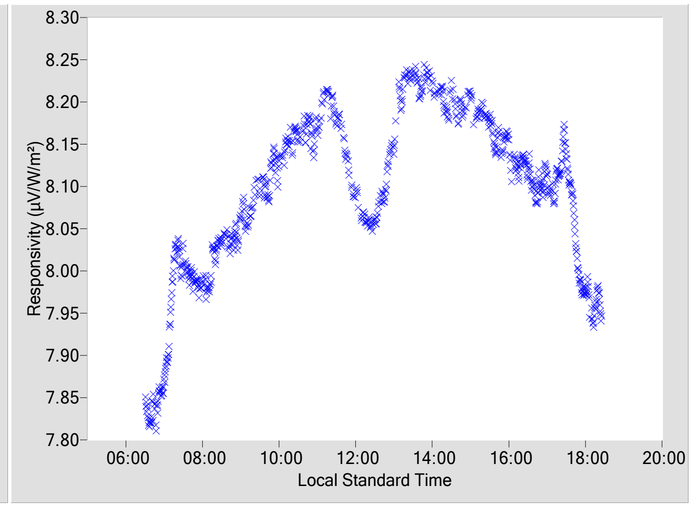


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0518	0.34	97.13	8.1646	0.34	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0637	0.34	95.53	8.1580	0.34	264.60
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0347	0.35	93.96	8.1123	0.35	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0400	0.35	92.24	8.1204	0.36	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0350	0.36	90.85	8.1309	0.36	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0195	0.37	89.30	8.1052	0.37	270.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9793	0.38	87.86	8.0861	0.38	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9853	0.39	86.39	8.0978	0.40	273.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9870	0.40	85.04	8.0949	0.41	275.01
18	8.0935	0.30	155.62	8.1477	0.30	204.78	64	7.9922	0.41	83.67	8.1141	0.43	276.45
20	8.1781	0.30	142.82	8.2318	0.30	217.24	66	8.0135	0.43	82.28	8.1501	0.45	277.86
22	8.1878	0.30	134.99	8.2351	0.30	225.71	68	8.0285	0.45	80.86	8.1047	0.48	279.22
24	8.1927	0.31	128.26	8.2295	0.30	231.68	70	7.9338	N/A	79.52	8.0374	0.52	280.57
26	8.1425	0.31	123.41	8.2231	0.31	236.56	72	7.8617	N/A	78.12	7.9768	N/A	281.98
28	8.1678	0.31	119.35	8.2108	0.31	240.58	74	7.8309	N/A	76.70	7.9705	N/A	283.38
30	8.1557	0.31	116.13	8.1922	0.31	244.30	76	7.8200	N/A	75.34	7.9585	N/A	284.79
32	8.1435	0.31	112.74	8.2092	0.31	247.36	78	N/A	N/A	N/A	7.9439	N/A	286.08
34	8.1506	0.32	109.91	8.2026	0.32	250.45	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1298	0.32	107.41	8.1932	0.32	252.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1306	0.32	105.14	8.1904	0.32	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0994	0.32	102.91	8.1869	0.32	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0966	0.33	100.92	8.1846	0.33	259.16	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0781	0.33	99.03	8.1694	0.33	261.01	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

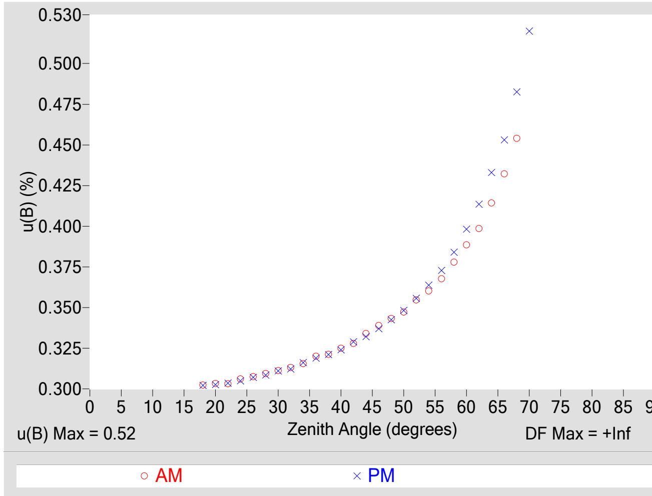


Figure 4. Residuals from Spline Interpolation

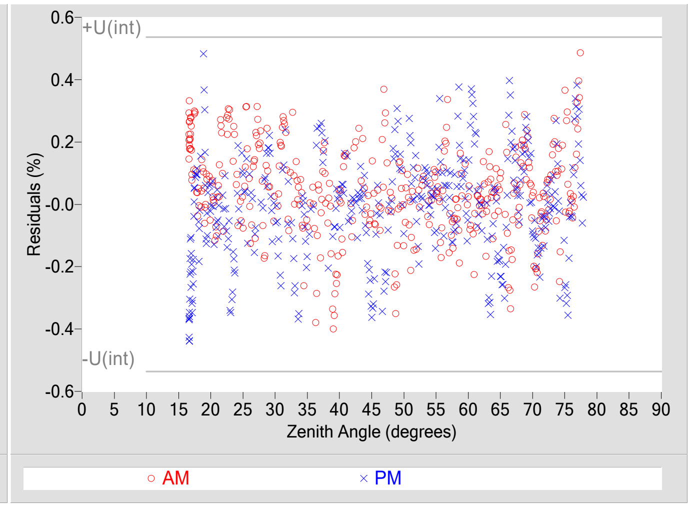


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.52
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	16192
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

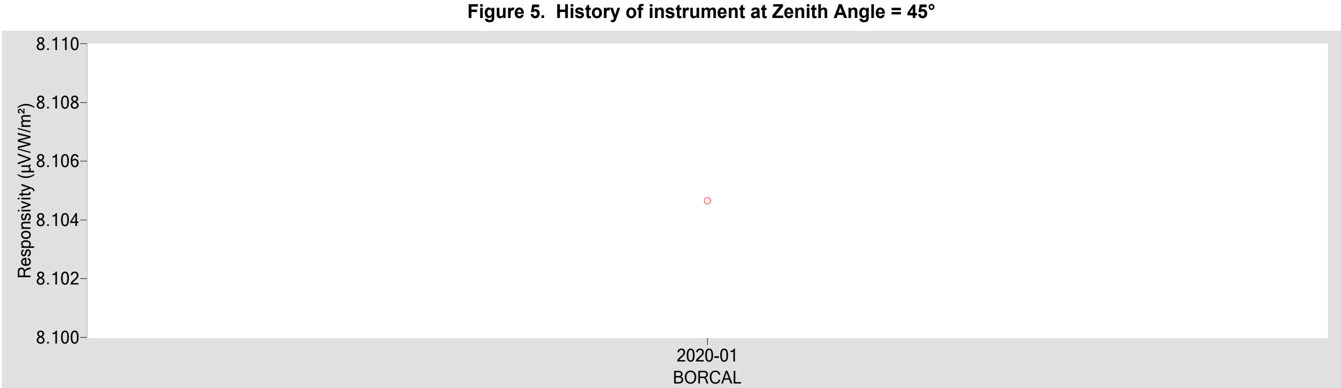
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.1046	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.78
Offset Uncertainty, U(off) (%)	+1.3 / -1.5
Expanded Uncertainty, U (%)	+2.1 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	33239
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33239 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

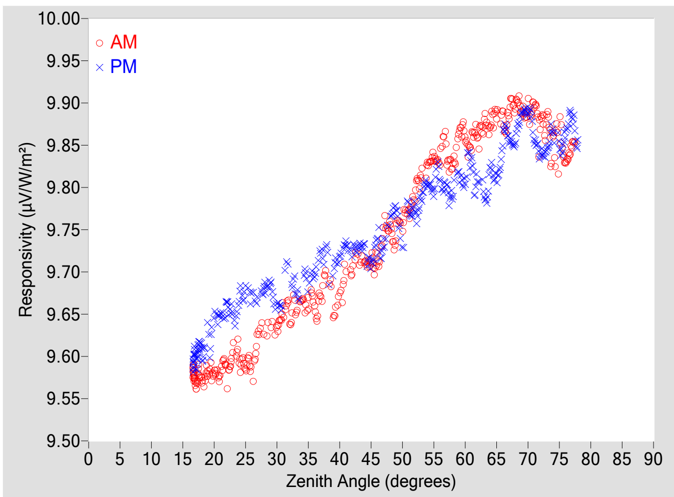


Figure 2. Responsivity vs Local Standard Time

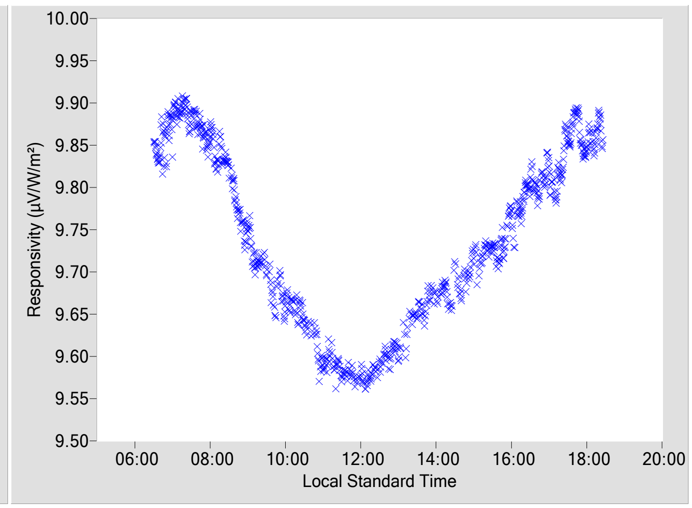


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.7144	0.31	97.25	9.7401	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.7528	0.32	95.59	9.7620	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7601	0.32	93.79	9.7291	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.7936	0.33	92.31	9.7717	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8245	0.33	90.81	9.8026	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8340	0.34	89.35	9.8101	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8273	0.34	87.87	9.7952	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8627	0.35	86.48	9.8068	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8593	0.36	85.00	9.8089	0.35	275.07
18	9.5728	0.29	155.25	9.6059	0.29	204.66	64	9.8738	0.37	83.63	9.8225	0.36	276.50
20	9.5805	0.29	142.34	9.6492	0.29	217.31	66	9.8810	0.38	82.24	9.8523	0.37	277.82
22	9.5831	0.29	135.08	9.6604	0.29	225.48	68	9.8972	0.40	80.90	9.8569	0.39	279.23
24	9.5981	0.29	128.45	9.6717	0.29	231.70	70	9.8890	N/A	79.49	9.8902	0.41	280.62
26	9.5800	0.29	123.61	9.6711	0.29	236.47	72	9.8701	N/A	78.17	9.8387	N/A	282.03
28	9.6262	0.29	119.57	9.6797	0.29	240.60	74	9.8502	N/A	76.75	9.8630	N/A	283.38
30	9.6324	0.29	115.82	9.6606	0.29	244.22	76	9.8305	N/A	75.31	9.8659	N/A	284.79
32	9.6492	0.30	112.67	9.7093	0.29	247.03	78	N/A	N/A	N/A	9.8513	N/A	286.12
34	9.6667	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.6553	0.30	107.32	9.6977	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.7015	0.30	105.30	9.7174	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.6712	0.30	102.98	9.7176	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7006	0.31	101.01	9.7253	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.7112	0.31	98.96	9.7332	0.30	260.95	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

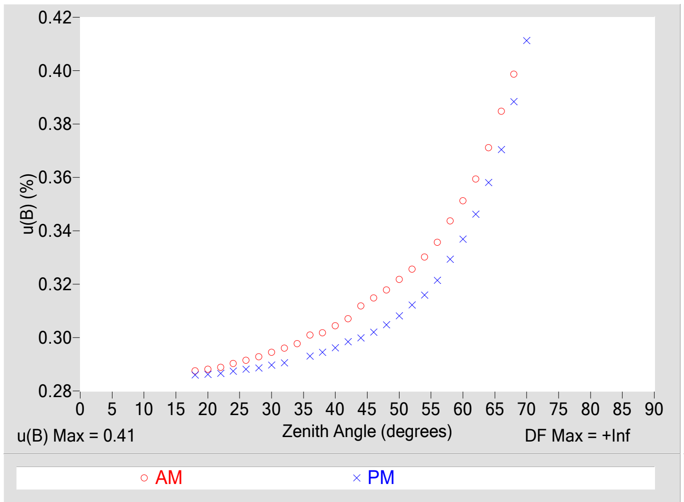


Figure 4. Residuals from Spline Interpolation

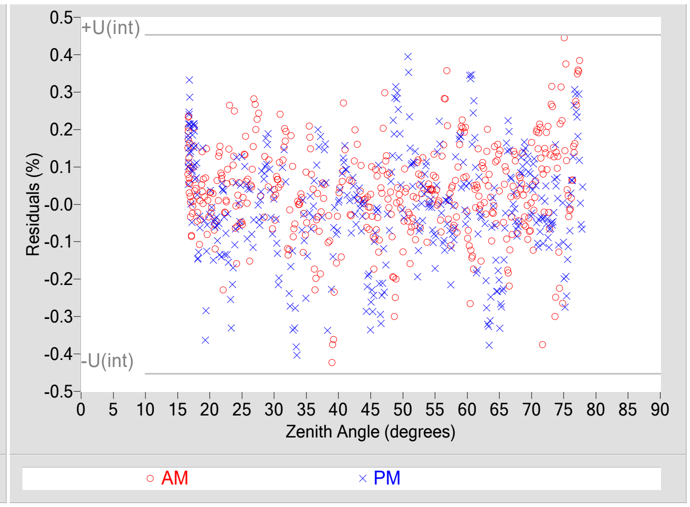


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	13644
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.92
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

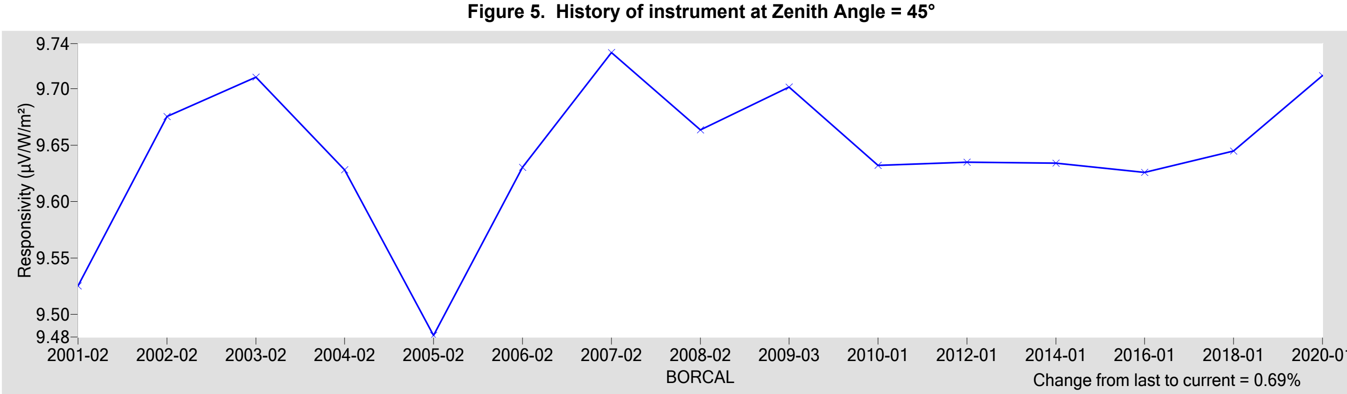
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.7117	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+1.6 / -0.82
Expanded Uncertainty, U (%)	+2.2 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33242
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33242 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

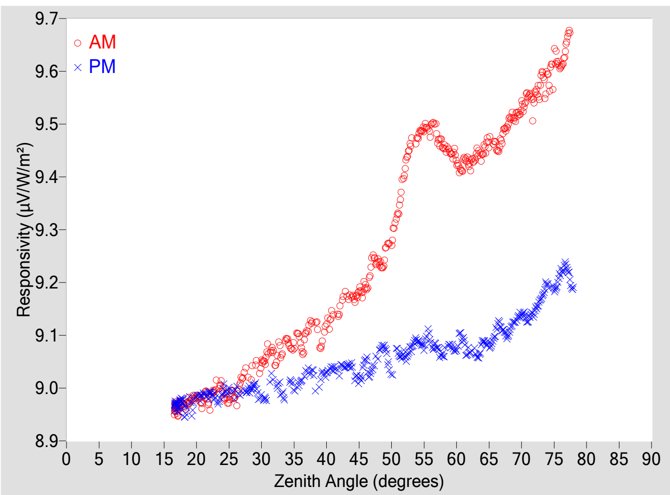


Figure 2. Responsivity vs Local Standard Time

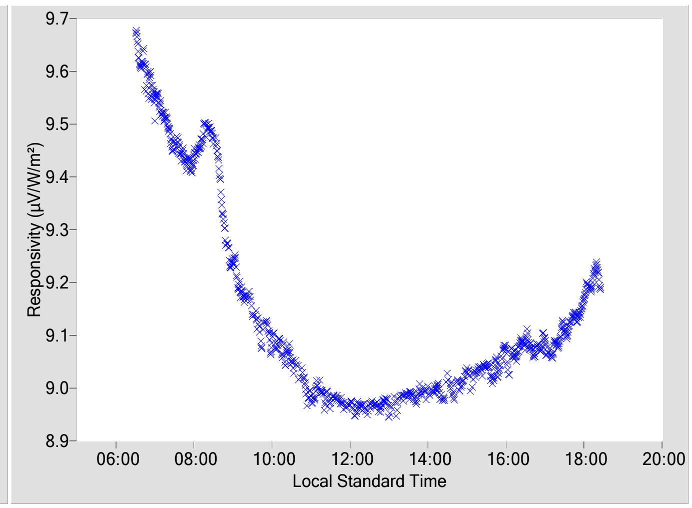


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.1924	0.31	97.25	9.0521	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2383	0.32	95.59	9.0665	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2844	0.32	93.79	9.0255	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.4120	0.33	92.31	9.0612	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4733	0.33	90.81	9.0891	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4872	0.34	89.35	9.0896	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4562	0.34	87.87	9.0656	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.4348	0.35	86.48	9.0736	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.4226	0.36	85.00	9.0699	0.35	275.07
18	8.9670	0.29	155.25	8.9647	0.29	204.66	64	9.4438	0.37	83.63	9.0876	0.36	276.50
20	8.9841	0.29	142.34	8.9848	0.29	217.31	66	9.4602	0.38	82.24	9.1030	0.37	277.82
22	8.9694	0.29	135.08	8.9896	0.29	225.48	68	9.5025	0.40	80.90	9.1019	0.39	279.23
24	8.9954	0.29	128.45	8.9958	0.29	231.70	70	9.5299	N/A	79.49	9.1392	0.41	280.62
26	8.9765	0.29	123.61	8.9930	0.29	236.47	72	9.5429	N/A	78.17	9.1450	N/A	282.03
28	9.0209	0.29	119.57	8.9959	0.29	240.60	74	9.5838	N/A	76.75	9.1948	N/A	283.38
30	9.0434	0.29	115.82	8.9812	0.29	244.22	76	9.6090	N/A	75.31	9.2197	N/A	284.79
32	9.0548	0.30	112.67	9.0157	0.29	247.03	78	N/A	N/A	N/A	9.1889	N/A	286.12
34	9.0891	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0820	0.30	107.32	9.0113	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1257	0.30	105.30	9.0219	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1192	0.30	102.98	9.0284	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1428	0.31	101.01	9.0341	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1723	0.31	98.96	9.0441	0.30	260.95	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

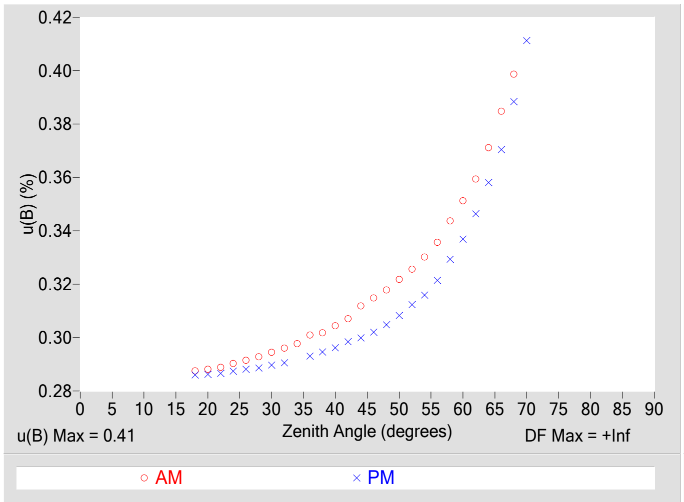


Figure 4. Residuals from Spline Interpolation

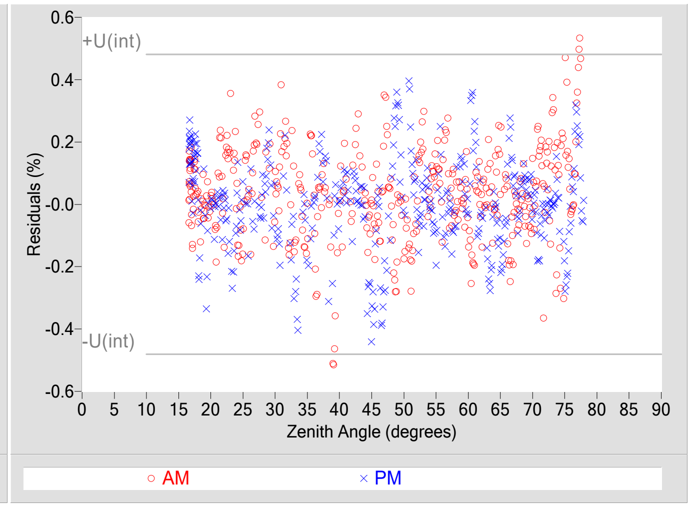


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	11389
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

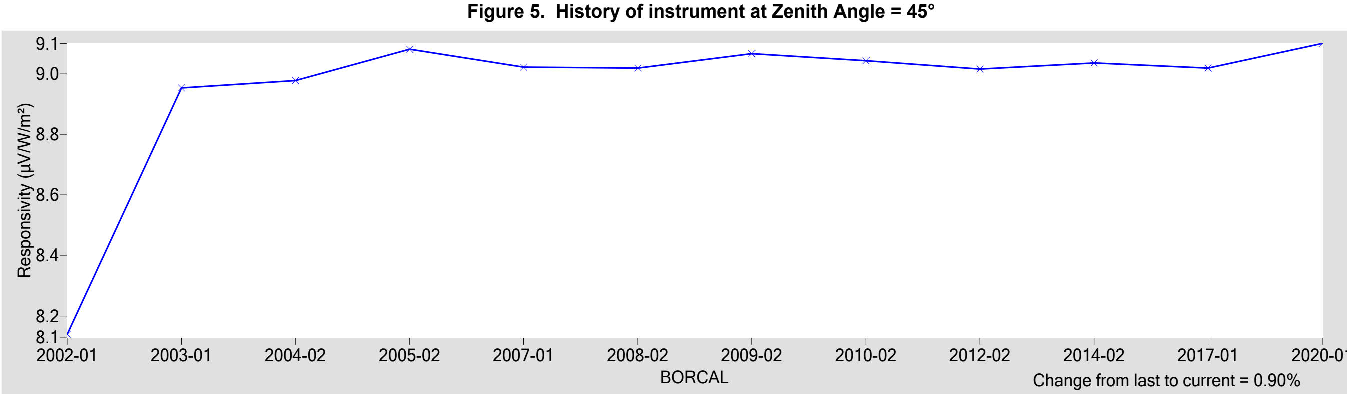
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.0998	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+4.3 / -1.3
Expanded Uncertainty, U (%)	+4.9 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33247
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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* [1]

where,

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

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

Figure 1. Responsivity vs Zenith Angle

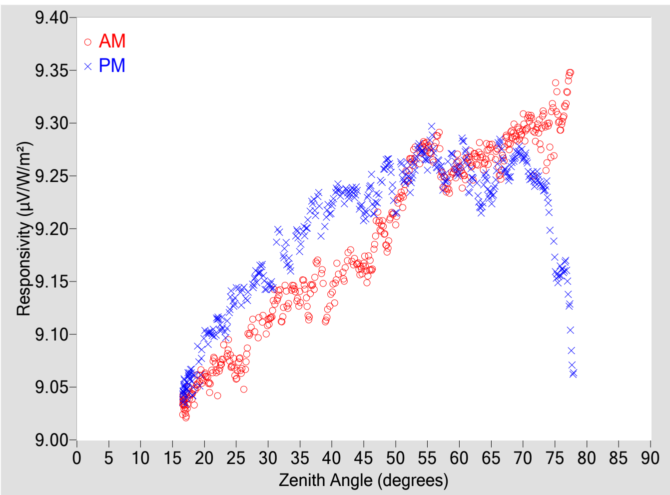


Figure 2. Responsivity vs Local Standard Time

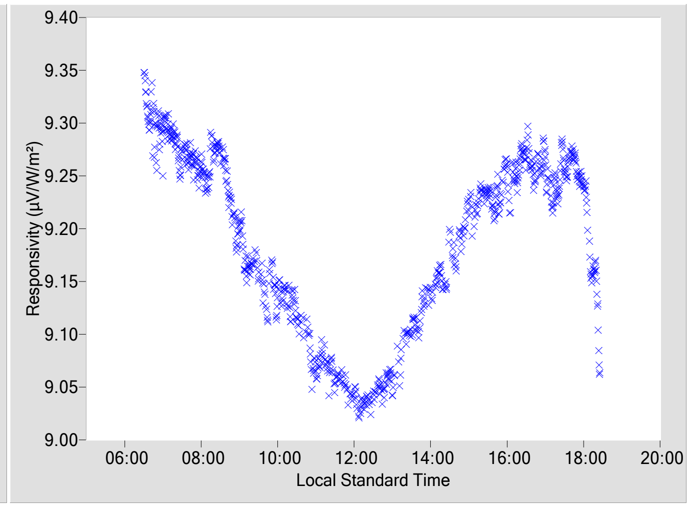


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.1655	0.31	97.25	9.2404	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2011	0.32	95.59	9.2522	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2143	0.32	93.79	9.2149	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.2530	0.33	92.31	9.2499	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2719	0.33	90.81	9.2737	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2687	0.34	89.35	9.2742	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2385	0.34	87.87	9.2516	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2610	0.35	86.48	9.2552	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2596	0.36	85.00	9.2502	0.35	275.07
18	9.0420	0.29	155.25	9.0554	0.29	204.66	64	9.2654	0.37	83.63	9.2479	0.36	276.50
20	9.0604	0.29	142.34	9.0999	0.29	217.31	66	9.2666	0.38	82.24	9.2646	0.37	277.82
22	9.0609	0.29	135.08	9.1124	0.29	225.48	68	9.2841	0.40	80.90	9.2530	0.39	279.23
24	9.0789	0.29	128.45	9.1303	0.29	231.70	70	9.2946	N/A	79.49	9.2684	0.41	280.62
26	9.0594	0.29	123.61	9.1382	0.29	236.47	72	9.2828	N/A	78.17	9.2468	N/A	282.03
28	9.1024	0.29	119.57	9.1526	0.29	240.60	74	9.2873	N/A	76.75	9.2170	N/A	283.38
30	9.1094	0.29	115.82	9.1459	0.29	244.22	76	9.2984	N/A	75.31	9.1610	N/A	284.79
32	9.1240	0.30	112.67	9.1968	0.29	247.03	78	N/A	N/A	N/A	9.0628	N/A	286.12
34	9.1437	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1304	0.30	107.32	9.2007	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1703	0.30	105.30	9.2199	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1380	0.30	102.98	9.2224	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1560	0.31	101.01	9.2320	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1656	0.31	98.96	9.2377	0.30	260.95	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

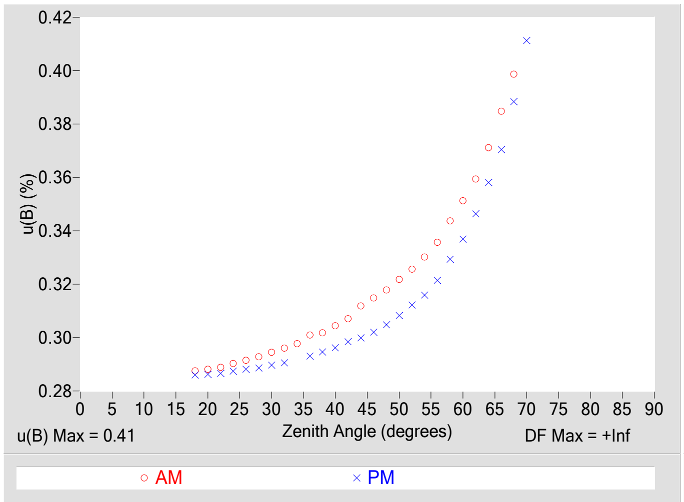


Figure 4. Residuals from Spline Interpolation

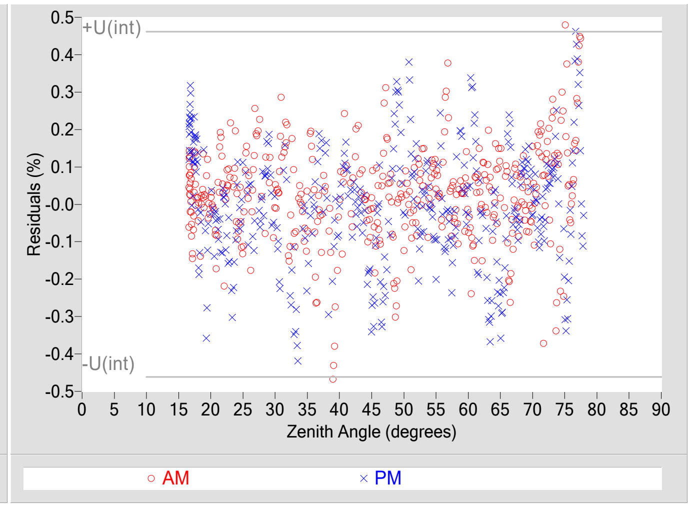


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	12906
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.92
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

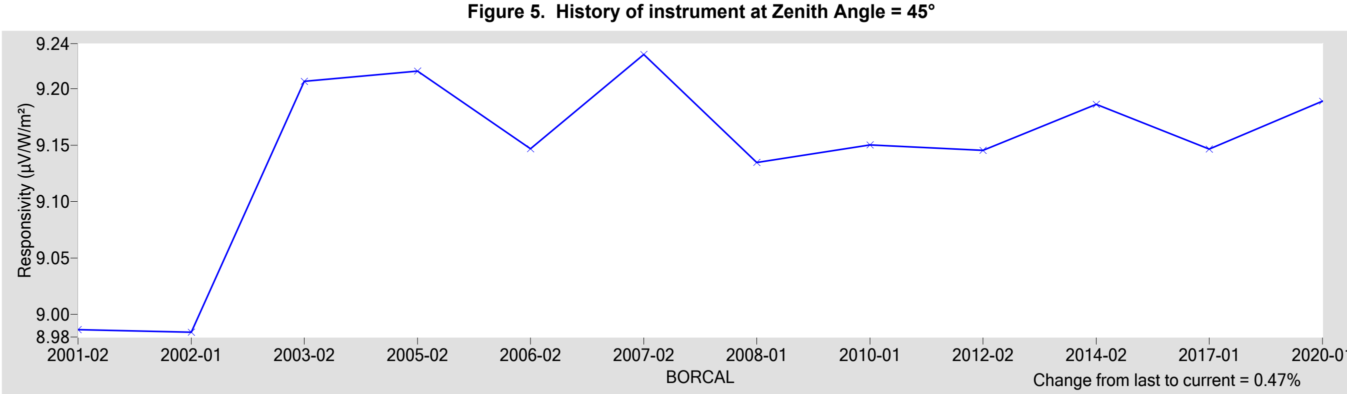
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.1891	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+0.93 / -0.87
Expanded Uncertainty, U (%)	+1.6 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	33259
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33259 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

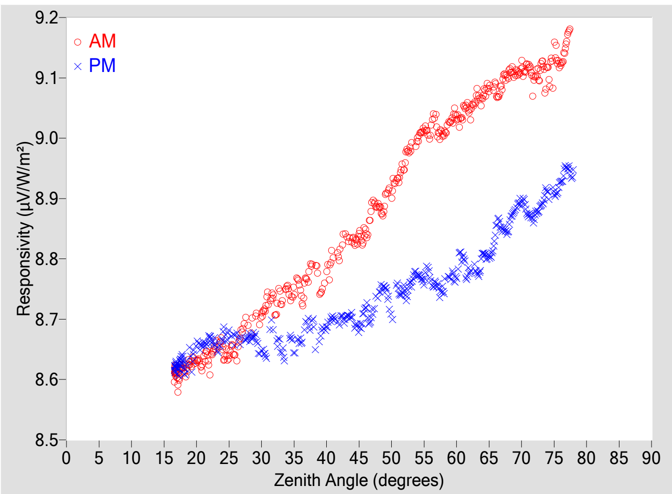


Figure 2. Responsivity vs Local Standard Time

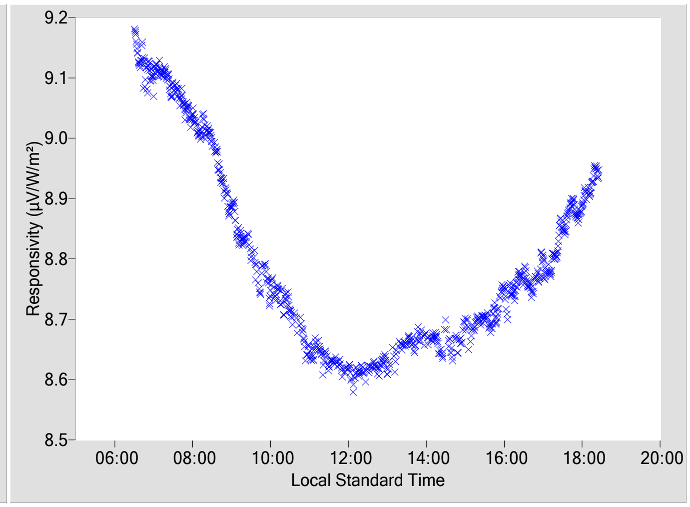


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	8.8430	0.31	97.25	8.7184	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8871	0.32	95.59	8.7418	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9154	0.32	93.79	8.7039	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9578	0.33	92.31	8.7449	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9960	0.33	90.81	8.7728	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0085	0.34	89.35	8.7669	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.0065	0.34	87.87	8.7525	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0392	0.35	86.48	8.7707	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0426	0.36	85.00	8.7799	0.35	275.07
18	8.6156	0.29	155.25	8.6240	0.29	204.66	64	9.0678	0.37	83.63	8.8071	0.36	276.50
20	8.6313	0.29	142.34	8.6594	0.29	217.31	66	9.0810	0.38	82.24	8.8401	0.37	277.82
22	8.6257	0.29	135.08	8.6689	0.29	225.48	68	9.1067	0.40	80.90	8.8505	0.39	279.23
24	8.6502	0.29	128.45	8.6749	0.29	231.70	70	9.1143	N/A	79.49	8.8955	0.41	280.62
26	8.6375	0.29	123.61	8.6692	0.29	236.47	72	9.0945	N/A	78.17	8.8704	N/A	282.03
28	8.6901	0.29	119.57	8.6700	0.29	240.60	74	9.1061	N/A	76.75	8.9089	N/A	283.38
30	8.7046	0.29	115.82	8.6471	0.29	244.22	76	9.1223	N/A	75.31	8.9279	N/A	284.79
32	8.7193	0.30	112.67	8.6827	0.29	247.03	78	N/A	N/A	N/A	8.9416	N/A	286.12
34	8.7506	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7423	0.30	107.32	8.6626	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7911	0.30	105.30	8.6838	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7763	0.30	102.94	8.6877	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8065	0.31	101.01	8.6973	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8308	0.31	98.96	8.7072	0.30	260.95	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

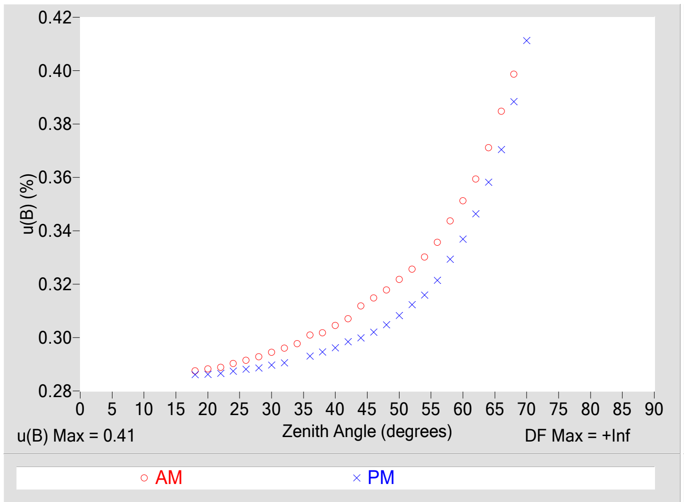


Figure 4. Residuals from Spline Interpolation

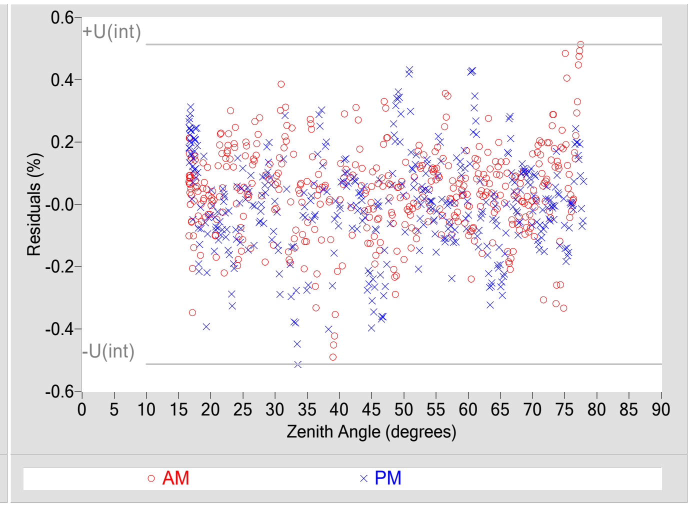


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	9445
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.95
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

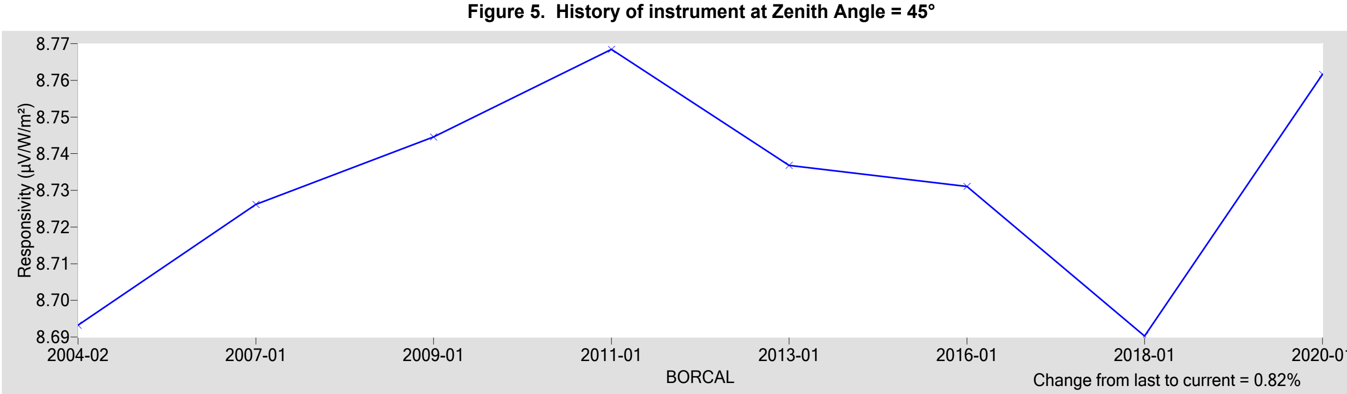
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7616	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+3.2 / -1.3
Expanded Uncertainty, U (%)	+3.9 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33261
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33261 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

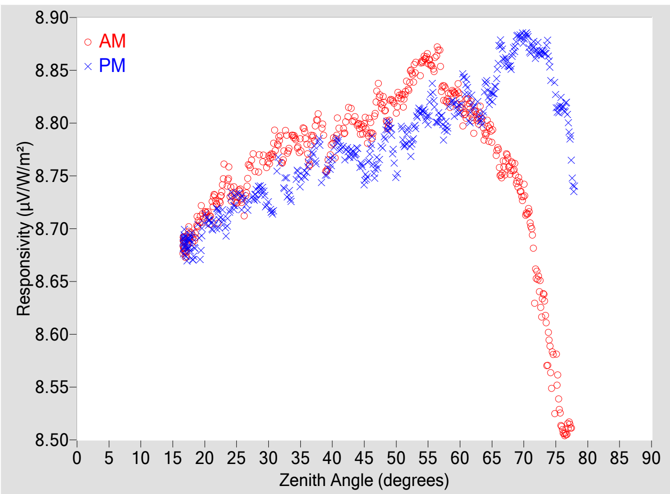


Figure 2. Responsivity vs Local Standard Time

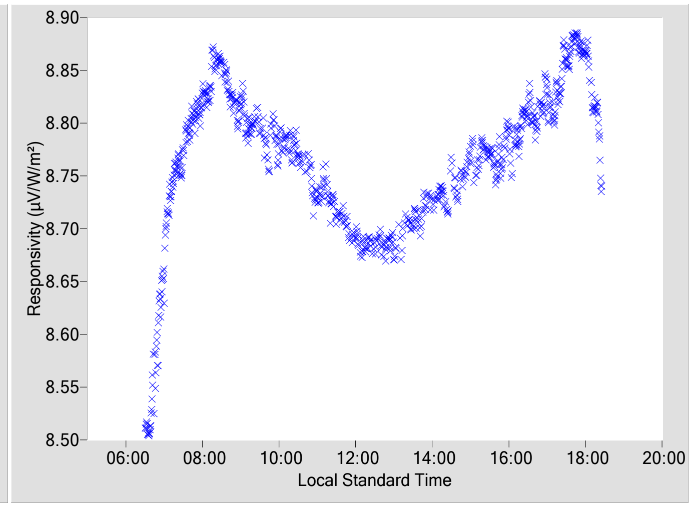


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7945	0.31	97.25	8.7756	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8176	0.32	95.59	8.7828	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8180	0.32	93.79	8.7503	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8377	0.33	92.31	8.7835	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8554	0.33	90.81	8.8103	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8541	0.34	89.35	8.8165	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8229	0.34	87.87	8.8012	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8243	0.35	86.48	8.8134	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8038	0.36	85.00	8.8190	0.35	275.07
18	8.6923	0.29	155.25	8.6830	0.29	204.66	64	8.7912	0.37	83.63	8.8353	0.36	276.50
20	8.7140	0.29	142.34	8.7097	0.29	217.31	66	8.7667	0.38	82.24	8.8592	0.37	277.82
22	8.7196	0.29	135.08	8.7135	0.29	225.48	68	8.7582	0.40	80.90	8.8576	0.39	279.23
24	8.7389	0.29	128.45	8.7242	0.29	231.70	70	8.7286	N/A	79.49	8.8815	0.41	280.62
26	8.7219	0.29	123.61	8.7259	0.29	236.47	72	8.6511	N/A	78.17	8.8674	N/A	282.03
28	8.7543	0.29	119.57	8.7314	0.29	240.60	74	8.5839	N/A	76.75	8.8539	N/A	283.38
30	8.7636	0.29	115.82	8.7220	0.29	244.22	76	8.5096	N/A	75.31	8.8173	N/A	284.79
32	8.7723	0.30	112.67	8.7621	0.29	247.03	78	N/A	N/A	N/A	8.7377	N/A	286.12
34	8.7866	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7753	0.30	107.32	8.7559	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8088	0.30	105.30	8.7727	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7792	0.30	102.98	8.7677	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7942	0.31	101.01	8.7726	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7978	0.31	98.96	8.7763	0.30	260.95	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

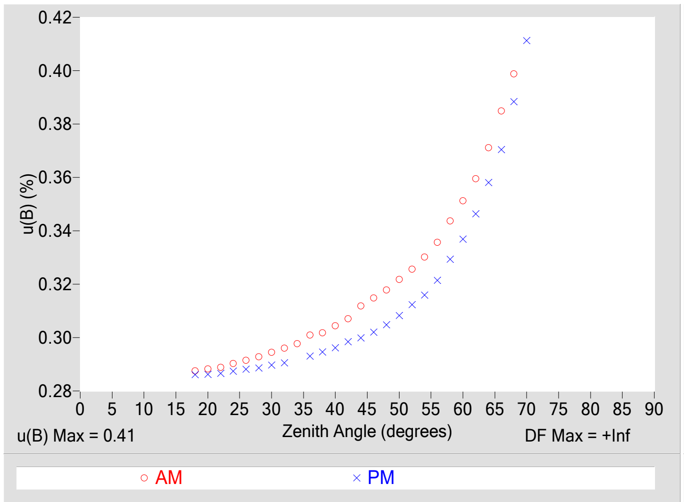


Figure 4. Residuals from Spline Interpolation

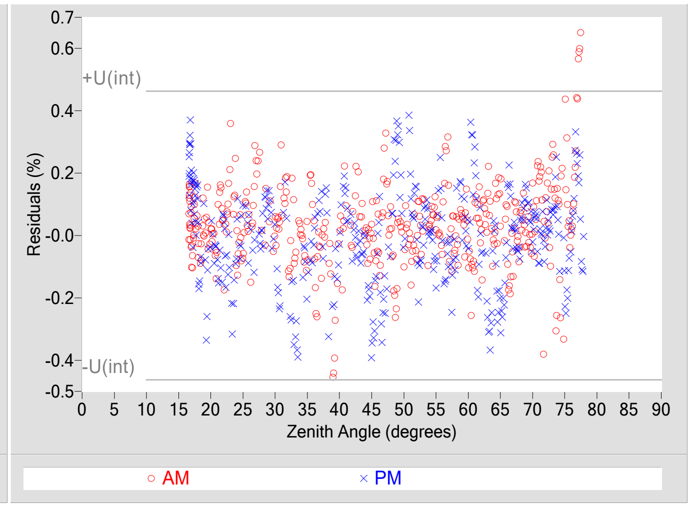


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	12758
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

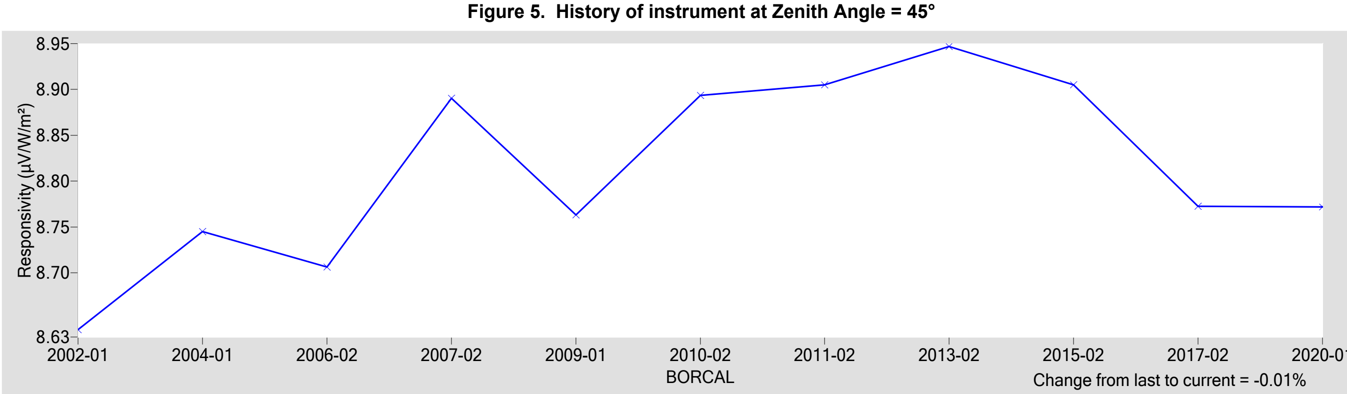
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.7718	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+0.95 / -0.57
Expanded Uncertainty, U (%)	+1.6 / -1.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	33271
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33271 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 pygeometer (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

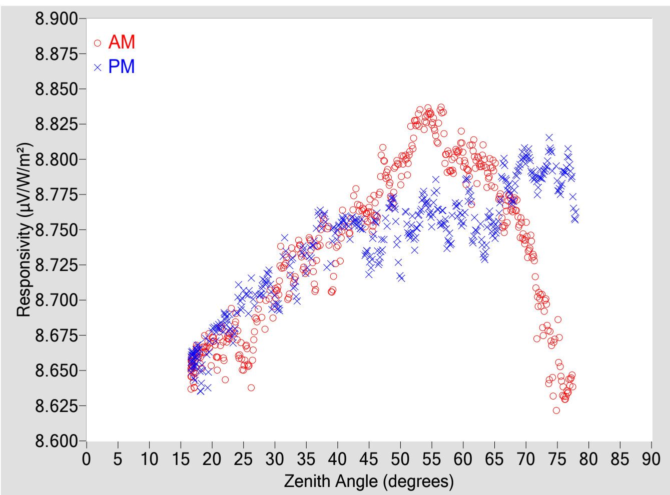


Figure 2. Responsivity vs Local Standard Time

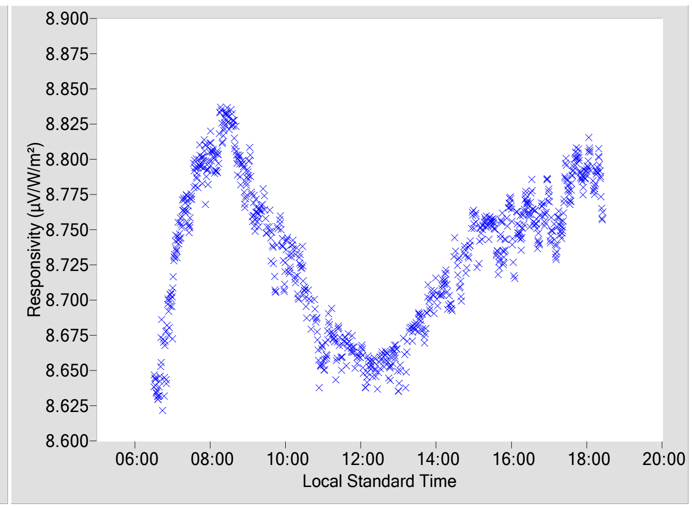


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7638	0.31	97.25	8.7552	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7877	0.32	95.59	8.7612	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7906	0.32	93.79	8.7164	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8150	0.33	92.31	8.7479	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8271	0.33	90.81	8.7701	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8165	0.34	89.35	8.7655	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7937	0.34	87.87	8.7468	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8060	0.35	86.48	8.7576	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7958	0.36	85.00	8.7517	0.35	275.07
18	8.6589	0.29	155.25	8.6523	0.29	204.66	64	8.7889	0.37	83.63	8.7583	0.36	276.50
20	8.6684	0.29	142.34	8.6792	0.29	217.31	66	8.7661	0.38	82.24	8.7753	0.37	277.82
22	8.6573	0.29	135.08	8.6872	0.29	225.48	68	8.7680	0.40	80.90	8.7739	0.39	279.23
24	8.6740	0.29	128.45	8.6987	0.29	231.70	70	8.7427	N/A	79.49	8.8025	0.41	280.62
26	8.6480	0.29	123.61	8.7042	0.29	236.47	72	8.6953	N/A	78.17	8.7843	N/A	282.03
28	8.6878	0.29	119.57	8.7083	0.29	240.60	74	8.6609	N/A	76.75	8.8028	N/A	283.38
30	8.6998	0.29	115.82	8.6990	0.29	244.22	76	8.6323	N/A	75.31	8.7910	N/A	284.79
32	8.7125	0.30	112.67	8.7347	0.29	247.03	78	N/A	N/A	N/A	8.7597	N/A	286.12
34	8.7368	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7235	0.30	107.32	8.7374	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7570	0.30	105.30	8.7501	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7376	0.30	102.98	8.7498	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7512	0.31	101.01	8.7514	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7627	0.31	98.96	8.7539	0.30	260.95	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

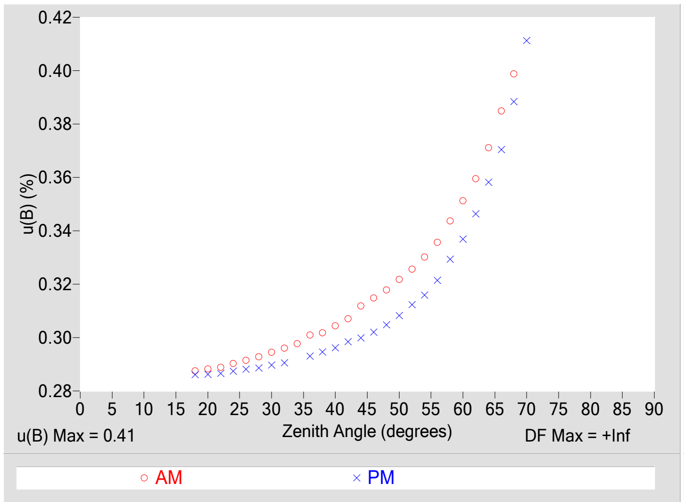


Figure 4. Residuals from Spline Interpolation

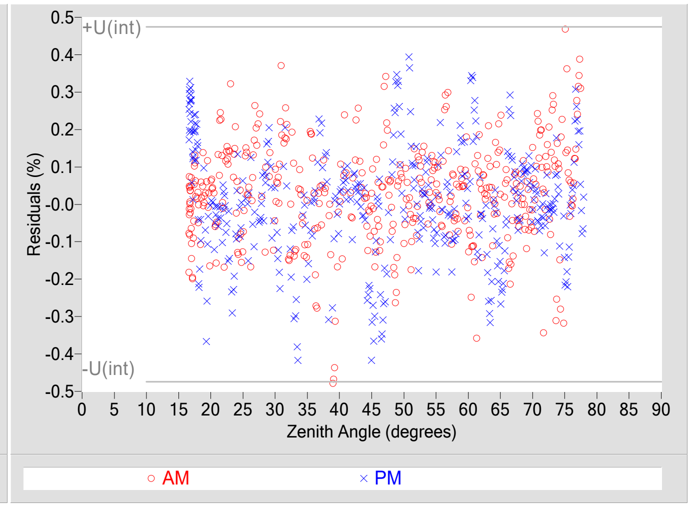


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	11859
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

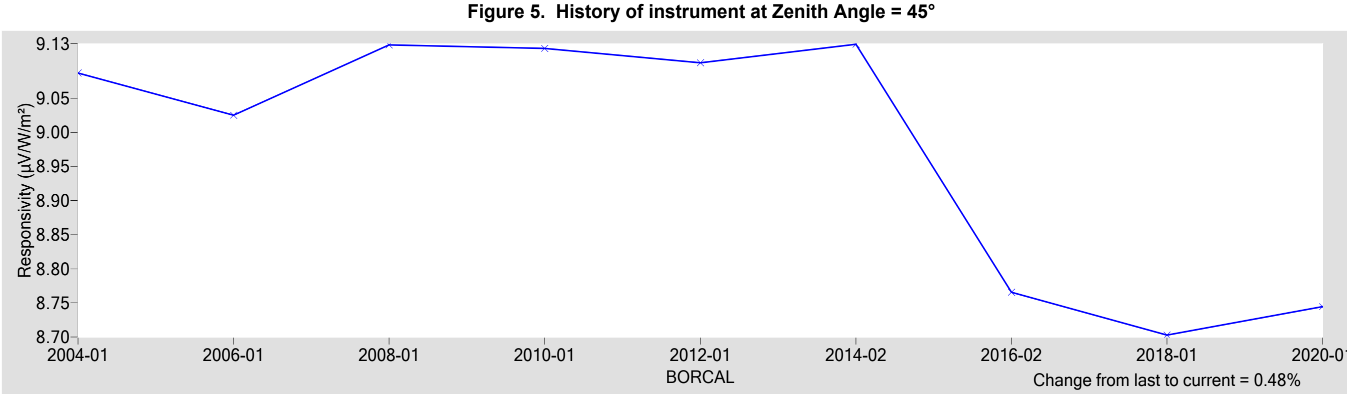
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7446	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+0.94 / -0.52
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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33274
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33274 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

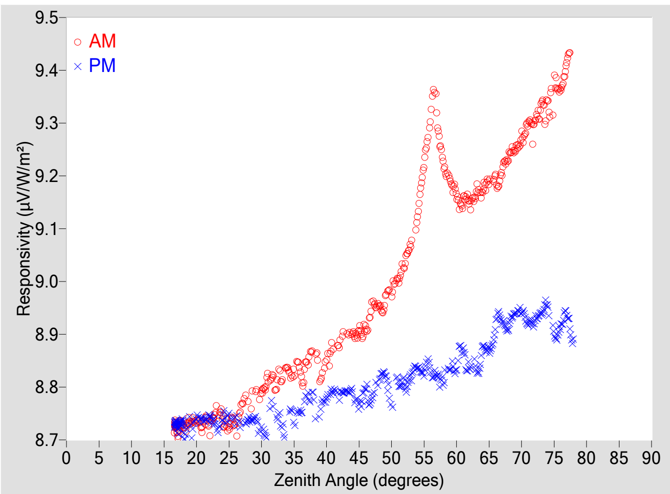


Figure 2. Responsivity vs Local Standard Time

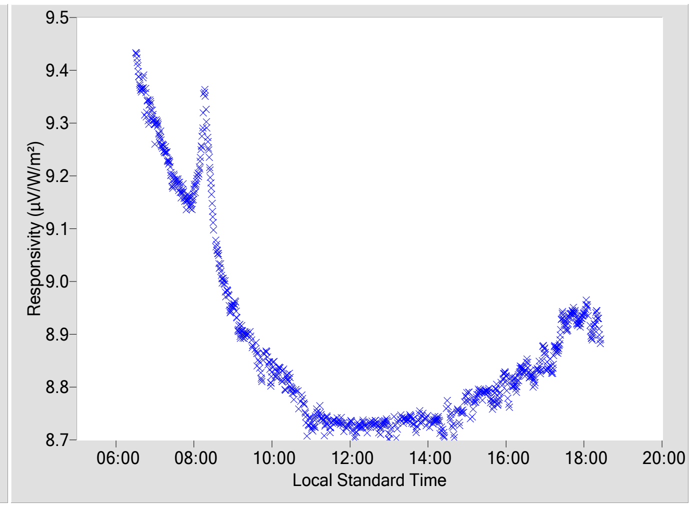


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.9111	0.31	97.25	8.7972	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9540	0.32	95.59	8.8110	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9840	0.32	93.79	8.7646	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0335	0.33	92.31	8.8049	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1225	0.33	90.81	8.8362	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3066	0.34	89.35	8.8320	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2234	0.34	87.87	8.8161	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1683	0.35	86.48	8.8351	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1482	0.36	85.00	8.8389	0.35	275.07
18	8.7255	0.29	155.25	8.7205	0.29	204.66	64	9.1716	0.37	83.63	8.8739	0.36	276.50
20	8.7354	0.29	142.34	8.7431	0.29	217.31	66	9.1912	0.38	82.24	8.9108	0.37	277.82
22	8.7247	0.29	135.08	8.7433	0.29	225.48	68	9.2350	0.40	80.90	8.9141	0.39	279.23
24	8.7408	0.29	128.45	8.7448	0.29	231.70	70	9.2691	N/A	79.49	8.9433	0.41	280.62
26	8.7215	0.29	123.61	8.7386	0.29	236.47	72	9.2930	N/A	78.17	8.9251	N/A	282.03
28	8.7725	0.29	119.57	8.7378	0.29	240.60	74	9.3306	N/A	76.75	8.9493	N/A	283.38
30	8.7890	0.29	115.82	8.7210	0.29	244.22	76	9.3650	N/A	75.31	8.9159	N/A	284.79
32	8.8049	0.30	112.67	8.7630	0.29	247.03	78	N/A	N/A	N/A	8.8867	N/A	286.12
34	8.8341	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8232	0.30	107.32	8.7525	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8685	0.30	105.30	8.7743	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8497	0.30	102.98	8.7792	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8803	0.31	101.01	8.7856	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9007	0.31	98.96	8.7942	0.30	260.95	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

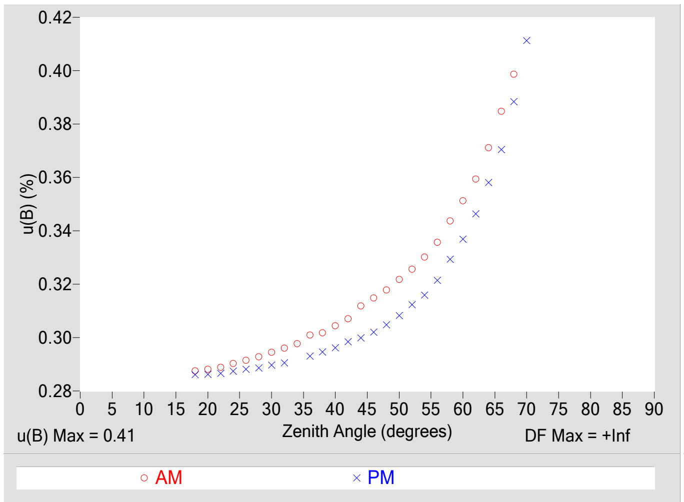


Figure 4. Residuals from Spline Interpolation

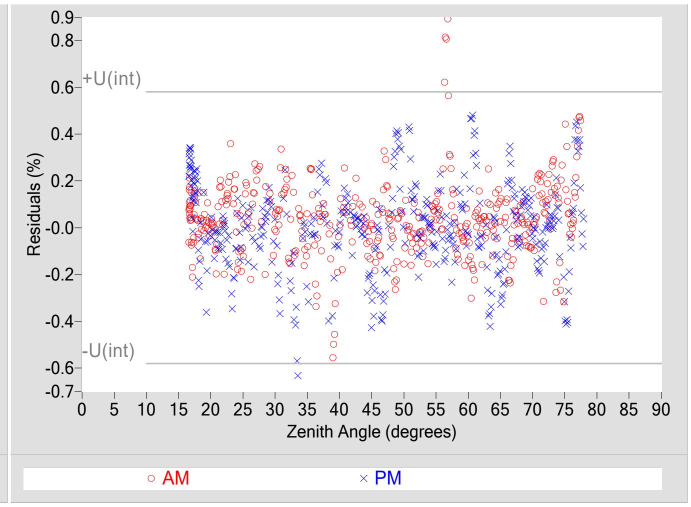


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.50
Effective degrees of freedom, DF(c)	6663
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

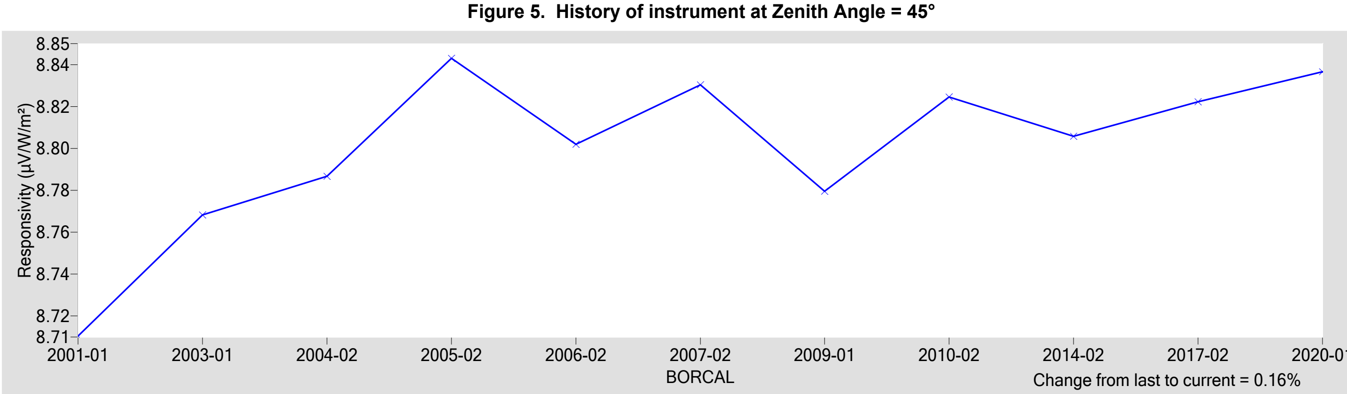
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8365	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+5.3 / -1.3
Expanded Uncertainty, U (%)	+6.0 / -2.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for 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:**	33277
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33277 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

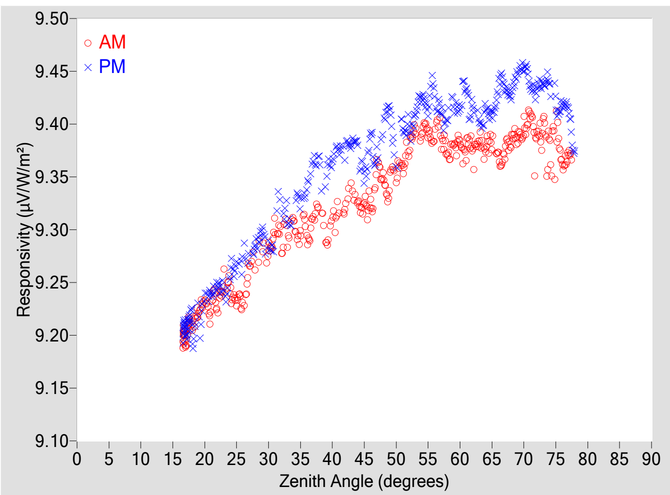


Figure 2. Responsivity vs Local Standard Time

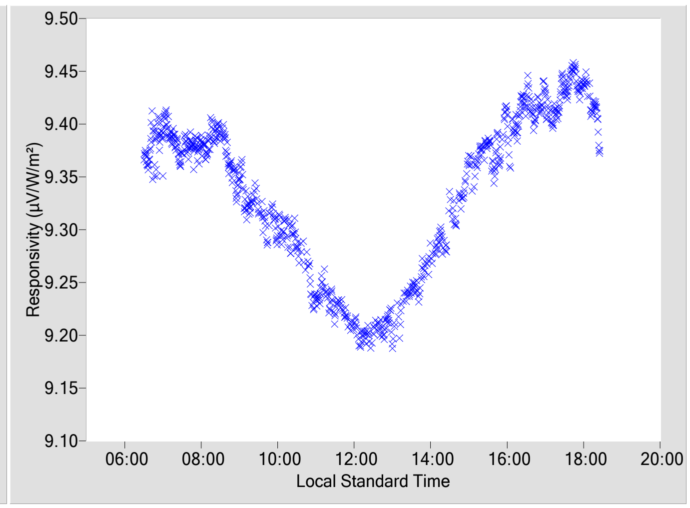


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	9.3247	0.31	97.25	9.3870	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.3478	0.32	95.59	9.4000	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.3529	0.32	93.79	9.3592	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.3764	0.33	92.31	9.3967	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.3903	0.33	90.81	9.4254	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.3873	0.34	89.35	9.4284	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.3718	0.34	87.87	9.4067	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.3837	0.35	86.48	9.4155	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.3735	0.36	85.00	9.4168	0.35	275.07
18	9.2093	0.29	155.25	9.2080	0.29	204.66	64	9.3767	0.37	83.63	9.4147	0.36	276.50
20	9.2317	0.29	142.34	9.2362	0.29	217.31	66	9.3685	0.38	82.24	9.4325	0.37	277.82
22	9.2255	0.29	135.08	9.2473	0.29	225.48	68	9.3840	0.40	80.90	9.4283	0.39	279.23
24	9.2424	0.29	128.45	9.2612	0.29	231.70	70	9.3939	N/A	79.49	9.4532	0.41	280.62
26	9.2279	0.29	123.61	9.2731	0.29	236.47	72	9.3814	N/A	78.17	9.4320	N/A	282.03
28	9.2618	0.29	119.57	9.2849	0.29	240.60	74	9.3765	N/A	76.75	9.4358	N/A	283.38
30	9.2790	0.29	115.82	9.2845	0.29	244.22	76	9.3623	N/A	75.31	9.4195	N/A	284.79
32	9.2874	0.30	112.67	9.3286	0.29	247.03	78	N/A	N/A	N/A	9.3734	N/A	286.12
34	9.3049	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.2938	0.30	107.32	9.3401	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.3217	0.30	105.30	9.3592	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.3103	0.30	102.98	9.3657	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3187	0.31	101.01	9.3763	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3254	0.31	98.96	9.3821	0.30	260.95	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

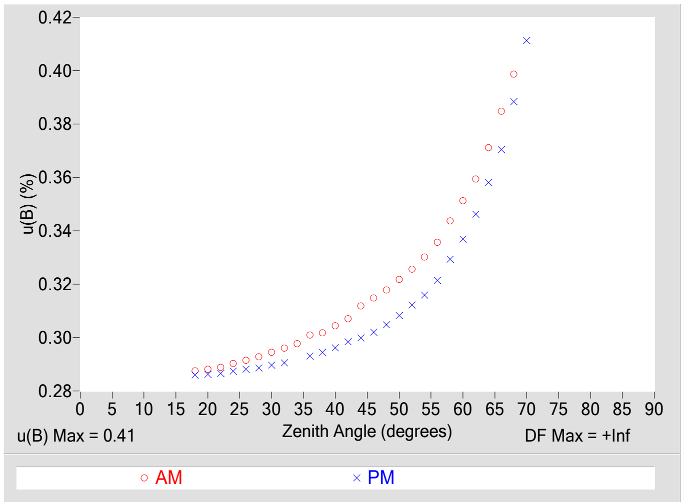


Figure 4. Residuals from Spline Interpolation

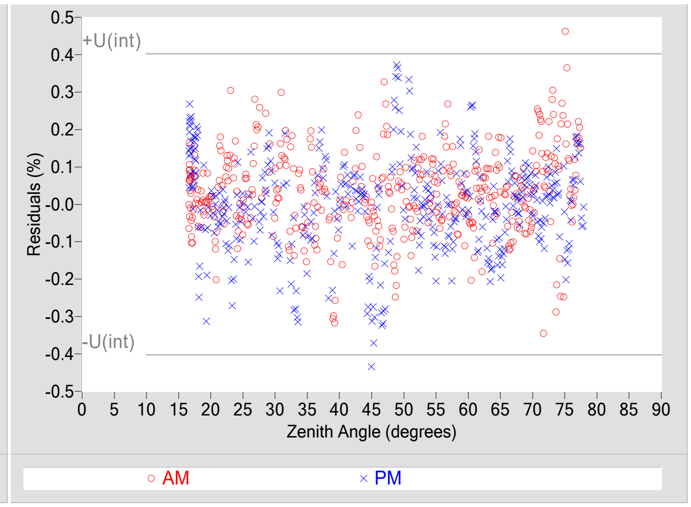


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.46
Effective degrees of freedom, DF(c)	19823
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.90
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

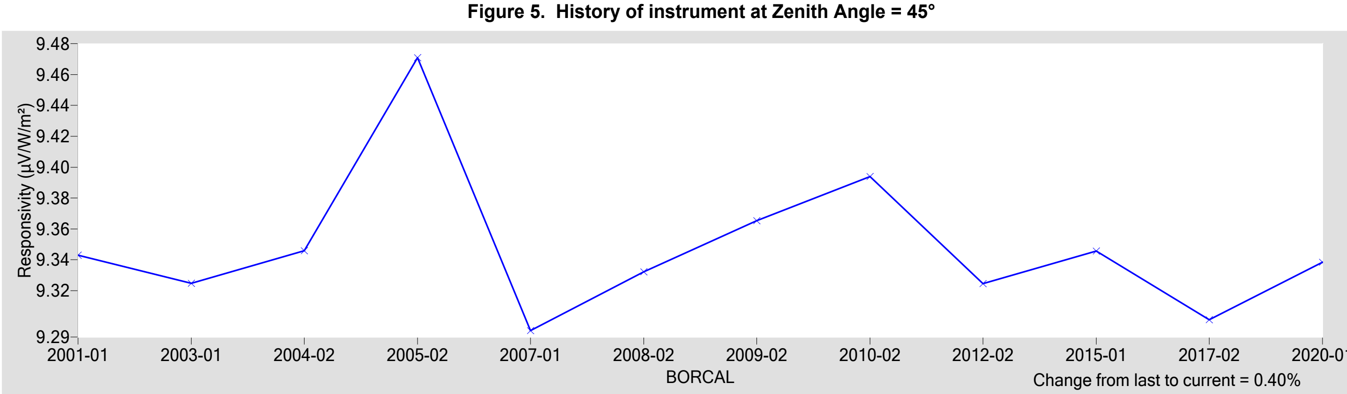
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3384	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+0.96 / -0.64
Expanded Uncertainty, U (%)	+1.7 / -1.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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: 5/19/2020

Due Date: 5/19/2021

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

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

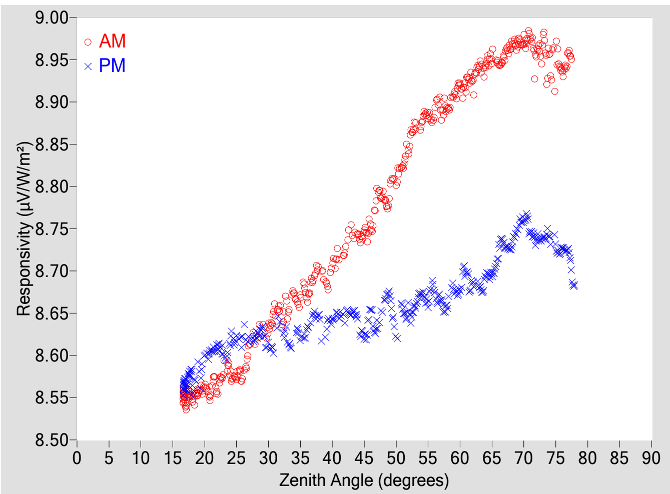


Figure 2. Responsivity vs Local Standard Time

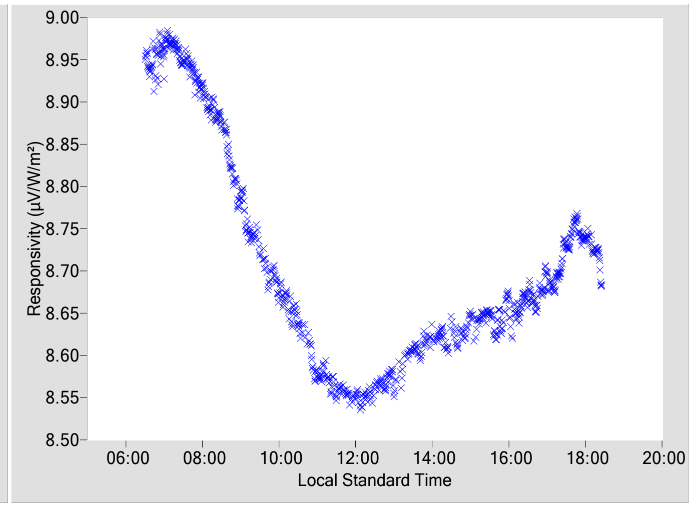


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7522	0.31	97.25	8.6518	0.30	262.81
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7871	0.32	95.59	8.6607	0.30	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8094	0.32	93.79	8.6215	0.31	266.21
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8473	0.33	92.31	8.6507	0.31	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8747	0.33	90.81	8.6727	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8845	0.34	89.35	8.6757	0.32	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8917	0.34	87.87	8.6611	0.33	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9202	0.35	86.48	8.6770	0.34	273.64
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9233	0.36	85.00	8.6855	0.35	275.07
18	8.5493	0.29	155.25	8.5690	0.29	204.66	64	8.9426	0.37	83.63	8.6942	0.36	276.50
20	8.5625	0.29	142.34	8.6002	0.29	217.31	66	8.9454	0.38	82.24	8.7192	0.37	277.82
22	8.5573	0.29	135.08	8.6101	0.29	225.48	68	8.9666	0.40	80.90	8.7279	0.39	279.23
24	8.5796	0.29	128.45	8.6196	0.29	231.70	70	8.9695	N/A	79.49	8.7606	0.41	280.62
26	8.5747	0.29	123.61	8.6228	0.29	236.47	72	8.9523	N/A	78.17	8.7368	N/A	282.03
28	8.6134	0.29	119.57	8.6231	0.29	240.60	74	8.9471	N/A	76.75	8.7386	N/A	283.38
30	8.6301	0.29	115.82	8.6108	0.29	244.22	76	8.9360	N/A	75.31	8.7275	N/A	284.79
32	8.6442	0.30	112.67	8.6399	0.29	247.03	78	N/A	N/A	N/A	8.6826	N/A	286.12
34	8.6714	0.30	109.88	N/A	N/A	N/A	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6693	0.30	107.32	8.6297	0.29	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7049	0.30	105.30	8.6389	0.29	255.04	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7064	0.30	102.98	8.6417	0.30	257.21	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7217	0.31	101.01	8.6467	0.30	259.14	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7419	0.31	98.96	8.6458	0.30	260.95	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

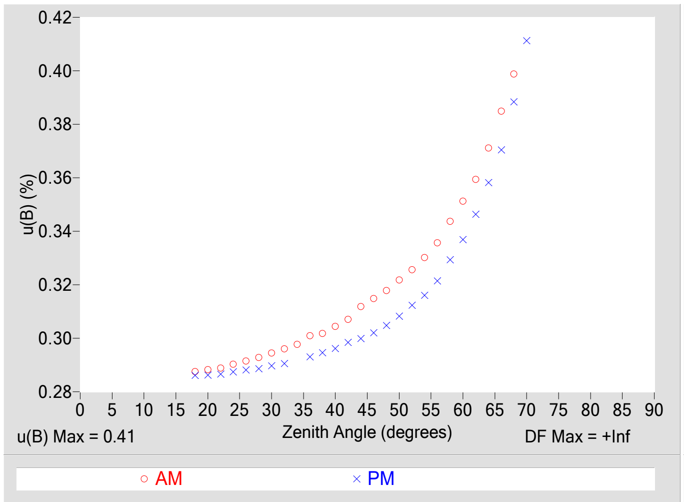


Figure 4. Residuals from Spline Interpolation

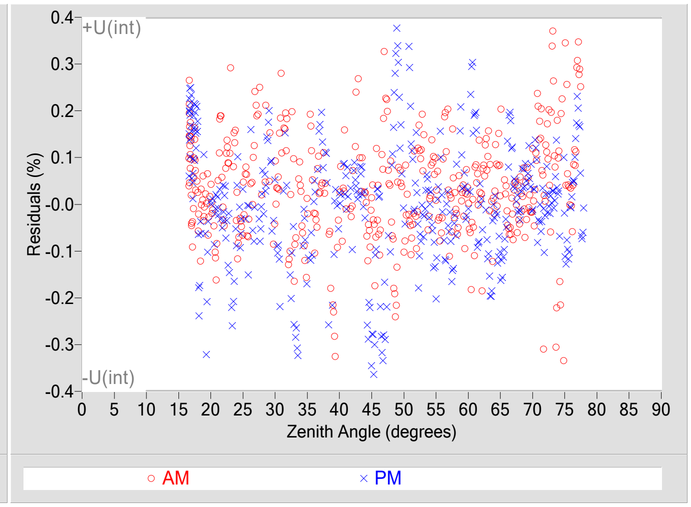


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.46
Effective degrees of freedom, DF(c)	20396
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.90
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

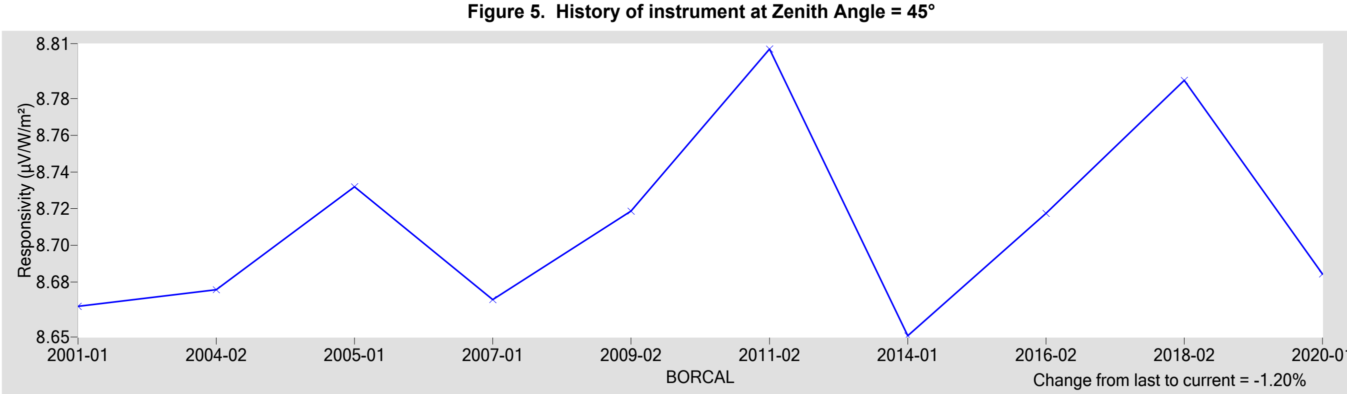
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6844	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+2.7 / -0.85
Expanded Uncertainty, U (%)	+3.4 / -1.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	33374
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33374 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

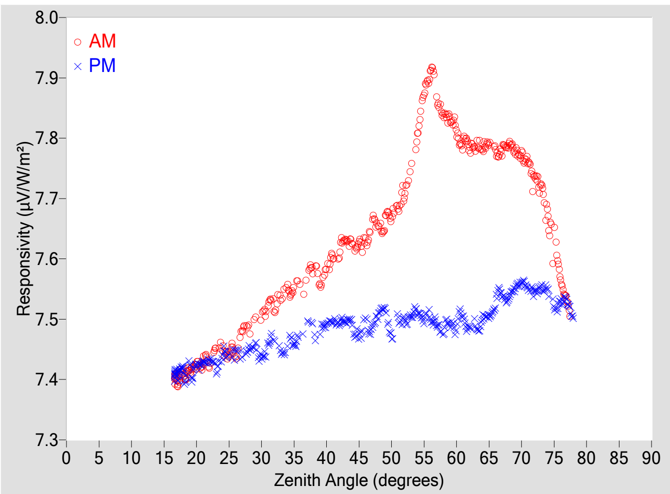


Figure 2. Responsivity vs Local Standard Time

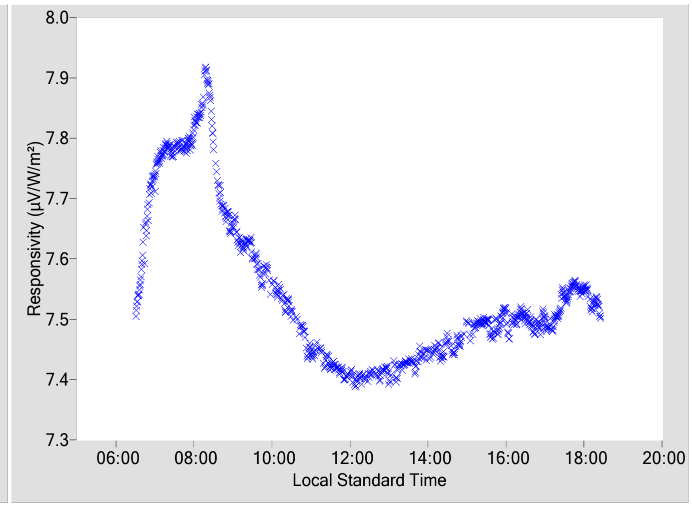


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6295	0.31	97.28	7.5001	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6560	0.32	95.63	7.5079	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6705	0.32	93.89	7.4722	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.7096	0.33	92.36	7.4987	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8024	0.33	90.81	7.5109	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9060	0.34	89.35	7.5018	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8384	0.34	87.87	7.4789	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8090	0.35	86.40	7.4870	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7842	0.36	85.01	7.4870	0.35	275.07
18	7.4042	0.29	154.51	7.4095	0.29	204.69	64	7.7837	0.37	83.60	7.5006	0.36	276.46
20	7.4249	0.29	142.76	7.4251	0.29	217.23	66	7.7800	0.38	82.25	7.5252	0.37	277.82
22	7.4246	0.29	134.80	7.4316	0.29	225.22	68	7.7884	0.40	80.91	7.5344	0.39	279.24
24	7.4513	0.29	128.44	7.4415	0.29	231.69	70	7.7712	N/A	79.49	7.5613	0.41	280.63
26	7.4399	0.29	123.49	7.4432	0.29	236.40	72	7.7323	N/A	78.13	7.5447	N/A	281.99
28	7.4845	0.29	119.31	7.4495	0.29	240.65	74	7.6707	N/A	76.76	7.5468	N/A	283.39
30	7.5054	0.29	115.79	7.4384	0.29	244.28	76	7.5662	N/A	75.31	7.5285	N/A	284.75
32	7.5183	0.30	112.70	7.4642	0.29	247.30	78	N/A	N/A	N/A	7.5034	N/A	286.12
34	7.5512	0.30	109.85	7.4551	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5577	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5806	0.30	105.24	7.4770	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5857	0.30	102.94	7.4911	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6098	0.31	100.90	7.4938	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6276	0.31	99.13	7.4906	0.30	260.98	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

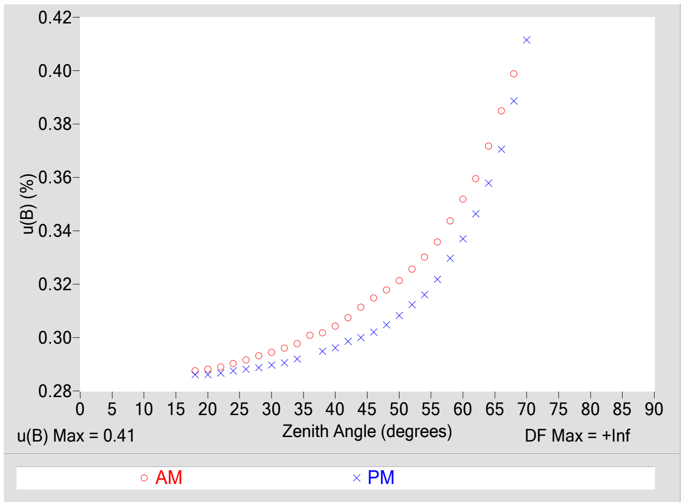


Figure 4. Residuals from Spline Interpolation

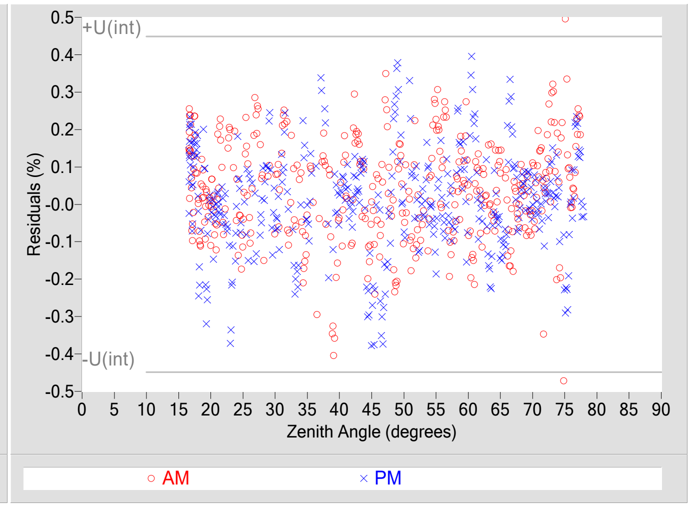


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	13831
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.92
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

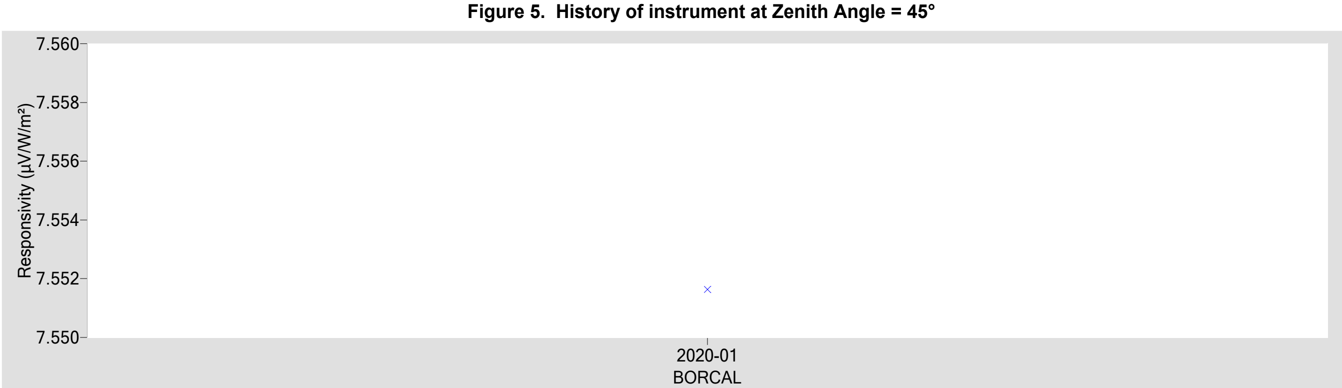
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5516	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+4.7 / -1.5
Expanded Uncertainty, U (%)	+5.4 / -2.2
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Pyranometer (Ventilated)

Model: 8-48

Calibration Date: 5/19/2020

Customer: NSA

Test Dates: 5/19

Manufacturer: Eppley

Serial Number: 33375

Due Date: 5/19/2021

Environmental Conditions: see page 4

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33375 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

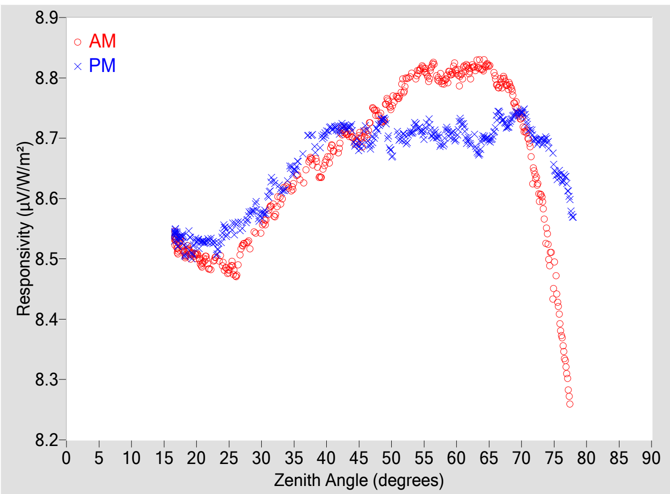


Figure 2. Responsivity vs Local Standard Time

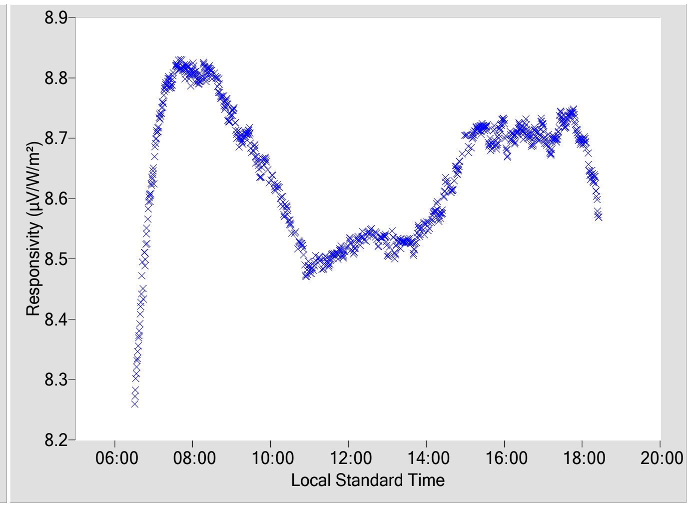


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7061	0.31	97.28	8.7157	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7404	0.32	95.63	8.7195	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7555	0.32	93.89	8.6751	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7873	0.33	92.36	8.7011	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8065	0.33	90.81	8.7179	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8080	0.34	89.35	8.7152	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7925	0.34	87.87	8.6927	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8102	0.35	86.40	8.7032	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8094	0.36	85.01	8.6947	0.35	275.07
18	8.5107	0.29	154.51	8.5244	0.29	204.69	64	8.8173	0.37	83.60	8.6992	0.36	276.46
20	8.5064	0.29	142.76	8.5310	0.29	217.23	66	8.7975	0.38	82.25	8.7213	0.37	277.82
22	8.4854	0.29	134.80	8.5313	0.29	225.22	68	8.7875	0.40	80.91	8.7217	0.39	279.24
24	8.4924	0.29	128.44	8.5429	0.29	231.69	70	8.7313	N/A	79.49	8.7438	0.41	280.63
26	8.4743	0.29	123.49	8.5524	0.29	236.40	72	8.6383	N/A	78.13	8.6984	N/A	281.99
28	8.5247	0.29	119.31	8.5710	0.29	240.65	74	8.5283	N/A	76.76	8.6924	N/A	283.39
30	8.5494	0.29	115.79	8.5738	0.29	244.28	76	8.3847	N/A	75.31	8.6381	N/A	284.75
32	8.5763	0.30	112.70	8.6271	0.29	247.30	78	N/A	N/A	N/A	8.5691	N/A	286.12
34	8.6203	0.30	109.94	8.6295	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6310	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6607	0.30	105.24	8.6896	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6648	0.30	102.94	8.7095	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6897	0.31	100.90	8.7144	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7033	0.31	99.13	8.7115	0.30	260.98	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

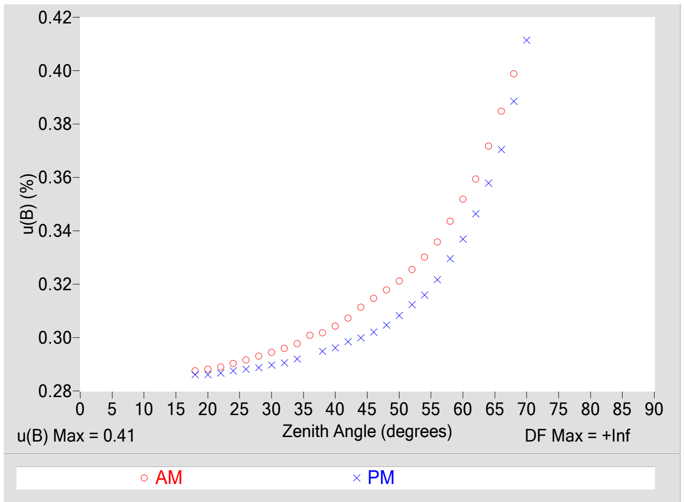


Figure 4. Residuals from Spline Interpolation

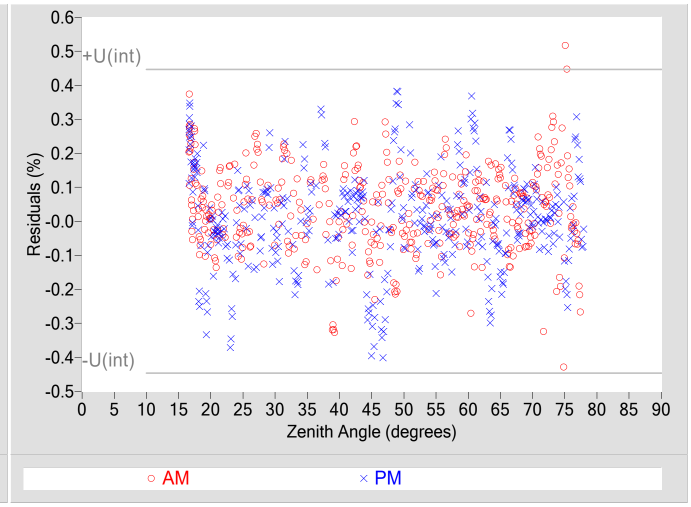


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	13951
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.92
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

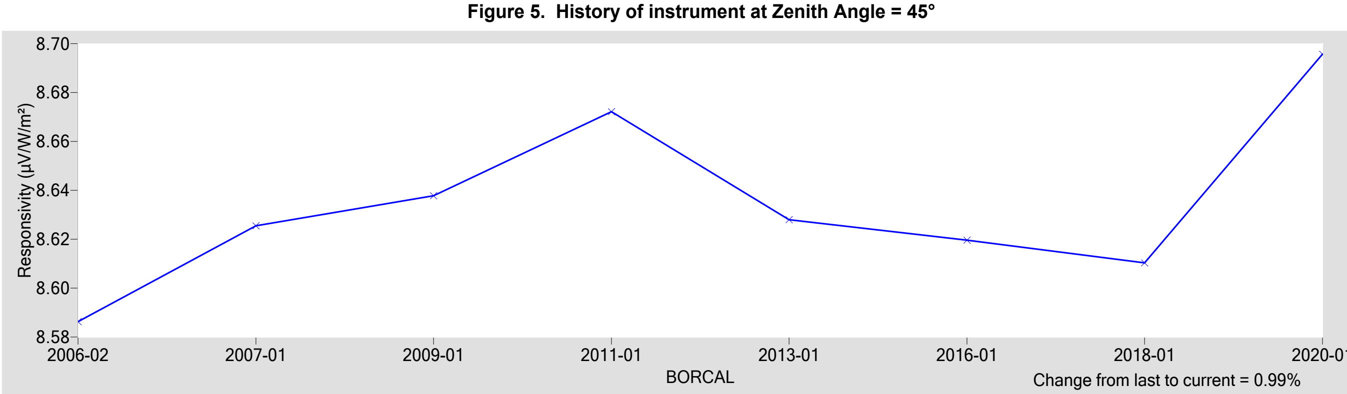
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6957	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+1.3 / -1.7
Expanded Uncertainty, U (%)	+2.0 / -2.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	33551E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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
33551E6 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

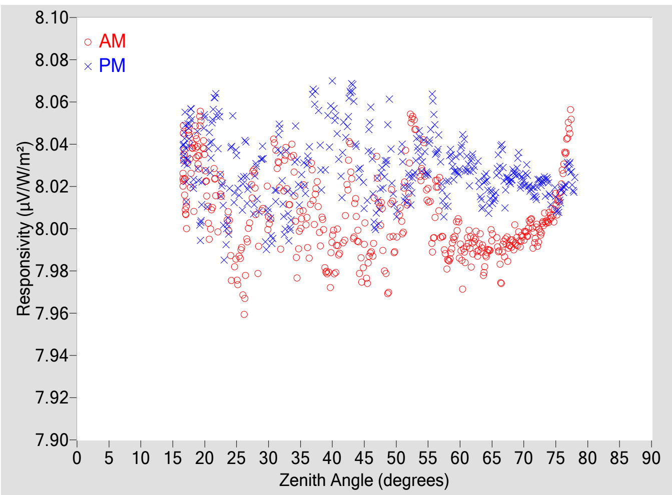


Figure 2. Responsivity vs Local Standard Time

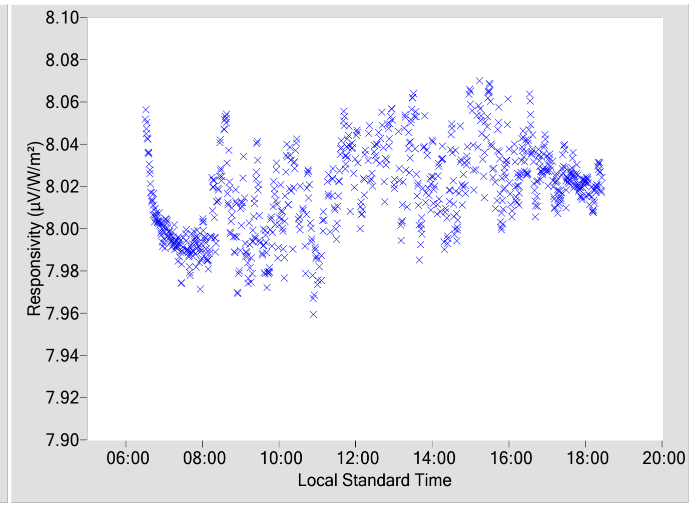


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9882	0.29	97.31	8.0449	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9931	0.29	95.57	8.0263	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9926	0.29	93.95	8.0071	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0251	0.29	92.37	8.0205	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0291	0.29	90.82	8.0310	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0017	0.30	89.36	8.0469	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9840	0.30	87.79	8.0177	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9913	0.30	86.41	8.0334	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9905	0.30	85.02	8.0316	0.29	275.08
18	8.0325	0.28	155.76	8.0402	0.28	204.65	64	7.9848	0.30	83.64	8.0241	0.30	276.47
20	8.0322	0.28	142.83	8.0455	0.28	217.28	66	7.9898	0.30	82.26	8.0289	0.30	277.83
22	8.0070	0.28	135.05	8.0526	0.28	225.38	68	7.9929	0.30	80.92	8.0236	0.30	279.24
24	7.9914	0.29	128.53	8.0235	0.28	231.54	70	7.9970	N/A	79.48	8.0227	0.30	280.64
26	7.9715	0.29	123.40	8.0196	0.28	236.40	72	7.9967	N/A	78.10	8.0174	N/A	281.96
28	8.0173	0.29	119.60	8.0222	0.28	240.63	74	8.0050	N/A	76.77	8.0177	N/A	283.36
30	8.0069	0.29	115.90	8.0075	0.28	244.31	76	8.0245	N/A	75.32	8.0173	N/A	284.76
32	8.0048	0.29	112.97	8.0295	0.28	247.40	78	N/A	N/A	N/A	8.0198	N/A	286.09
34	8.0201	0.29	109.83	8.0323	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9994	0.29	107.37	8.0283	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0002	0.29	105.10	8.0354	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9914	0.29	102.87	8.0617	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0038	0.29	100.92	8.0468	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9943	0.29	99.03	8.0305	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

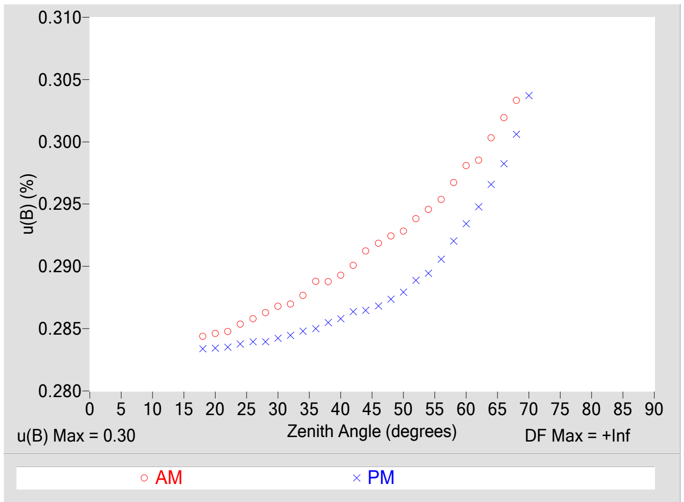


Figure 4. Residuals from Spline Interpolation

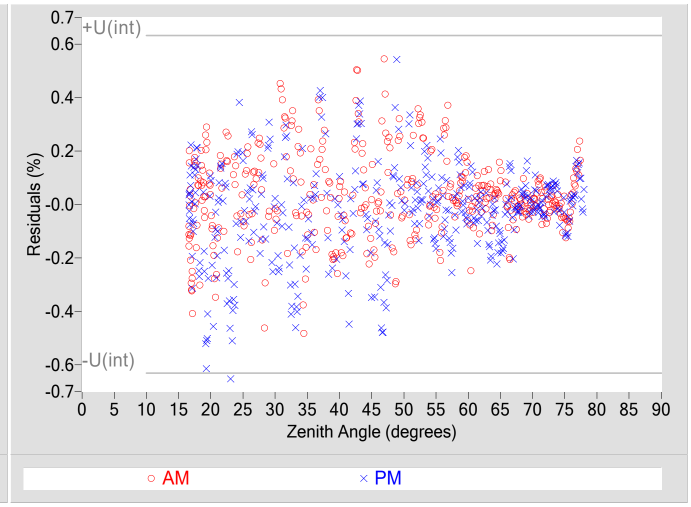


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.44
Effective degrees of freedom, DF(c)	2645
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.86
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

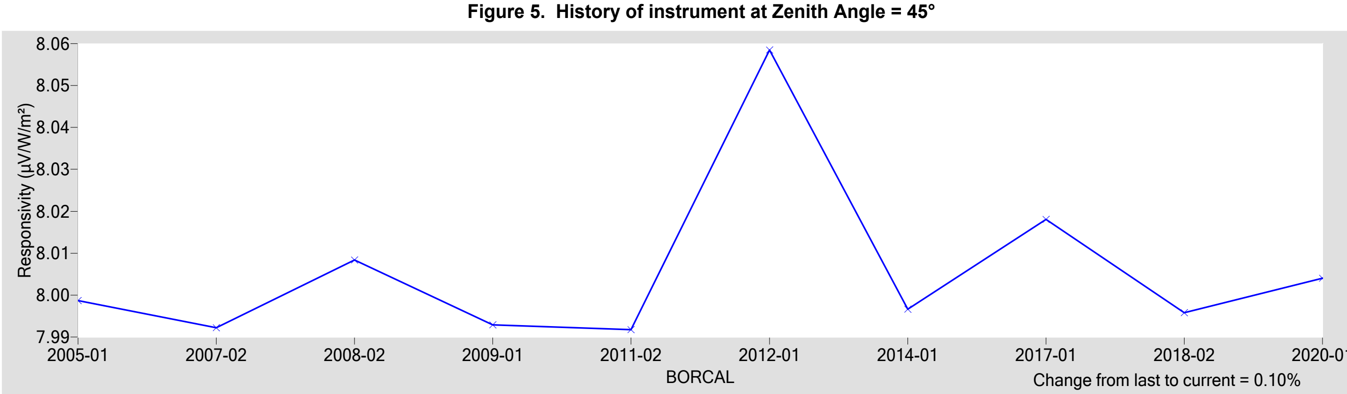
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0040	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.72 / -0.25
Expanded Uncertainty, U (%)	+1.3 / -0.83
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:**	33784
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33784 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

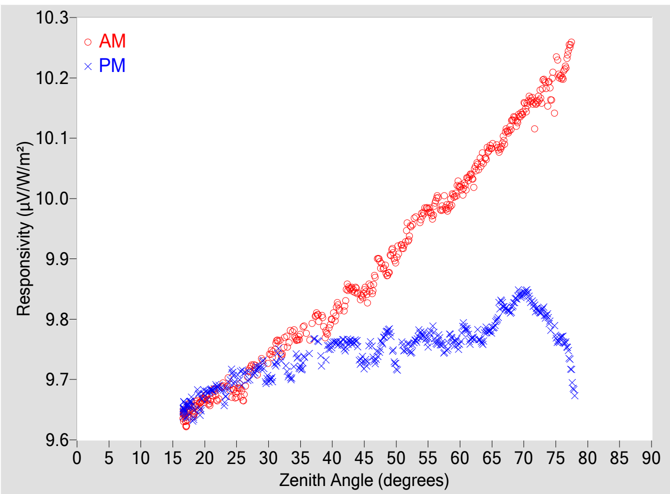


Figure 2. Responsivity vs Local Standard Time

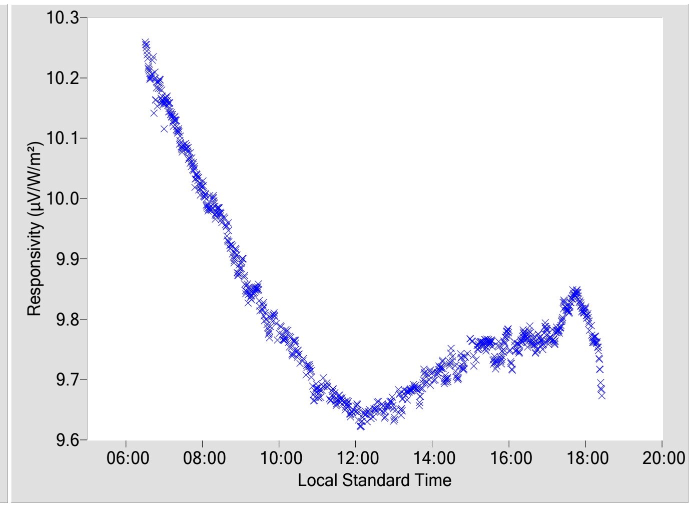


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.8506	0.31	97.28	9.7581	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8867	0.32	95.63	9.7669	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.9035	0.32	93.89	9.7216	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.9426	0.33	92.36	9.7536	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.9698	0.33	90.81	9.7736	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.9828	0.34	89.35	9.7715	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.9836	0.34	87.87	9.7531	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.019	0.35	86.40	9.7622	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.034	0.36	85.01	9.7685	0.35	275.07
18	9.6450	0.29	154.51	9.6525	0.29	204.69	64	10.071	0.37	83.60	9.7810	0.36	276.46
20	9.6693	0.29	142.76	9.6785	0.29	217.23	66	10.083	0.38	82.25	9.8094	0.37	277.82
22	9.6681	0.29	134.80	9.6885	0.29	225.22	68	10.121	0.40	80.91	9.8157	0.39	279.24
24	9.6869	0.29	128.44	9.7013	0.29	231.69	70	10.150	N/A	79.49	9.8443	0.41	280.63
26	9.6716	0.29	123.49	9.7054	0.29	236.40	72	10.161	N/A	78.09	9.8156	N/A	281.99
28	9.7171	0.29	119.31	9.7159	0.29	240.65	74	10.177	N/A	76.76	9.7933	N/A	283.39
30	9.7345	0.29	115.79	9.7015	0.29	244.28	76	10.202	N/A	75.31	9.7693	N/A	284.75
32	9.7469	0.30	112.70	9.7346	0.29	247.30	78	N/A	N/A	N/A	9.6782	N/A	286.12
34	9.7752	0.30	109.85	9.7216	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.7765	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.8017	0.30	105.24	9.7416	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.8034	0.30	102.94	9.7589	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8289	0.31	100.90	9.7561	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8457	0.31	99.13	9.7535	0.30	260.98	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

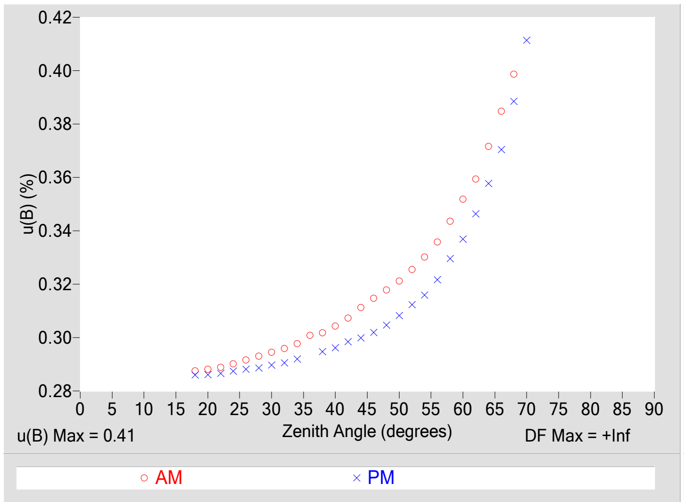


Figure 4. Residuals from Spline Interpolation

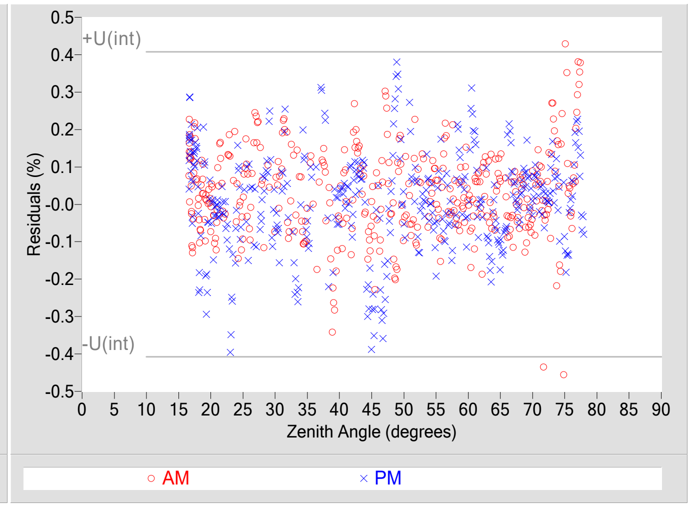


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.46
Effective degrees of freedom, DF(c)	18662
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.90
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

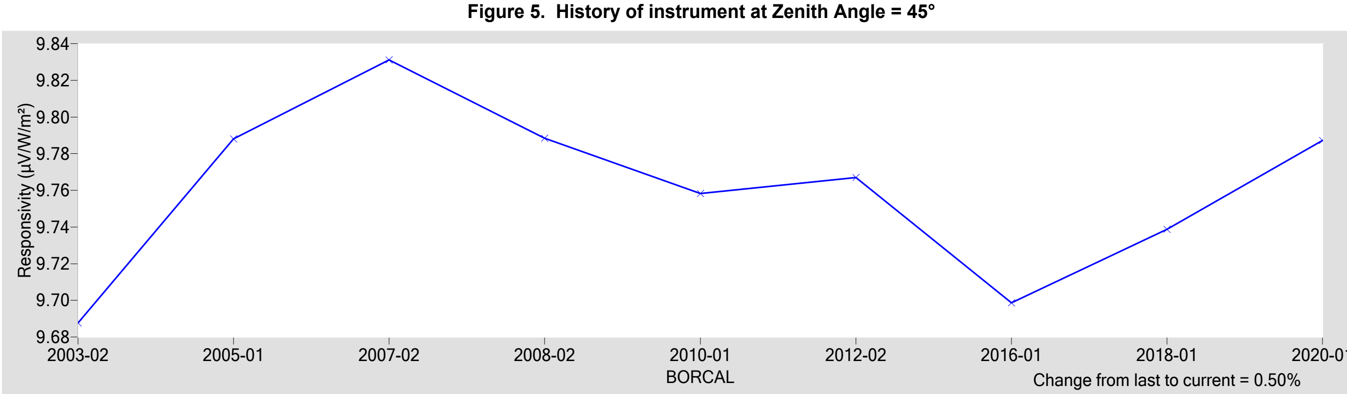
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.7873	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+2.4 / -0.88
Expanded Uncertainty, U (%)	+3.1 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	33785
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33785 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),		*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

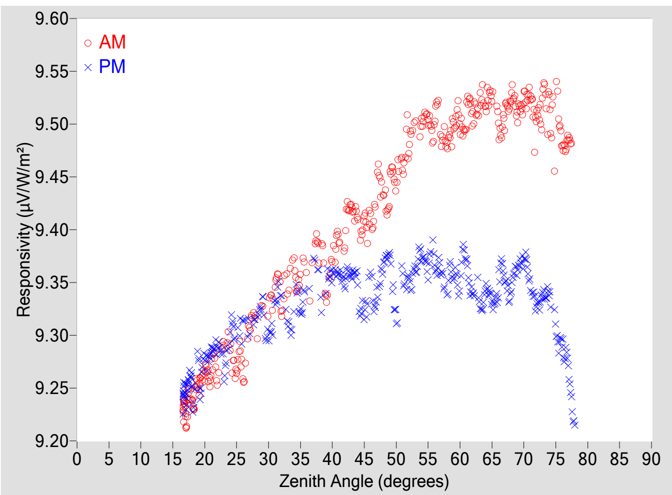


Figure 2. Responsivity vs Local Standard Time

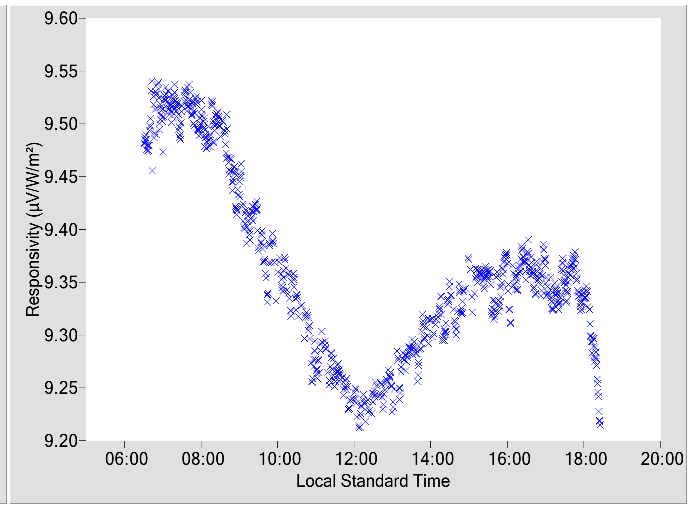


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.4098	0.31	97.28	9.3568	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4369	0.32	95.63	9.3664	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.4481	0.32	93.89	9.3179	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.4843	0.33	92.36	9.3518	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.4983	0.33	90.81	9.3749	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.4970	0.34	89.35	9.3712	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.4813	0.34	87.87	9.3430	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5003	0.35	86.40	9.3511	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.5082	0.36	85.01	9.3404	0.35	275.07
18	9.2357	0.29	154.51	9.2495	0.29	204.69	64	9.5202	0.37	83.60	9.3433	0.36	276.46
20	9.2662	0.29	142.76	9.2794	0.29	217.23	66	9.5022	0.38	82.25	9.3438	0.37	277.82
22	9.2611	0.29	134.80	9.2896	0.29	225.22	68	9.5248	0.40	80.91	9.3436	0.39	279.24
24	9.2862	0.29	128.44	9.3025	0.29	231.69	70	9.5221	N/A	79.49	9.3725	0.41	280.63
26	9.2618	0.29	123.49	9.3066	0.29	236.40	72	9.5032	N/A	78.13	9.3279	N/A	281.99
28	9.3105	0.29	119.31	9.3159	0.29	240.61	74	9.5106	N/A	76.76	9.3368	N/A	283.39
30	9.3267	0.29	115.79	9.3010	0.29	244.28	76	9.4817	N/A	75.31	9.2917	N/A	284.75
32	9.3287	0.30	112.70	9.3378	0.29	247.30	78	N/A	N/A	N/A	9.2169	N/A	286.12
34	9.3651	0.30	109.85	9.3226	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.3595	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.3779	0.30	105.24	9.3398	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.3754	0.30	102.94	9.3580	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3953	0.31	100.90	9.3525	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.4129	0.31	99.13	9.3466	0.30	260.98	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

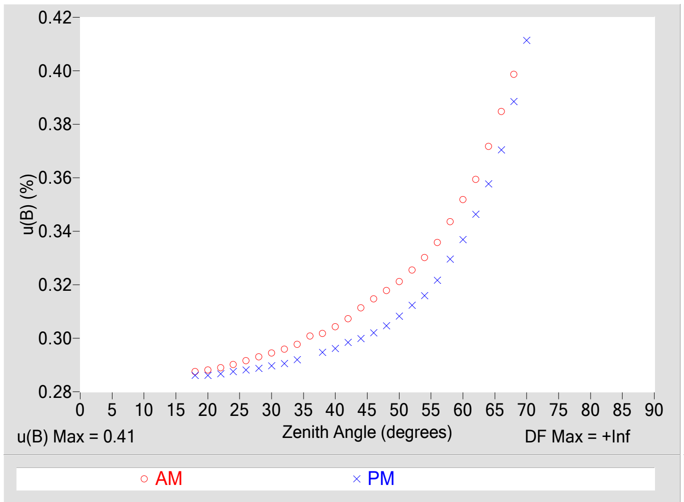


Figure 4. Residuals from Spline Interpolation

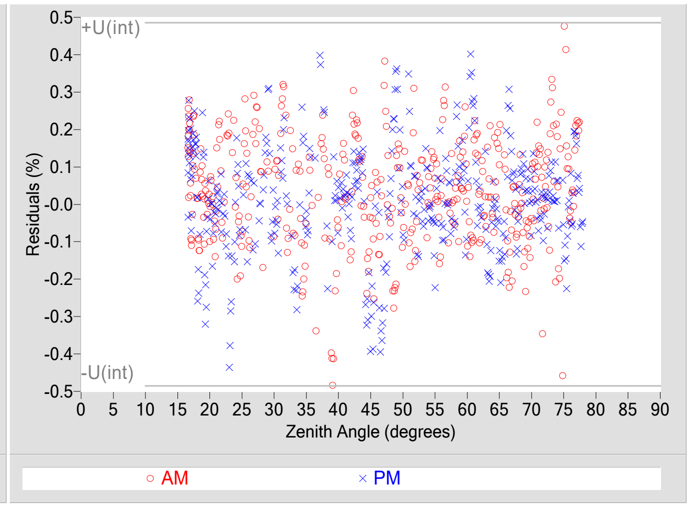


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	10810
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.94
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

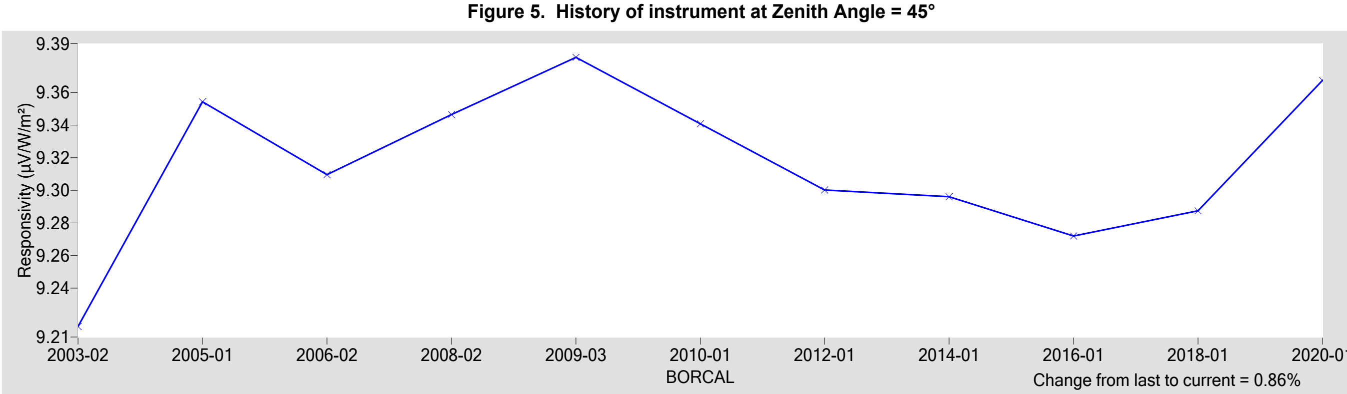
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.3675	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+1.4 / -0.71
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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	33860E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

33860E6 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

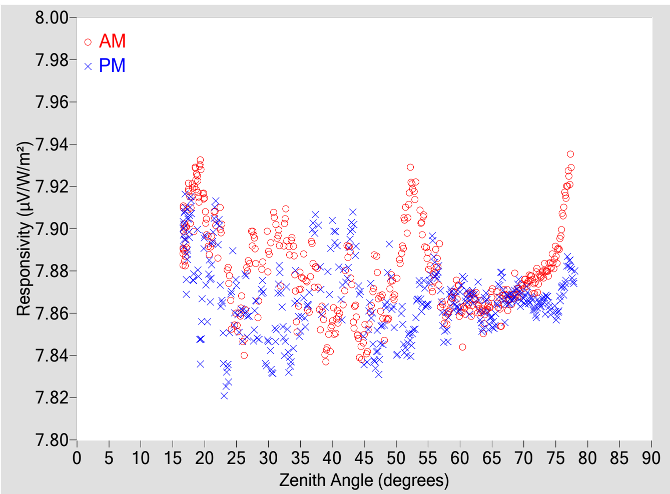


Figure 2. Responsivity vs Local Standard Time

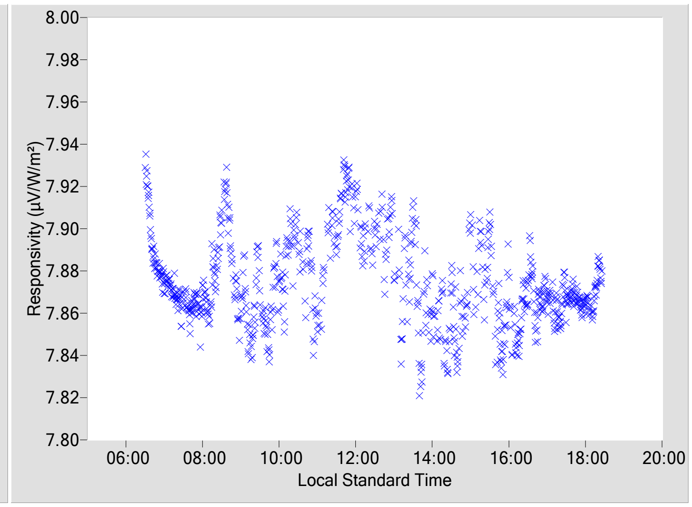


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.8597	0.29	97.31	7.8636	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8577	0.29	95.57	7.8544	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8726	0.29	93.95	7.8403	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9121	0.29	92.37	7.8466	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9034	0.29	90.82	7.8639	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8787	0.30	89.36	7.8842	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8590	0.30	87.79	7.8542	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8630	0.30	86.41	7.8677	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8655	0.30	85.02	7.8684	0.29	275.08
18	7.9135	0.28	155.76	7.8965	0.28	204.65	64	7.8597	0.30	83.64	7.8673	0.30	276.47
20	7.9110	0.28	142.83	7.8891	0.28	217.28	66	7.8654	0.30	82.26	7.8686	0.30	277.83
22	7.8938	0.28	135.05	7.9030	0.28	225.38	68	7.8668	0.30	80.92	7.8673	0.30	279.24
24	7.8676	0.29	128.53	7.8544	0.28	231.54	70	7.8742	N/A	79.48	7.8665	0.30	280.64
26	7.8506	0.29	123.40	7.8574	0.28	236.40	72	7.8758	N/A	78.10	7.8615	N/A	281.96
28	7.8898	0.29	119.60	7.8586	0.28	240.63	74	7.8812	N/A	76.77	7.8633	N/A	283.36
30	7.8889	0.29	115.90	7.8453	0.28	244.31	76	7.9039	N/A	75.32	7.8705	N/A	284.76
32	7.8824	0.29	112.97	7.8663	0.28	247.40	78	N/A	N/A	N/A	7.8764	N/A	286.09
34	7.8818	0.29	109.83	7.8628	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8706	0.29	107.37	7.8611	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8620	0.29	105.10	7.8786	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8552	0.29	102.87	7.8977	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8767	0.29	100.92	7.8777	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8489	0.29	99.03	7.8778	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

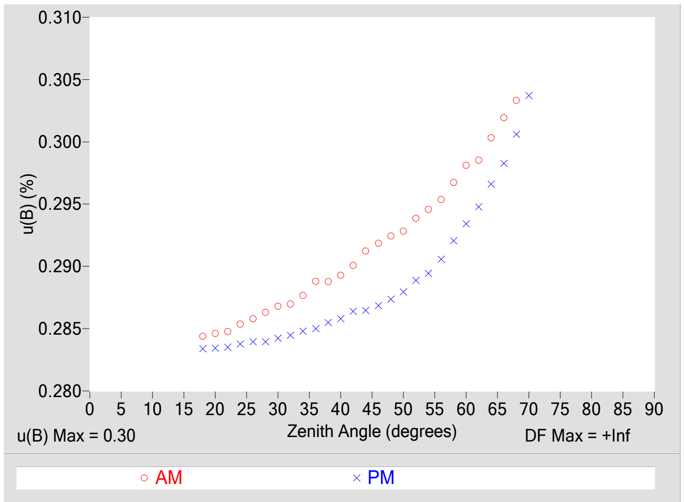


Figure 4. Residuals from Spline Interpolation

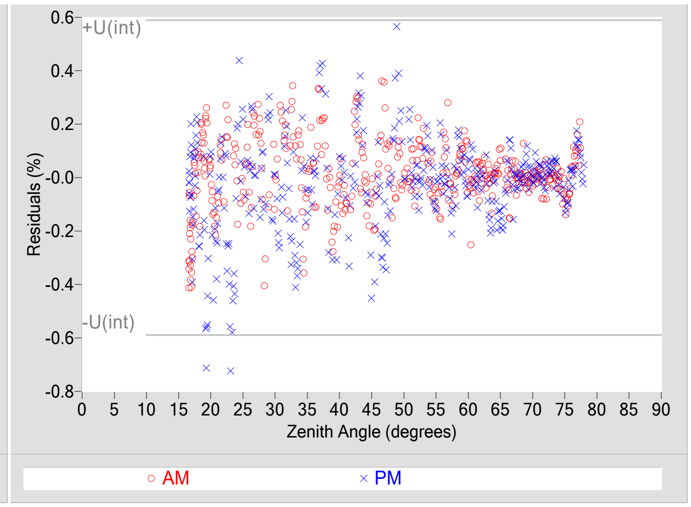


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.42
Effective degrees of freedom, DF(c)	3038
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.83
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

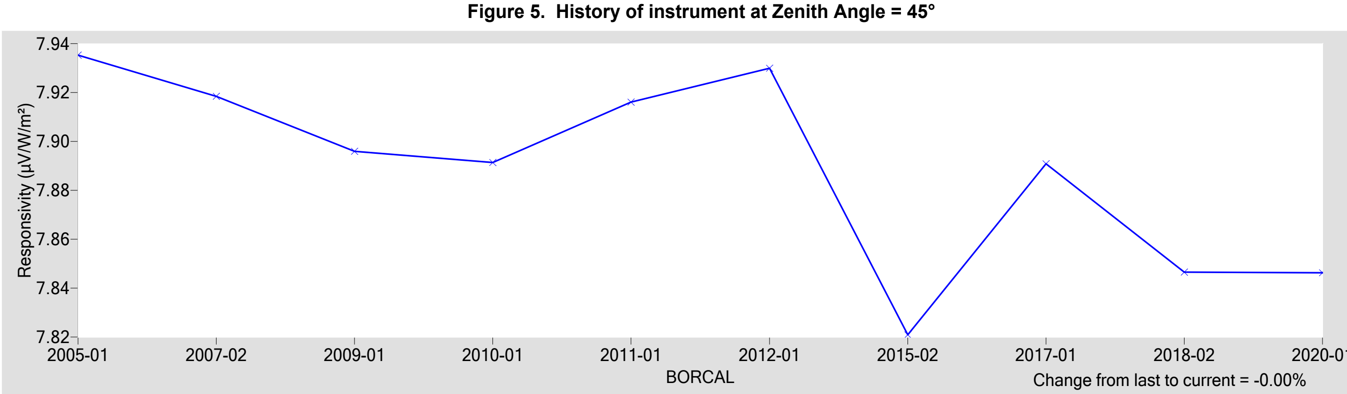
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8462	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.84 / -0.076
Expanded Uncertainty, U (%)	+1.4 / -0.66
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: 34066

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: AMF

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

34066 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

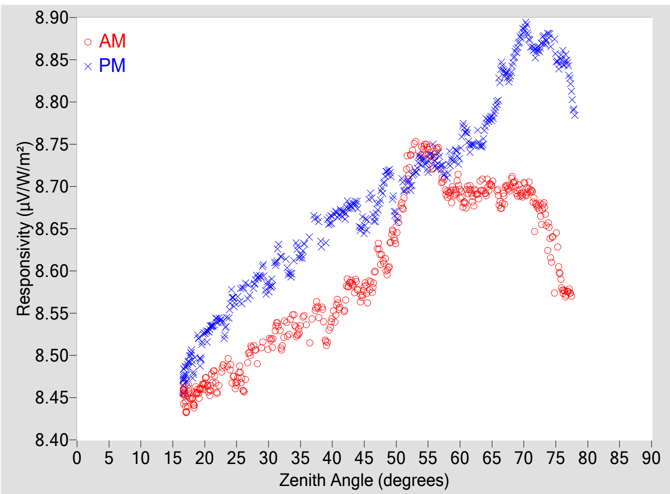


Figure 2. Responsivity vs Local Standard Time

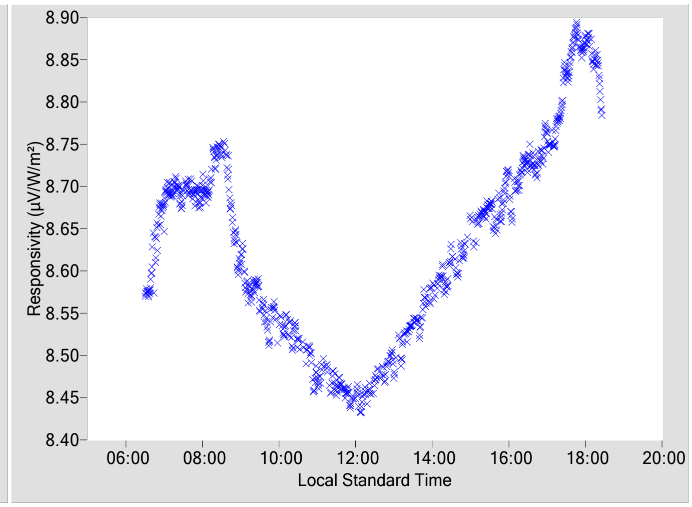


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5820	0.31	97.28	8.6876	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6134	0.32	95.63	8.7022	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6442	0.32	93.89	8.6637	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7236	0.33	92.36	8.7031	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7403	0.33	90.81	8.7304	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7305	0.34	89.35	8.7334	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6911	0.34	87.87	8.7177	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6932	0.35	86.40	8.7409	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6871	0.36	85.01	8.7498	0.35	275.07
18	8.4461	0.29	154.51	8.4920	0.29	204.69	64	8.6953	0.37	83.60	8.7732	0.36	276.46
20	8.4677	0.29	142.76	8.5264	0.29	217.23	66	8.6881	0.38	82.25	8.8101	0.37	277.82
22	8.4609	0.29	134.80	8.5420	0.29	225.22	68	8.7033	0.40	80.91	8.8367	0.39	279.24
24	8.4838	0.29	128.44	8.5613	0.29	231.69	70	8.6957	N/A	79.49	8.8878	0.41	280.63
26	8.4618	0.29	123.49	8.5738	0.29	236.40	72	8.6724	N/A	78.13	8.8593	N/A	281.99
28	8.5011	0.29	119.31	8.5892	0.29	240.65	74	8.6372	N/A	76.76	8.8758	N/A	283.39
30	8.5138	0.29	115.79	8.5820	0.29	244.28	76	8.5796	N/A	75.31	8.8523	N/A	284.75
32	8.5140	0.30	112.70	8.6169	0.29	247.30	78	N/A	N/A	N/A	8.7878	N/A	286.12
34	8.5413	0.30	109.85	8.6121	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5362	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5504	0.30	105.24	8.6407	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5454	0.30	102.94	8.6634	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5633	0.31	100.90	8.6691	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5811	0.31	99.13	8.6717	0.30	260.98	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

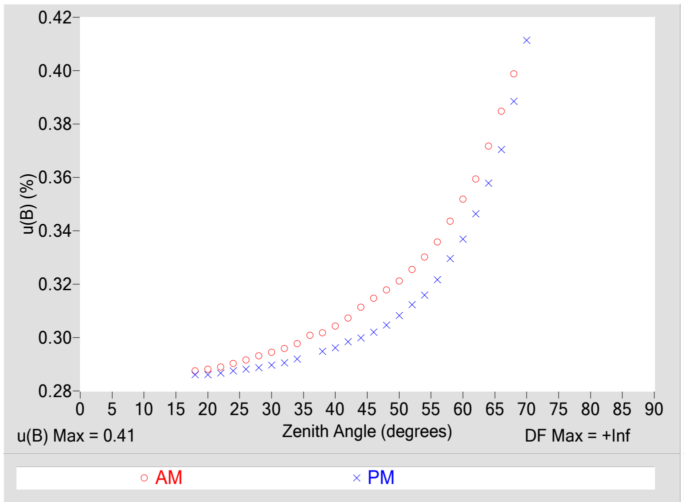


Figure 4. Residuals from Spline Interpolation

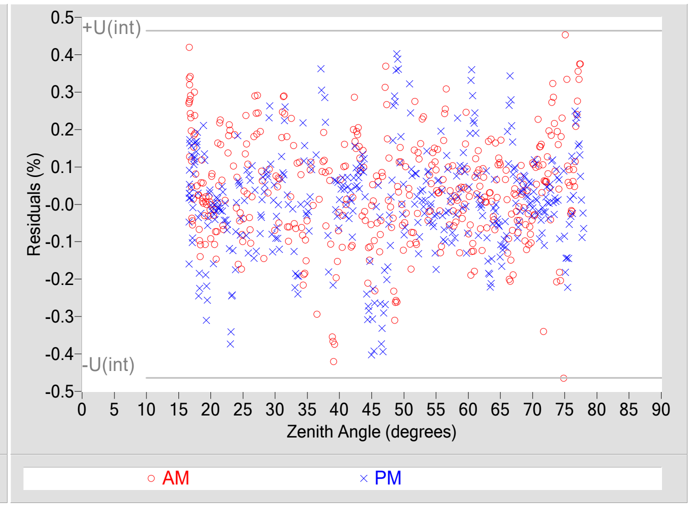


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	12436
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

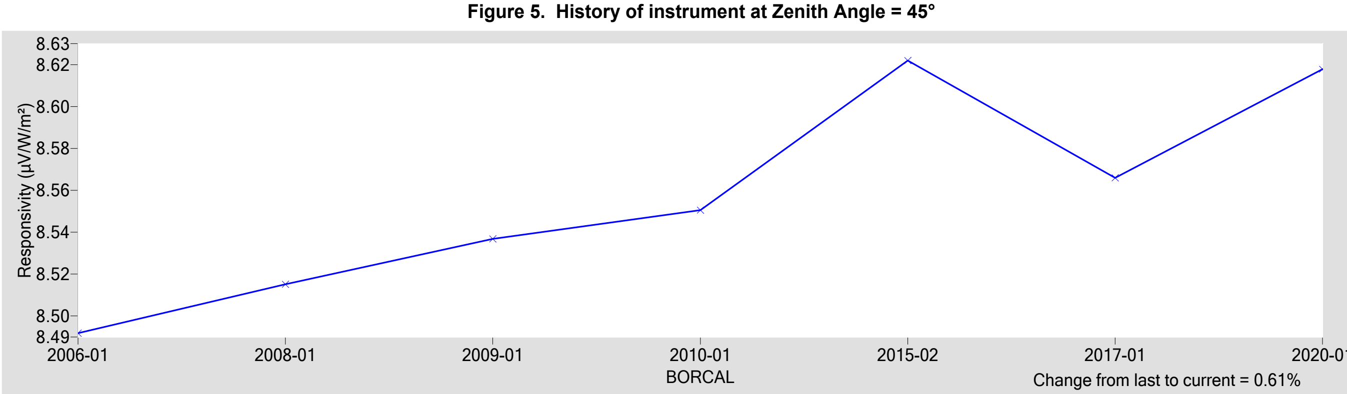
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6179	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+1.4 / -1.2
Expanded Uncertainty, U (%)	+2.1 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	34135E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

34135E6 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

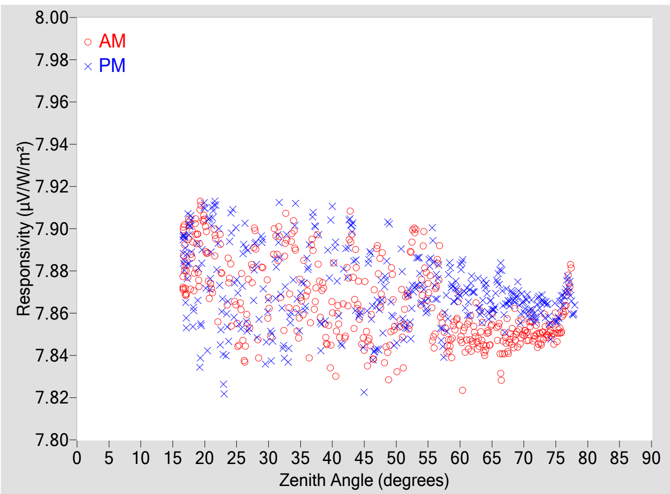


Figure 2. Responsivity vs Local Standard Time

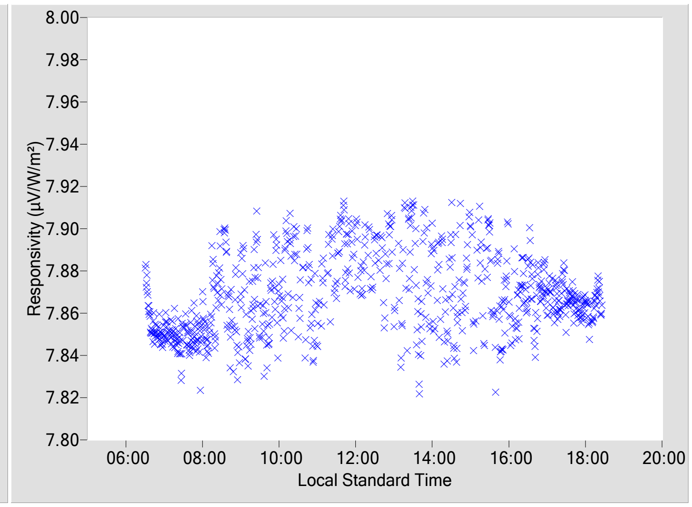


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8507	0.29	97.31	7.8767	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8638	0.29	95.57	7.8668	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8430	0.29	93.95	7.8499	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8667	0.29	92.37	7.8624	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8743	0.29	90.82	7.8677	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8522	0.30	89.36	7.8793	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8438	0.30	87.79	7.8639	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8534	0.30	86.41	7.8771	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8478	0.30	85.02	7.8719	0.29	275.08
18	7.8876	0.28	155.76	7.8826	0.28	204.65	64	7.8438	0.30	83.64	7.8721	0.30	276.47
20	7.9010	0.28	142.83	7.9009	0.28	217.28	66	7.8500	0.30	82.26	7.8766	0.30	277.83
22	7.8755	0.28	135.05	7.8962	0.28	225.38	68	7.8484	0.30	80.92	7.8678	0.30	279.24
24	7.8721	0.29	128.53	7.8865	0.28	231.54	70	7.8507	N/A	79.48	7.8639	0.30	280.64
26	7.8501	0.29	123.40	7.8765	0.28	236.40	72	7.8485	N/A	78.10	7.8604	N/A	281.96
28	7.8965	0.29	119.60	7.8797	0.28	240.63	74	7.8511	N/A	76.77	7.8561	N/A	283.36
30	7.8657	0.29	115.90	7.8595	0.28	244.31	76	7.8560	N/A	75.32	7.8657	N/A	284.76
32	7.8818	0.29	112.97	7.8652	0.28	247.40	78	N/A	N/A	N/A	7.8609	N/A	286.09
34	7.8958	0.29	109.83	7.8964	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8708	0.29	107.37	7.8780	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8721	0.29	105.10	7.8625	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8636	0.29	102.93	7.8995	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8609	0.29	100.92	7.8858	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8680	0.29	99.03	7.8676	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

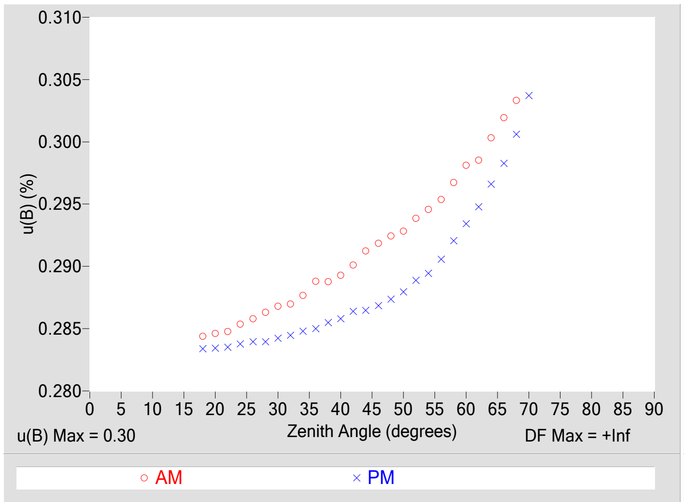


Figure 4. Residuals from Spline Interpolation

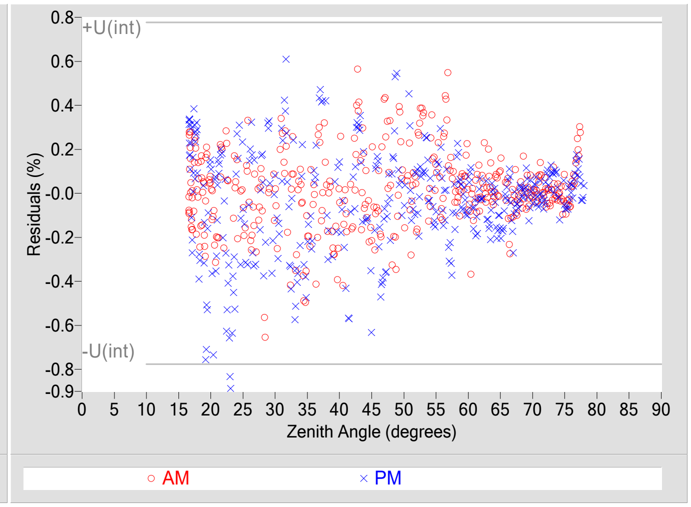


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.39
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	1850
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.97
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

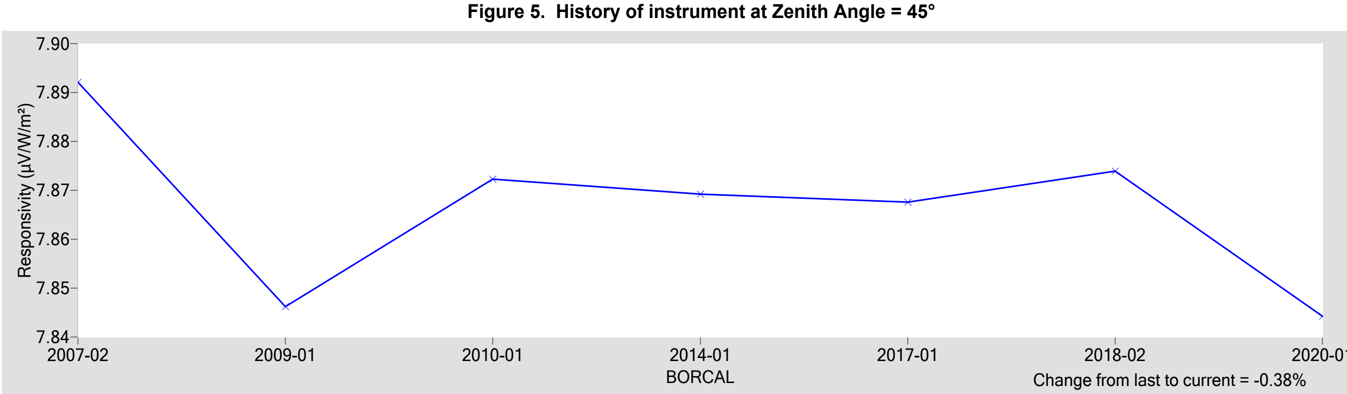
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8442	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.70 / -0.016
Expanded Uncertainty, U (%)	+1.3 / -0.60
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:**	34281
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

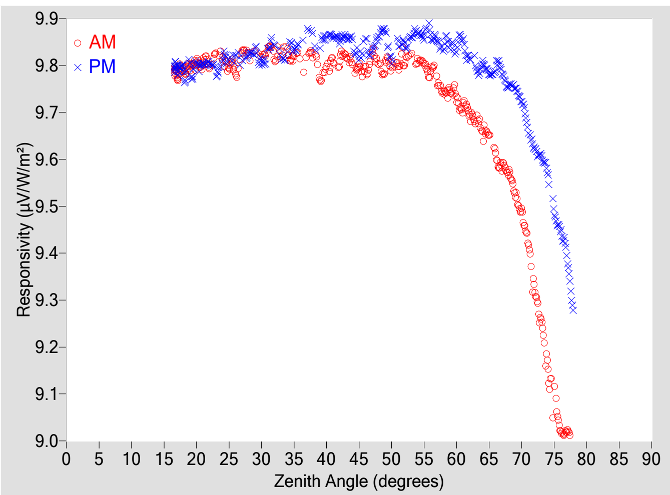


Figure 2. Responsivity vs Local Standard Time

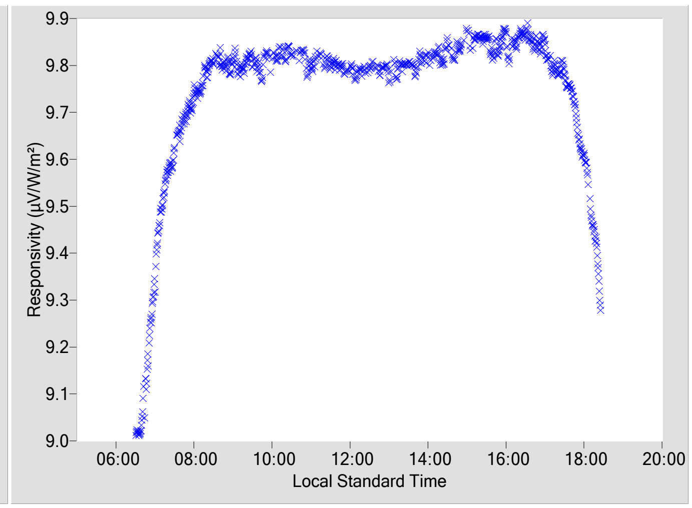


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	9.7904	0.31	97.28	9.8550	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8066	0.32	95.63	9.8611	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.7973	0.32	93.89	9.8132	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8125	0.33	92.36	9.8458	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.8072	0.33	90.81	9.8696	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7841	0.34	89.35	9.8682	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7424	0.34	87.87	9.8373	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.7293	0.35	86.40	9.8354	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6942	0.36	85.01	9.8154	0.35	275.07
18	9.7867	0.29	154.51	9.7857	0.29	204.69	64	9.6578	0.37	83.60	9.8036	0.36	276.46
20	9.8050	0.29	142.76	9.8045	0.29	217.23	66	9.6114	0.38	82.25	9.7939	0.37	277.82
22	9.7986	0.29	134.80	9.8049	0.29	225.22	68	9.5723	0.40	80.91	9.7557	0.39	279.24
24	9.8146	0.29	128.44	9.8141	0.29	231.69	70	9.4849	N/A	79.49	9.7223	0.41	280.63
26	9.7834	0.29	123.49	9.8163	0.29	236.40	72	9.3210	N/A	78.13	9.6231	N/A	281.99
28	9.8218	0.29	119.31	9.8237	0.29	240.65	74	9.1585	N/A	76.76	9.5662	N/A	283.39
30	9.8213	0.29	115.79	9.8102	0.29	244.28	76	9.0222	N/A	75.31	9.4497	N/A	284.75
32	9.8153	0.30	112.70	9.8436	0.29	247.30	78	N/A	N/A	N/A	9.2838	N/A	286.12
34	9.8298	0.30	109.85	9.8292	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.8142	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.8213	0.30	105.24	9.8473	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.7983	0.30	102.94	9.8608	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8063	0.31	100.90	9.8551	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8074	0.31	99.13	9.8524	0.30	260.98	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

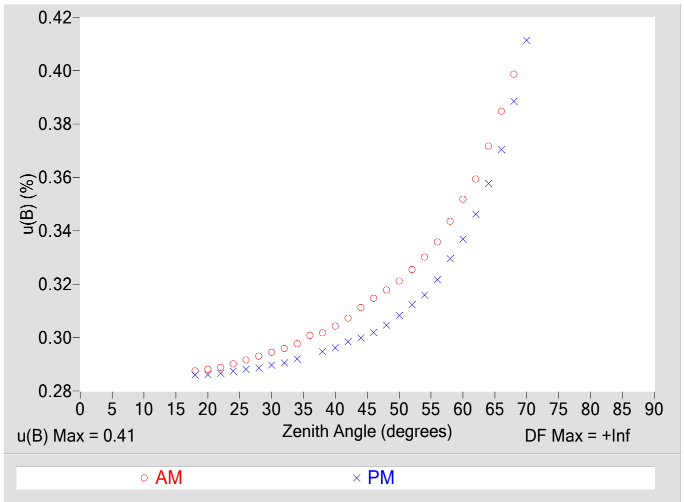


Figure 4. Residuals from Spline Interpolation

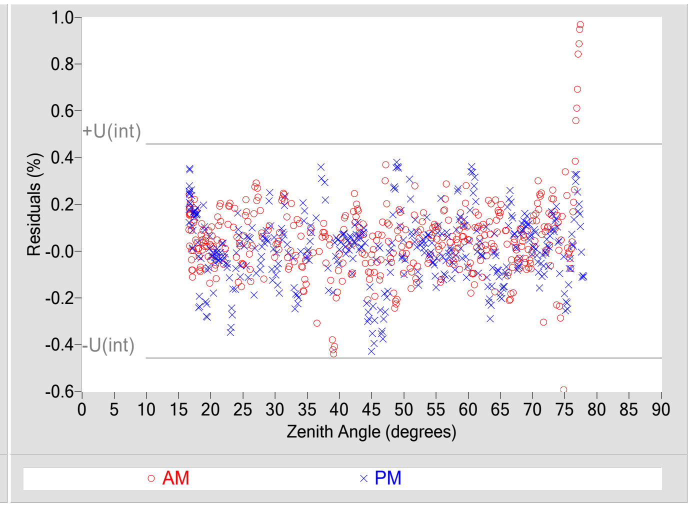


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	12927
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.92
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

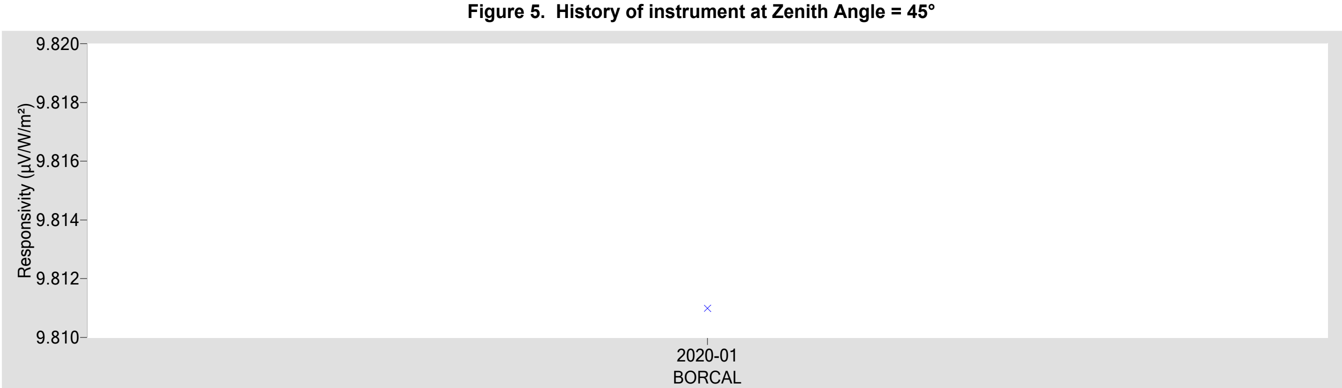
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.8110	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+0.60 / -0.83
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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	34504E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

34504E6 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

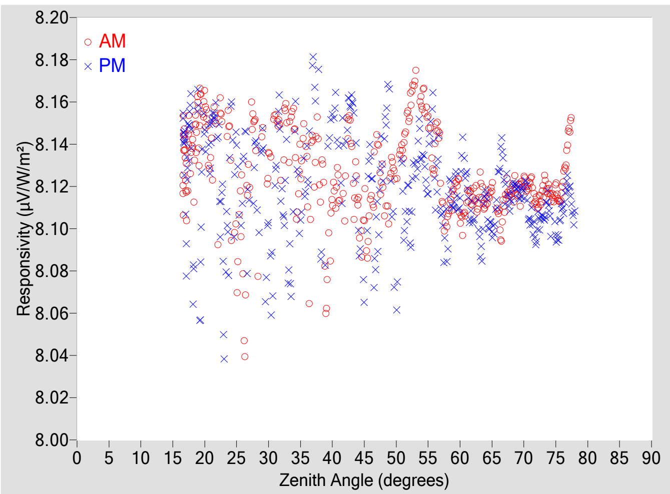


Figure 2. Responsivity vs Local Standard Time

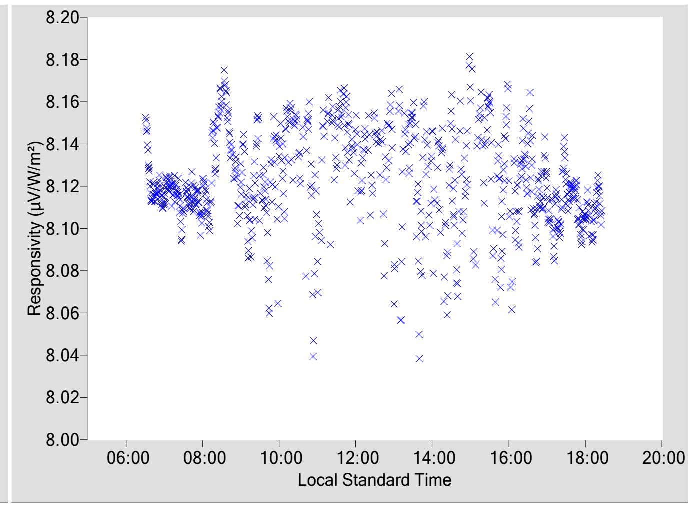


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1119	0.29	97.31	8.1307	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1187	0.29	95.57	8.1372	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1237	0.29	93.95	8.0682	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1556	0.29	92.37	8.1068	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1607	0.29	90.82	8.1337	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1344	0.30	89.36	8.1337	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1056	0.30	87.79	8.0999	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1091	0.30	86.41	8.1191	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1141	0.30	85.02	8.1061	0.29	275.08
18	8.1363	0.28	155.76	8.1194	0.28	204.65	64	8.1113	0.30	83.64	8.1160	0.30	276.47
20	8.1564	0.28	142.83	8.1456	0.28	217.28	66	8.1066	0.30	82.26	8.1212	0.30	277.83
22	8.1212	0.28	135.05	8.1488	0.28	225.38	68	8.1177	0.30	80.92	8.1148	0.30	279.24
24	8.1310	0.29	128.53	8.1324	0.28	231.54	70	8.1221	N/A	79.48	8.1195	0.30	280.64
26	8.0726	0.29	123.40	8.1199	0.28	236.40	72	8.1118	N/A	78.10	8.0979	N/A	281.96
28	8.1466	0.29	119.60	8.1319	0.28	240.63	74	8.1179	N/A	76.77	8.1081	N/A	283.36
30	8.1292	0.29	115.90	8.0971	0.28	244.31	76	8.1199	N/A	75.32	8.1085	N/A	284.76
32	8.1361	0.29	112.97	8.1214	0.28	247.40	78	N/A	N/A	N/A	8.1055	N/A	286.09
34	8.1462	0.29	109.83	8.1382	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1278	0.29	107.37	8.1252	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1253	0.29	105.10	8.1167	0.29	255.14	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1144	0.29	102.87	8.1528	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1245	0.29	100.92	8.1406	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1121	0.29	99.03	8.1090	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

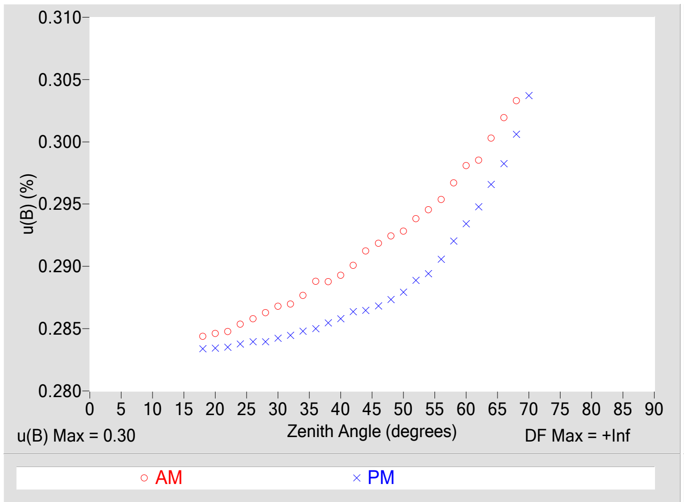


Figure 4. Residuals from Spline Interpolation

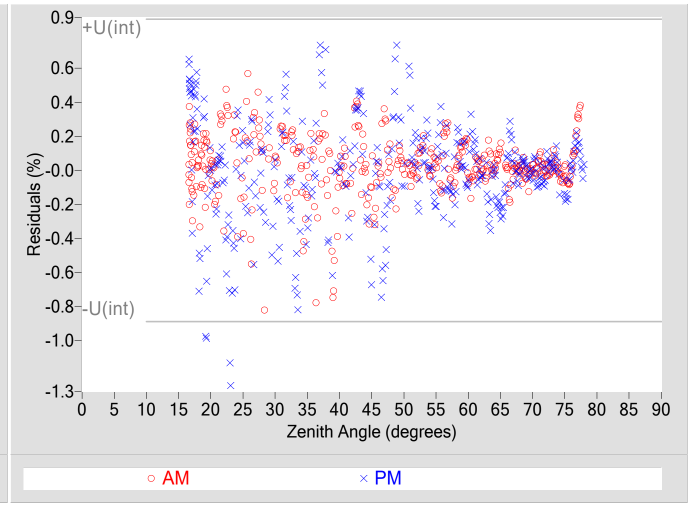


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.44
Combined Standard Uncertainty, u(c) (%)	±0.54
Effective degrees of freedom, DF(c)	1525
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

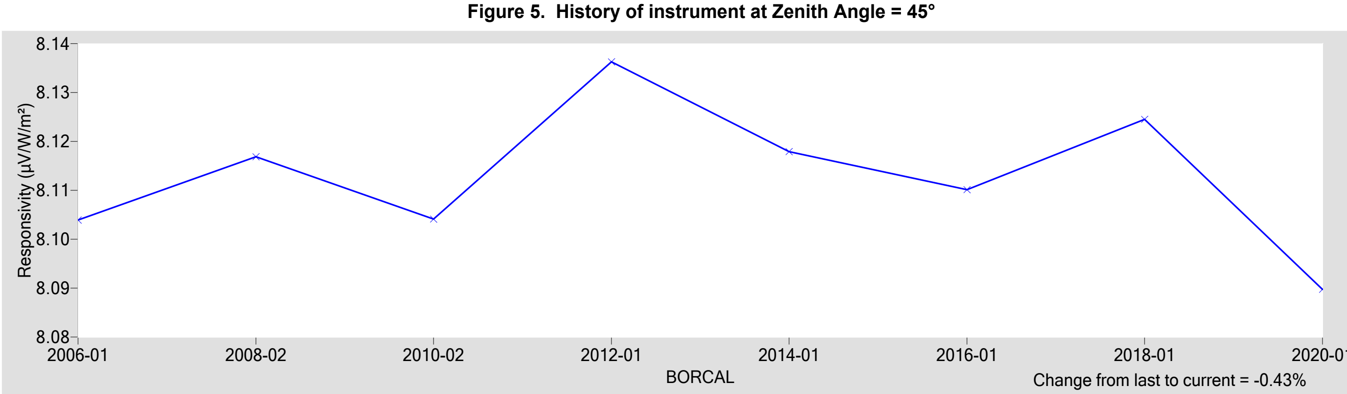
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0897	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.88 / -0.27
Expanded Uncertainty, U (%)	+1.5 / -0.85
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:**	34505E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

34505E6 Eppley NIP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

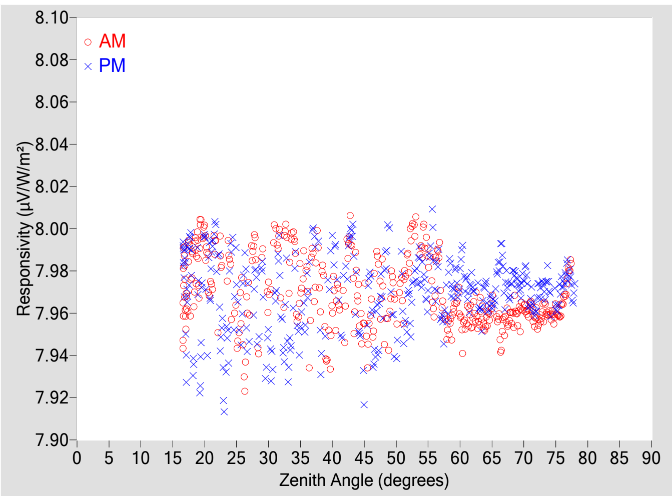


Figure 2. Responsivity vs Local Standard Time

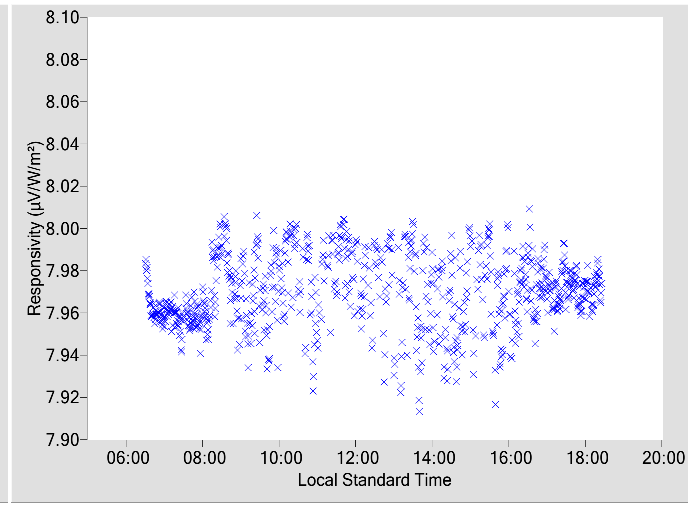


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.9602	0.29	97.31	7.9709	0.29	262.83
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9679	0.29	95.57	7.9737	0.29	264.57
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9608	0.29	93.95	7.9429	0.29	266.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9878	0.29	92.37	7.9625	0.29	267.79
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9916	0.29	90.82	7.9770	0.29	269.26
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9680	0.30	89.36	7.9814	0.29	270.79
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9515	0.30	87.79	7.9671	0.29	272.25
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9602	0.30	86.41	7.9795	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9579	0.30	85.02	7.9731	0.29	275.08
18	7.9777	0.28	155.76	7.9666	0.28	204.65	64	7.9540	0.30	83.64	7.9715	0.30	276.47
20	7.9953	0.28	142.83	7.9901	0.28	217.28	66	7.9557	0.30	82.26	7.9813	0.30	277.83
22	7.9726	0.28	135.05	7.9892	0.28	225.38	68	7.9586	0.30	80.92	7.9725	0.30	279.24
24	7.9782	0.29	128.53	7.9746	0.28	231.54	70	7.9625	N/A	79.48	7.9788	0.30	280.64
26	7.9437	0.29	123.40	7.9642	0.28	236.40	72	7.9569	N/A	78.10	7.9644	N/A	281.96
28	7.9927	0.29	119.60	7.9709	0.28	240.63	74	7.9596	N/A	76.77	7.9712	N/A	283.36
30	7.9685	0.29	115.90	7.9479	0.28	244.31	76	7.9638	N/A	75.32	7.9732	N/A	284.76
32	7.9835	0.29	112.97	7.9586	0.28	247.40	78	N/A	N/A	N/A	7.9694	N/A	286.09
34	7.9940	0.29	109.83	7.9775	0.28	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9776	0.29	107.37	7.9678	0.28	252.75	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9745	0.29	105.10	7.9545	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9642	0.29	102.87	7.9898	0.29	257.16	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9688	0.29	100.92	7.9800	0.29	259.10	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9684	0.29	99.03	7.9604	0.29	261.06	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

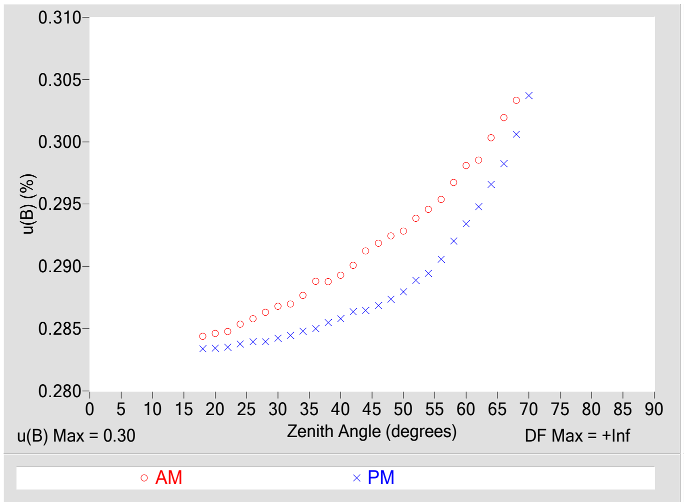


Figure 4. Residuals from Spline Interpolation

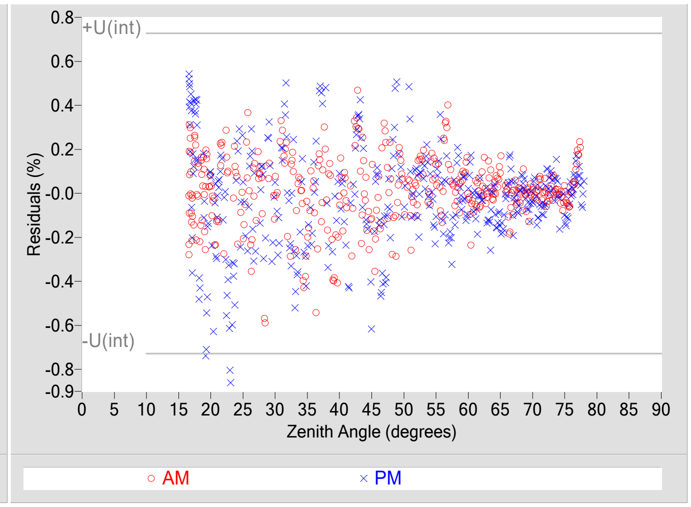


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.36
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	2056
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

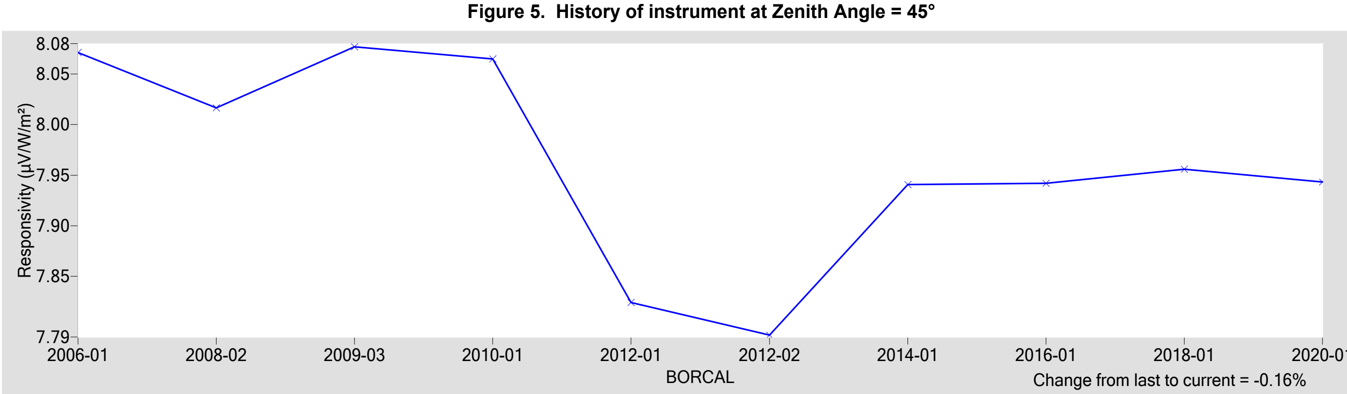
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9432	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.64 / -3.6e-3
Expanded Uncertainty, U (%)	+1.2 / -0.59
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:**	34506E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

34506E6 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

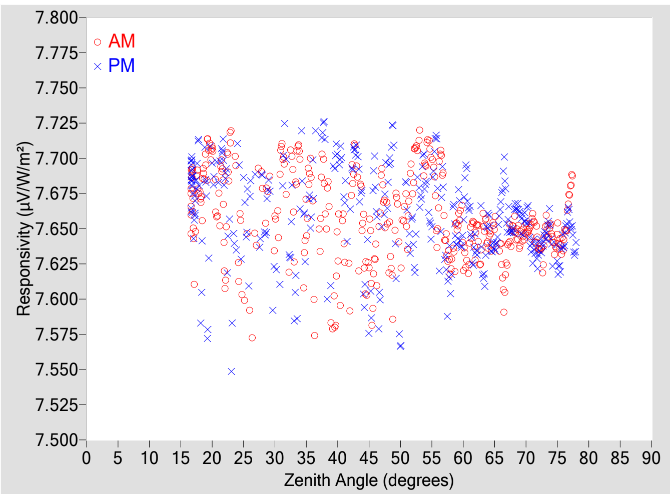


Figure 2. Responsivity vs Local Standard Time

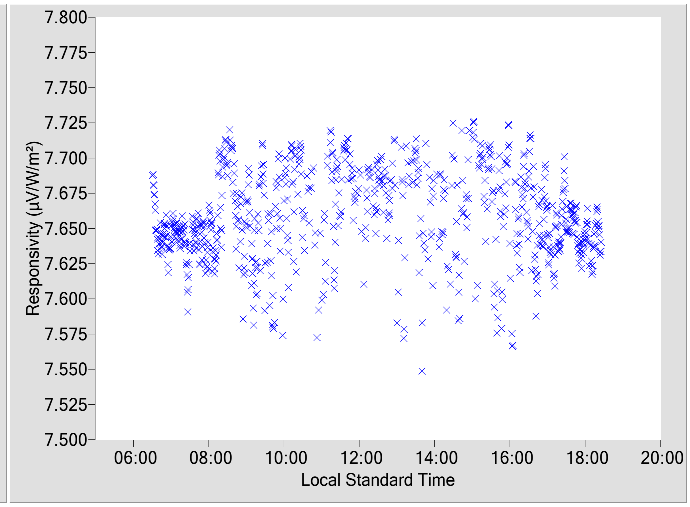


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6246	0.29	97.28	7.6785	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6489	0.29	95.51	7.6858	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6396	0.29	93.88	7.5695	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6901	0.29	92.35	7.6390	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6970	0.29	90.83	7.6867	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6623	0.30	89.32	7.6708	0.29	270.74
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6240	0.30	87.88	7.6188	0.29	272.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6393	0.30	86.42	7.6594	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6435	0.30	85.02	7.6364	0.29	275.04
18	7.6737	0.28	155.08	7.7021	0.28	203.28	64	7.6419	0.30	83.65	7.6558	0.30	276.48
20	7.7053	0.28	143.00	7.6933	0.28	217.45	66	7.6305	0.30	82.26	7.6690	0.30	277.84
22	7.6406	0.28	134.77	7.6935	0.28	225.40	68	7.6512	0.30	80.88	7.6553	0.30	279.25
24	7.6444	0.29	128.29	7.6802	0.28	231.71	70	7.6487	N/A	79.51	7.6604	0.30	280.64
26	7.5921	0.29	123.59	7.6554	0.28	236.51	72	7.6372	N/A	78.10	7.6312	N/A	281.96
28	7.6845	0.29	119.51	7.6748	0.28	240.78	74	7.6494	N/A	76.77	7.6445	N/A	283.36
30	7.6501	0.29	115.82	7.6221	0.28	244.29	76	7.6436	N/A	75.32	7.6410	N/A	284.77
32	7.6467	0.29	112.65	7.6655	0.28	247.40	78	N/A	N/A	N/A	7.6350	N/A	286.10
34	7.7047	0.29	110.07	7.6919	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6520	0.29	107.38	7.6762	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6729	0.29	105.10	7.7216	0.29	254.83	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6379	0.29	102.94	7.7029	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6466	0.29	100.87	7.6786	0.29	259.29	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6530	0.29	99.04	7.6375	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

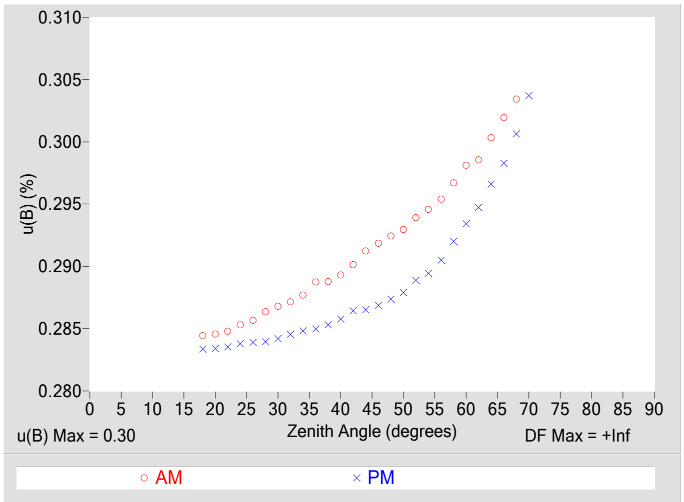


Figure 4. Residuals from Spline Interpolation

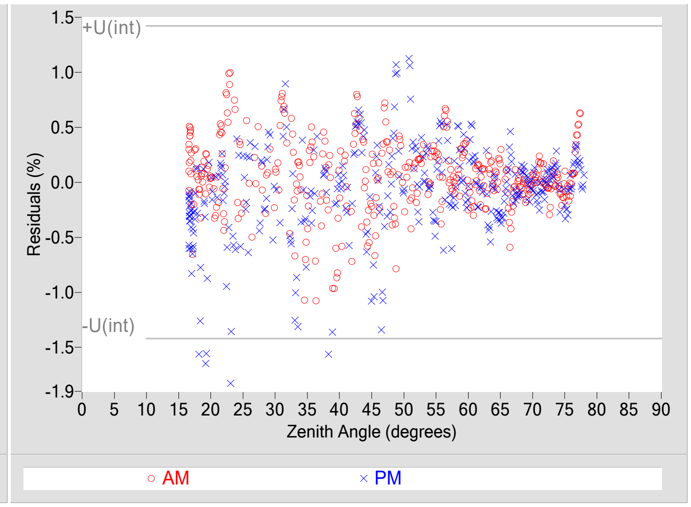


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.71
Combined Standard Uncertainty, u(c) (%)	±0.77
Effective degrees of freedom, DF(c)	935
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.5
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

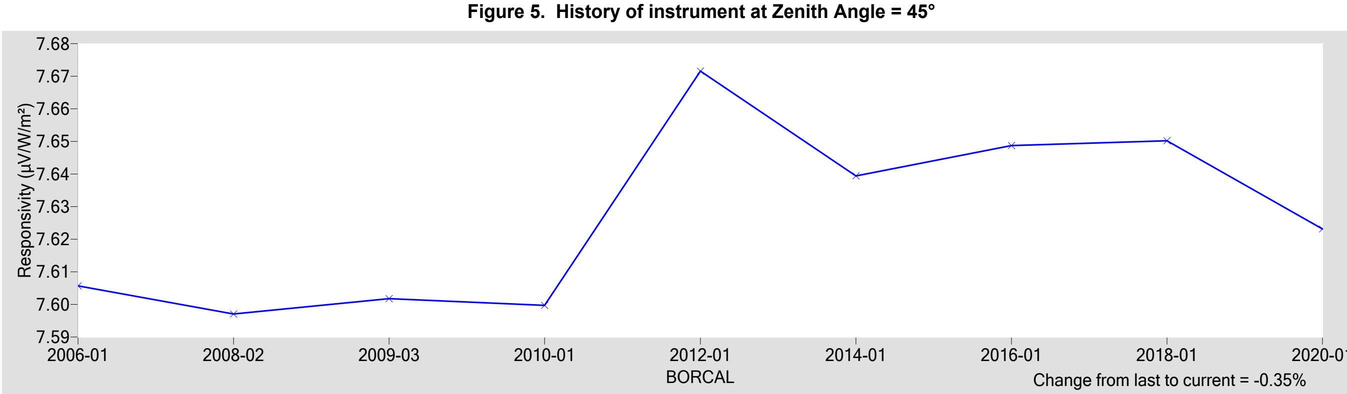
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6232	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+1.3 / -0.70
Expanded Uncertainty, U (%)	+1.9 / -1.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	34580
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

34580 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

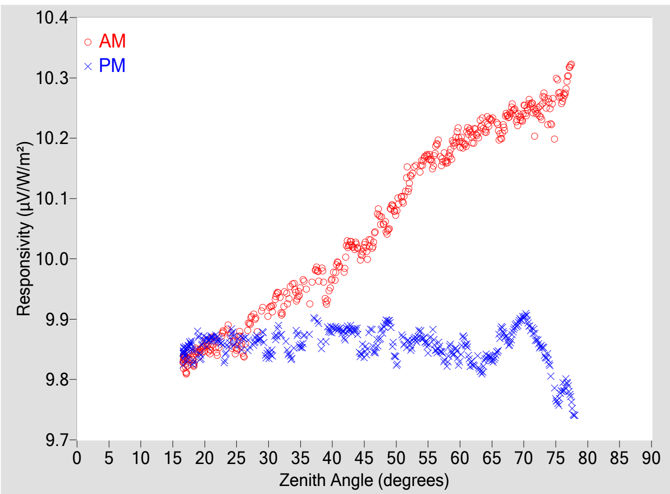


Figure 2. Responsivity vs Local Standard Time

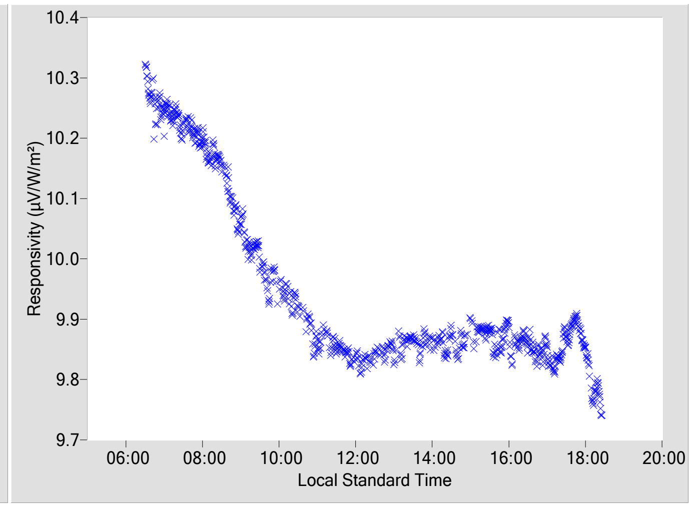


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	10.025	0.31	97.28	9.8813	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.062	0.32	95.63	9.8861	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.083	0.32	93.89	9.8314	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.129	0.33	92.36	9.8596	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.156	0.33	90.81	9.8715	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.167	0.34	89.35	9.8606	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.163	0.34	87.87	9.8299	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.195	0.35	86.40	9.8379	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.201	0.36	85.01	9.8253	0.35	275.07
18	9.8306	0.29	154.51	9.8471	0.29	204.69	64	10.217	0.37	83.60	9.8360	0.36	276.46
20	9.8559	0.29	142.76	9.8680	0.29	217.23	66	10.213	0.38	82.25	9.8566	0.37	277.82
22	9.8476	0.29	134.80	9.8677	0.29	225.22	68	10.245	0.40	80.91	9.8676	0.39	279.24
24	9.8732	0.29	128.44	9.8691	0.29	231.69	70	10.244	N/A	79.49	9.9050	0.41	280.63
26	9.8447	0.29	123.49	9.8621	0.29	236.40	72	10.245	N/A	78.09	9.8652	N/A	281.99
28	9.8938	0.29	119.31	9.8661	0.29	240.65	74	10.244	N/A	76.76	9.8215	N/A	283.39
30	9.9121	0.29	115.79	9.8425	0.29	244.28	76	10.265	N/A	75.31	9.7832	N/A	284.75
32	9.9157	0.30	112.70	9.8741	0.29	247.30	78	N/A	N/A	N/A	9.7406	N/A	286.12
34	9.9529	0.30	109.85	9.8523	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.9500	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.9710	0.30	105.24	9.8691	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.9697	0.30	102.94	9.8845	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.9966	0.31	100.90	9.8754	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.020	0.31	99.13	9.8714	0.30	260.98	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

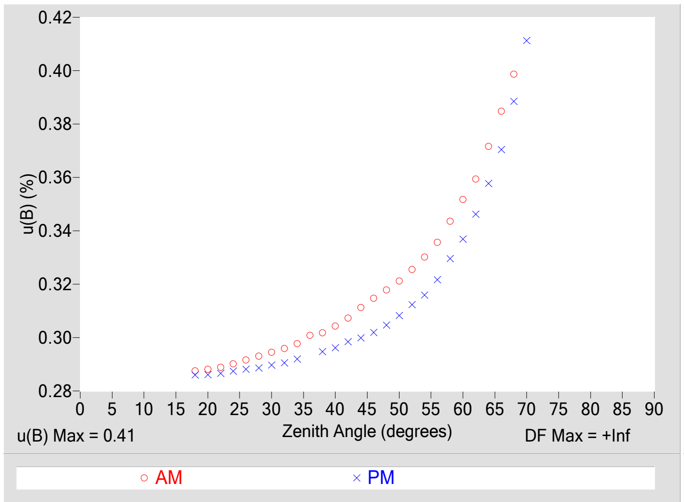


Figure 4. Residuals from Spline Interpolation

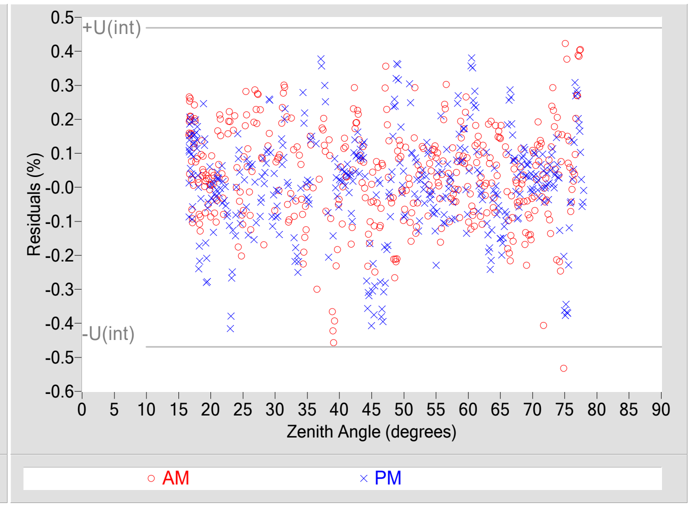


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	12001
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.93
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

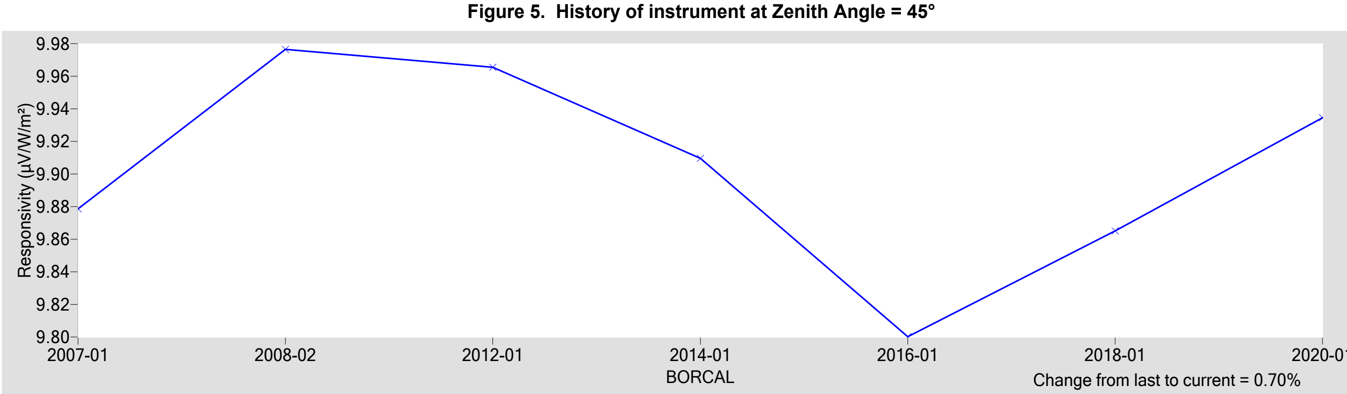
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.9346	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+2.6 / -1.1
Expanded Uncertainty, U (%)	+3.3 / -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).

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: 35751

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: AMF#2

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

35751 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

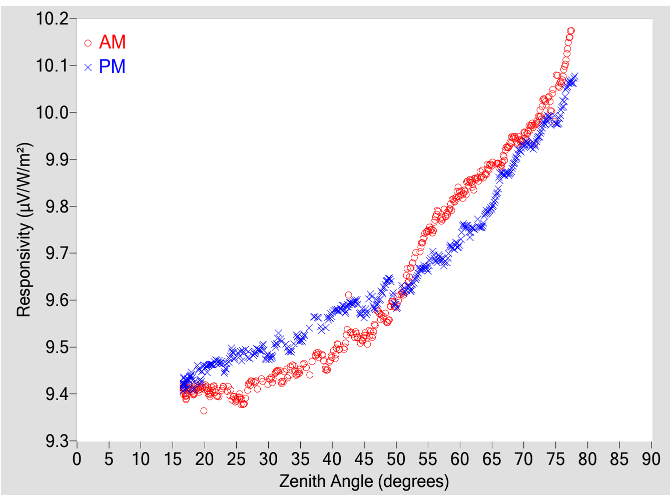


Figure 2. Responsivity vs Local Standard Time

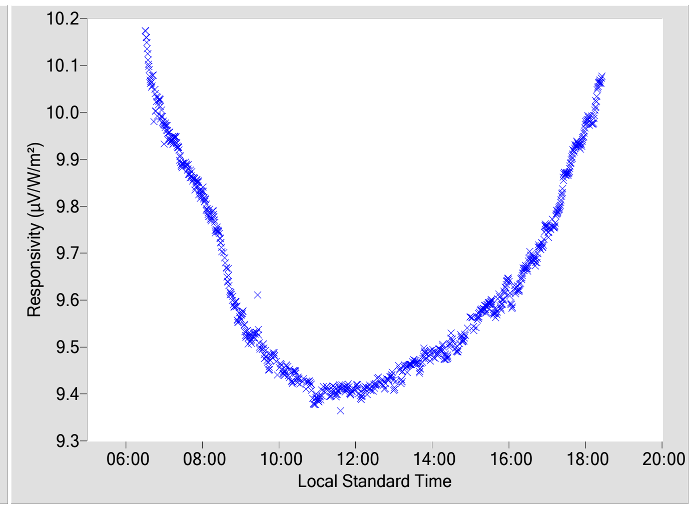


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.5282	0.31	97.28	9.6078	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.5647	0.32	95.63	9.6236	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.5921	0.32	93.89	9.5871	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6525	0.33	92.36	9.6260	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7180	0.33	90.81	9.6667	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.7609	0.34	89.35	9.6912	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.7840	0.34	87.87	9.6893	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8264	0.35	86.40	9.7261	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8462	0.36	85.01	9.7529	0.35	275.07
18	9.4046	0.29	154.51	9.4287	0.29	204.69	64	9.8731	0.37	83.60	9.7847	0.36	276.46
20	9.4148	0.29	142.40	9.4587	0.29	217.23	66	9.8890	0.38	82.25	9.8418	0.37	277.82
22	9.3972	0.29	134.80	9.4696	0.29	225.22	68	9.9384	0.40	80.91	9.8762	0.39	279.24
24	9.4020	0.29	128.44	9.4829	0.29	231.69	70	9.9482	N/A	79.49	9.9314	0.41	280.63
26	9.3810	0.29	123.49	9.4837	0.29	236.40	72	9.9721	N/A	78.13	9.9388	N/A	281.99
28	9.4207	0.29	119.31	9.4906	0.29	240.65	74	10.017	N/A	76.76	9.9846	N/A	283.39
30	9.4261	0.29	115.79	9.4790	0.29	244.28	76	10.073	N/A	75.31	10.009	N/A	284.75
32	9.4309	0.30	112.70	9.5145	0.29	247.30	78	N/A	N/A	N/A	10.075	N/A	286.12
34	9.4547	0.30	109.85	9.5073	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.4564	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.4826	0.30	105.24	9.5467	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.4837	0.30	102.94	9.5721	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.5074	0.31	100.90	9.5804	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.5232	0.31	99.13	9.5901	0.30	260.98	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

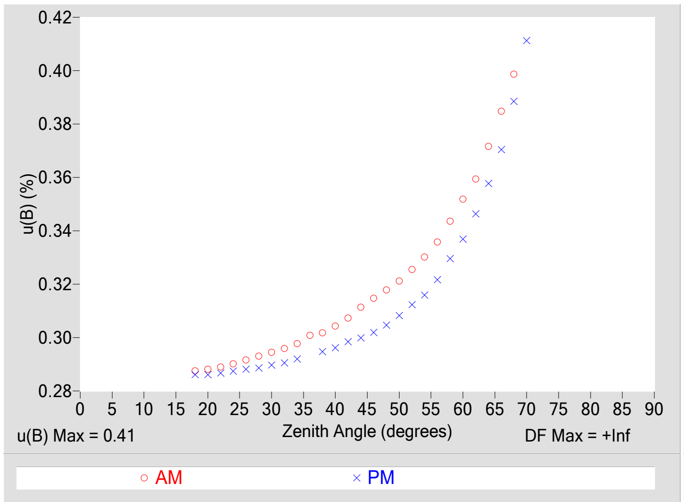


Figure 4. Residuals from Spline Interpolation

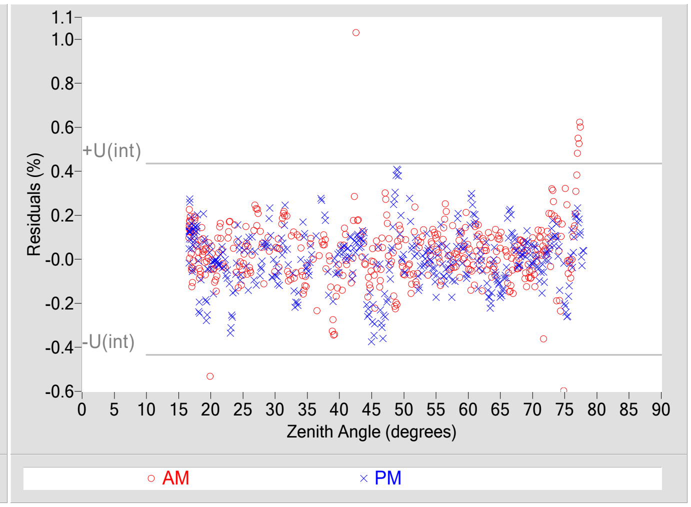


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.47
Effective degrees of freedom, DF(c)	15071
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.91
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

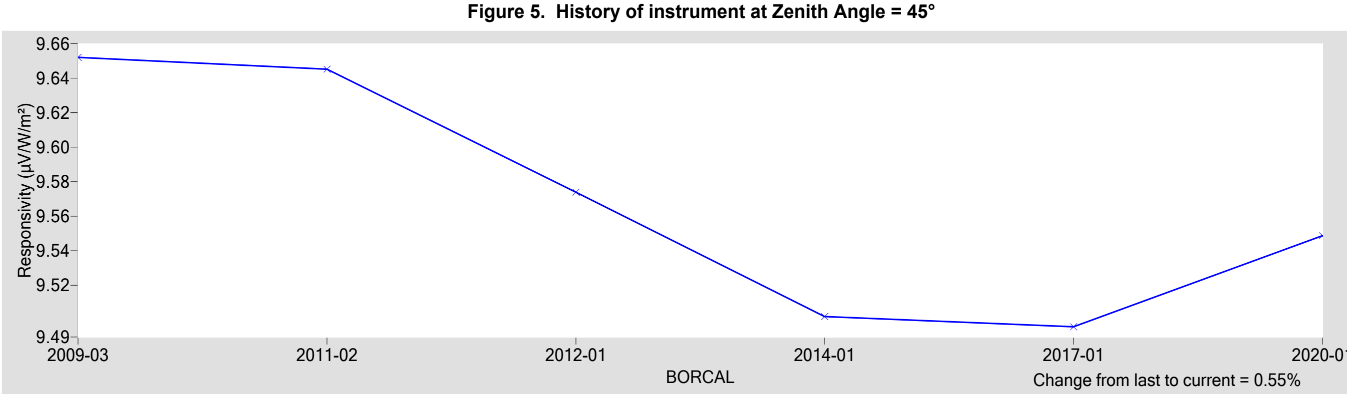
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.5486	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+2.9 / -1.3
Expanded Uncertainty, U (%)	+3.6 / -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: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 35804E6

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: AMF#2

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

35804E6 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

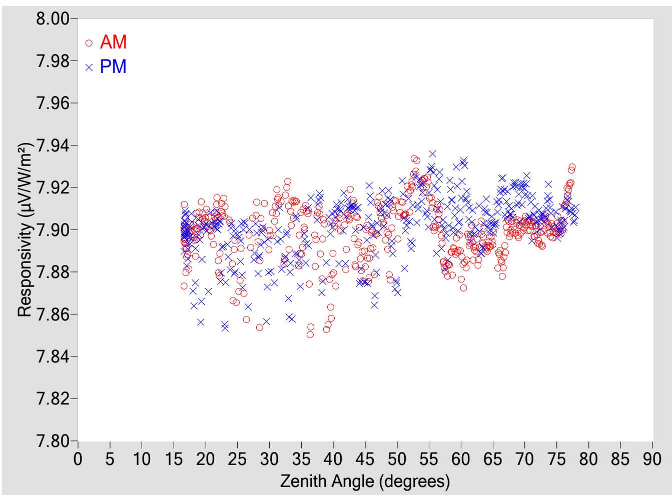


Figure 2. Responsivity vs Local Standard Time

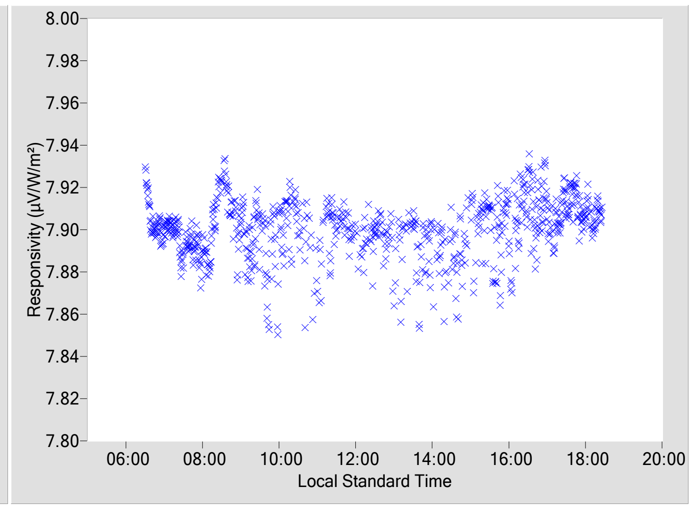


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8935	0.29	97.28	7.9059	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9019	0.29	95.51	7.9084	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9052	0.29	93.88	7.8736	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9164	0.29	92.35	7.8996	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9222	0.29	90.83	7.9185	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9030	0.30	89.32	7.9084	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8819	0.30	87.88	7.9040	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8870	0.30	86.42	7.9165	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8907	0.30	85.02	7.9020	0.29	275.04
18	7.8983	0.28	155.08	7.8884	0.28	204.18	64	7.8913	0.30	83.65	7.9081	0.30	276.48
20	7.9050	0.28	143.00	7.9014	0.28	217.45	66	7.8870	0.30	82.26	7.9142	0.30	277.84
22	7.8950	0.28	134.77	7.9042	0.28	225.40	68	7.9013	0.30	80.88	7.9131	0.30	279.25
24	7.8845	0.29	128.29	7.8955	0.28	231.62	70	7.9027	N/A	79.51	7.9211	0.30	280.64
26	7.8698	0.29	123.59	7.8916	0.28	236.36	72	7.8962	N/A	78.10	7.9039	N/A	281.96
28	7.9047	0.29	119.34	7.8918	0.28	240.85	74	7.9004	N/A	76.77	7.9110	N/A	283.36
30	7.8958	0.29	115.82	7.8851	0.28	244.14	76	7.9061	N/A	75.32	7.9040	N/A	284.77
32	7.8985	0.29	112.65	7.8869	0.28	247.35	78	N/A	N/A	N/A	7.9073	N/A	286.10
34	7.9115	0.29	109.96	7.9001	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8999	0.29	107.35	7.8986	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8958	0.29	105.10	7.9042	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8906	0.29	102.88	7.9057	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8977	0.29	100.86	7.9015	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8960	0.29	99.04	7.8927	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

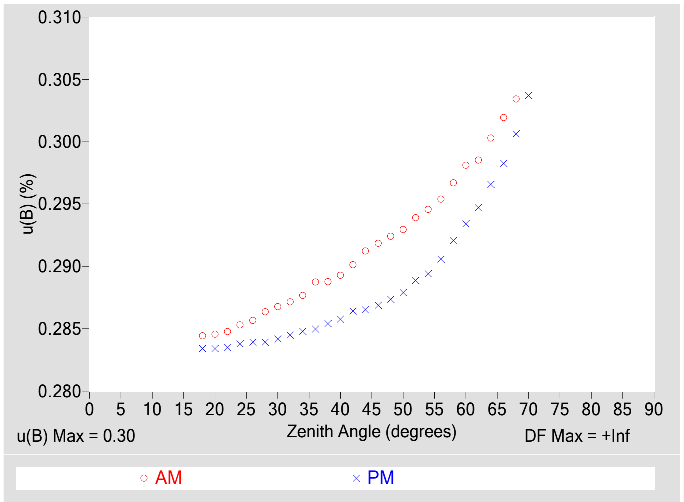


Figure 4. Residuals from Spline Interpolation

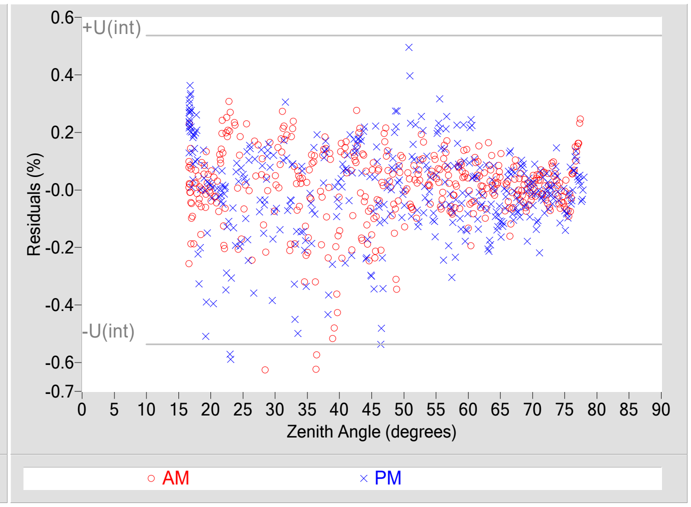


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	3709
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.79
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

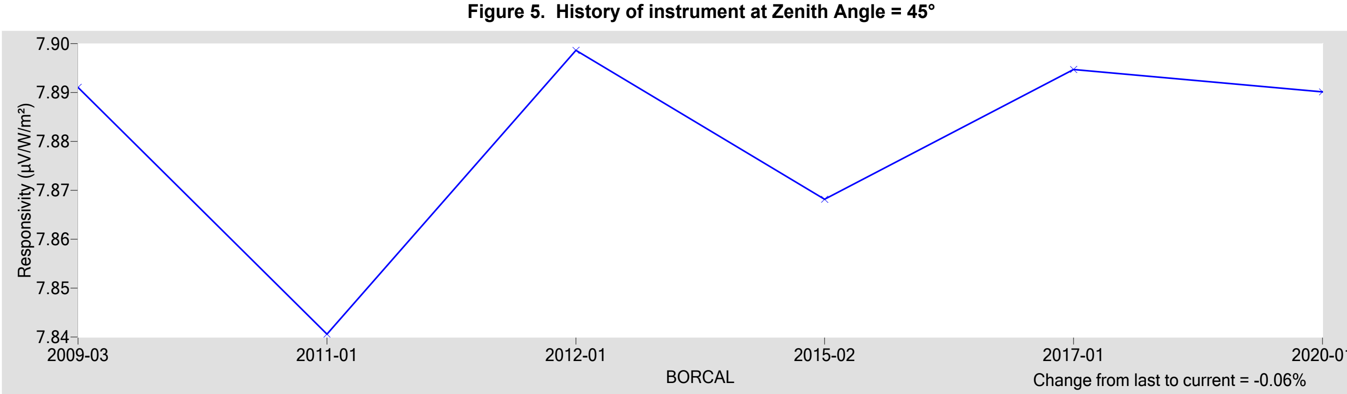
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8901	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.41 / -0.21
Expanded Uncertainty, U (%)	+0.99 / -0.79
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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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 - 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

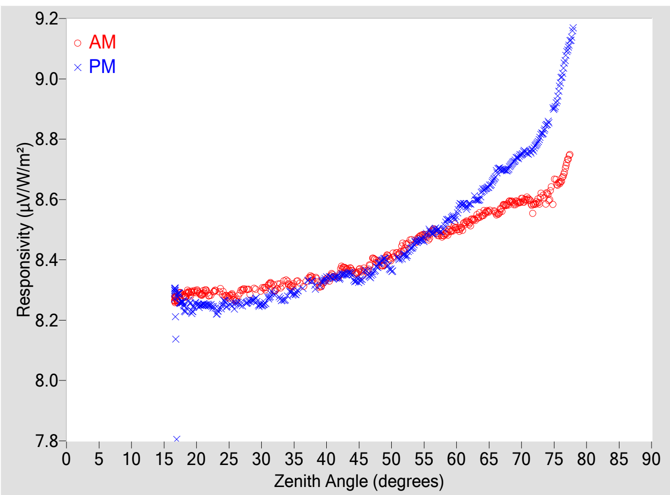


Figure 2. Responsivity vs Local Standard Time

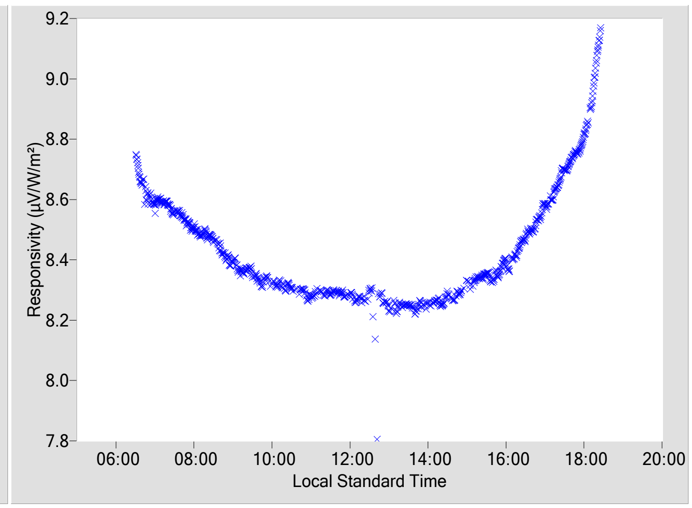


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3656	0.31	97.29	8.3638	0.30	262.82
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3941	0.32	95.63	8.3838	0.30	264.56
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4070	0.32	93.89	8.3652	0.31	266.16
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4419	0.33	92.36	8.4160	0.31	267.78
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4673	0.33	90.81	8.4622	0.32	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4817	0.34	89.35	8.4932	0.32	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4804	0.34	87.87	8.5065	0.33	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5044	0.35	86.40	8.5502	0.34	273.67
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5223	0.36	85.01	8.5860	0.35	275.07
18	8.2809	0.29	154.51	8.2471	0.29	204.69	64	8.5507	0.37	83.60	8.6295	0.36	276.46
20	8.2960	0.29	142.40	8.2543	0.29	217.23	66	8.5564	0.38	82.25	8.6796	0.37	277.82
22	8.2837	0.29	134.80	8.2499	0.29	225.22	68	8.5876	0.40	80.91	8.7031	0.39	279.24
24	8.2910	0.29	128.44	8.2538	0.29	231.69	70	8.5964	N/A	79.49	8.7512	0.41	280.63
26	8.2682	0.29	123.49	8.2503	0.29	236.40	72	8.5810	N/A	78.13	8.7726	N/A	281.99
28	8.2964	0.29	119.31	8.2607	0.29	240.65	74	8.6082	N/A	76.76	8.8528	N/A	283.39
30	8.3020	0.29	115.79	8.2507	0.29	244.28	76	8.6604	N/A	75.31	8.9866	N/A	284.75
32	8.3029	0.30	112.70	8.2854	0.29	247.30	78	N/A	N/A	N/A	9.1642	N/A	286.12
34	8.3251	0.30	109.85	8.2804	0.29	250.15	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3233	0.30	107.50	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3386	0.30	105.24	8.3161	0.29	255.13	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3364	0.30	102.94	8.3389	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3537	0.31	100.90	8.3432	0.30	259.15	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3673	0.31	99.13	8.3484	0.30	260.98	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

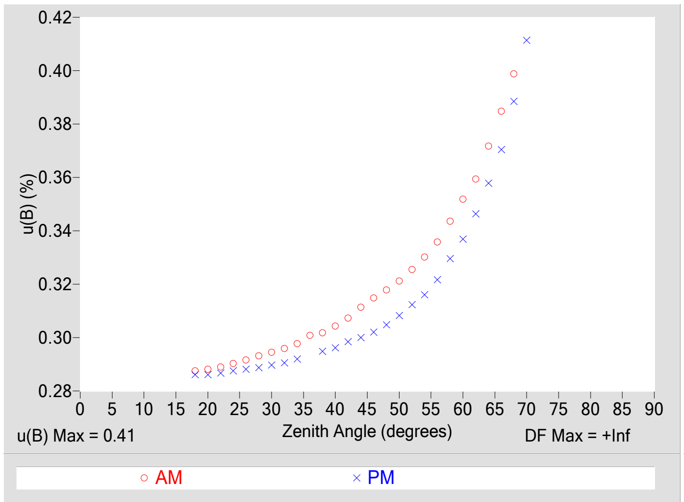


Figure 4. Residuals from Spline Interpolation

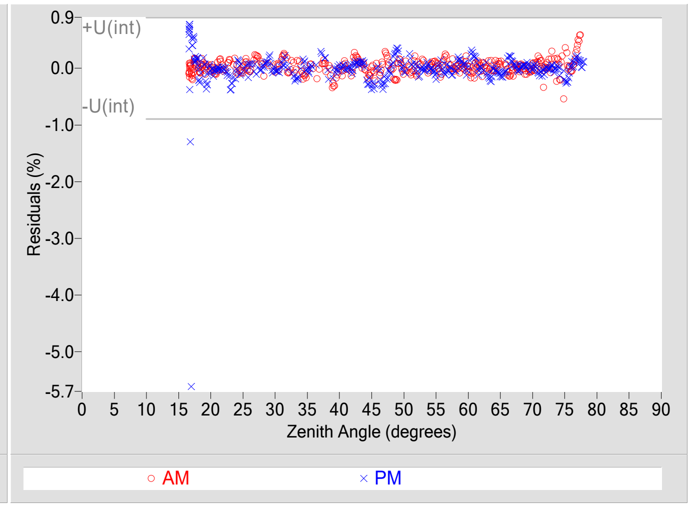


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.41
Type-A Interpolating Function, u(int) (%)	±0.45
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	2454
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

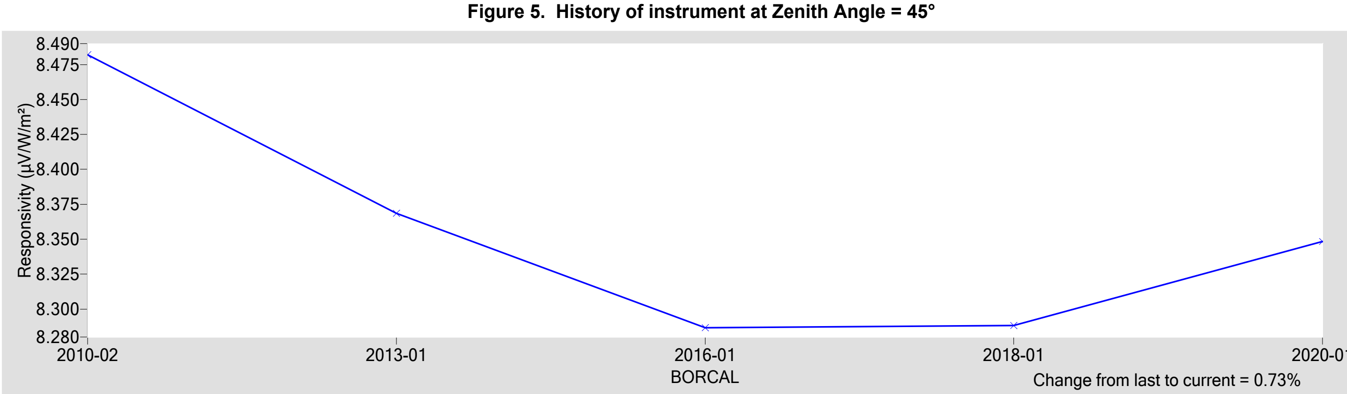
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3484	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.69
Offset Uncertainty, U(off) (%)	+2.4 / -1.2
Expanded Uncertainty, U (%)	+3.1 / -1.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	37285E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

37285E6 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

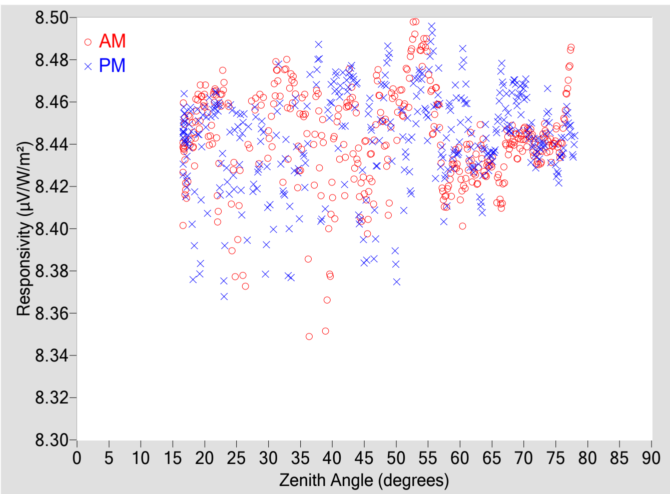


Figure 2. Responsivity vs Local Standard Time

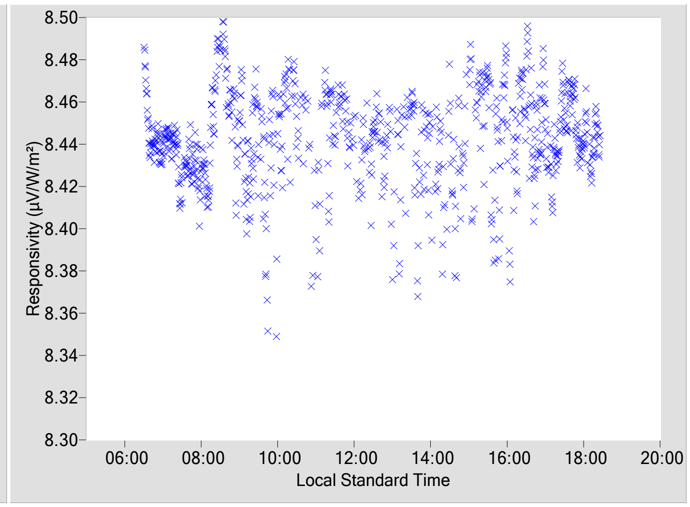


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4269	0.29	97.28	8.4511	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4482	0.29	95.51	8.4634	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4533	0.29	93.88	8.3825	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4714	0.29	92.35	8.4312	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4839	0.29	90.83	8.4711	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4535	0.30	89.32	8.4560	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4163	0.30	87.88	8.4331	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4241	0.30	86.42	8.4532	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4274	0.30	85.02	8.4337	0.29	275.04
18	8.4425	0.28	155.08	8.4274	0.28	204.18	64	8.4264	0.30	83.65	8.4411	0.30	276.48
20	8.4614	0.28	143.00	8.4531	0.28	217.45	66	8.4196	0.30	82.26	8.4548	0.30	277.84
22	8.4328	0.28	134.77	8.4604	0.28	225.40	68	8.4422	0.30	80.88	8.4549	0.30	279.25
24	8.4197	0.29	128.29	8.4442	0.28	231.62	70	8.4433	N/A	79.51	8.4671	0.30	280.64
26	8.3779	0.29	123.59	8.4349	0.28	236.36	72	8.4339	N/A	78.10	8.4354	N/A	281.96
28	8.4590	0.29	119.51	8.4390	0.28	240.85	74	8.4403	N/A	76.77	8.4498	N/A	283.36
30	8.4408	0.29	115.82	8.4169	0.28	244.14	76	8.4431	N/A	75.32	8.4372	N/A	284.77
32	8.4424	0.29	112.65	8.4359	0.28	247.35	78	N/A	N/A	N/A	8.4393	N/A	286.10
34	8.4661	0.29	109.96	8.4492	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4283	0.29	107.38	8.4432	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4410	0.29	105.10	8.4628	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4260	0.29	102.88	8.4659	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4413	0.29	100.86	8.4466	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4344	0.29	99.04	8.4366	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

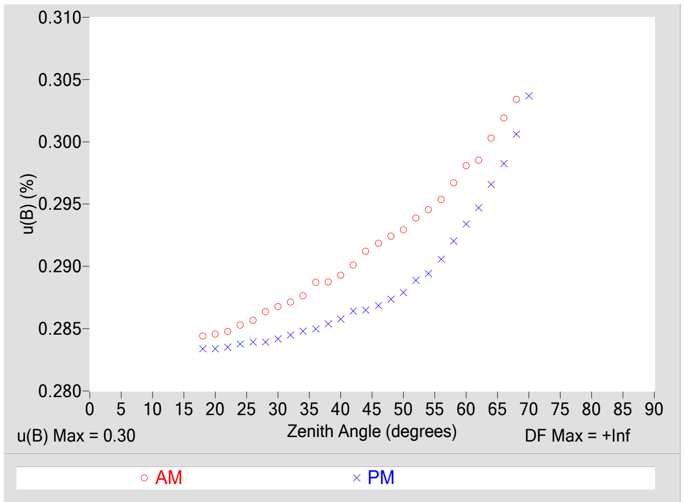


Figure 4. Residuals from Spline Interpolation

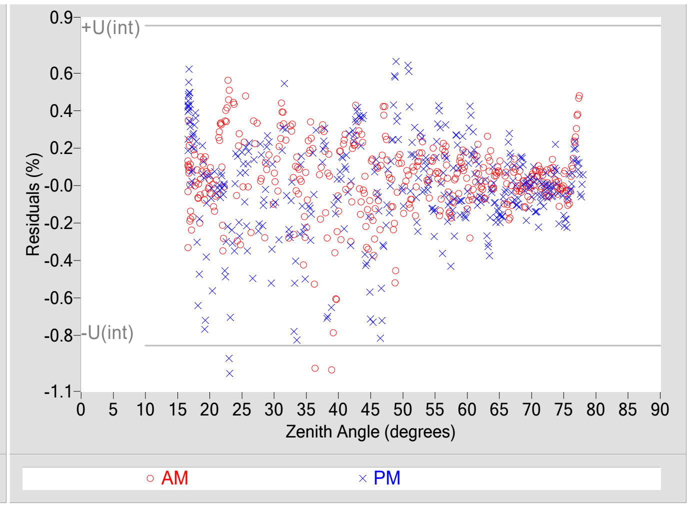


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.43
Combined Standard Uncertainty, u(c) (%)	±0.52
Effective degrees of freedom, DF(c)	1592
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.0
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

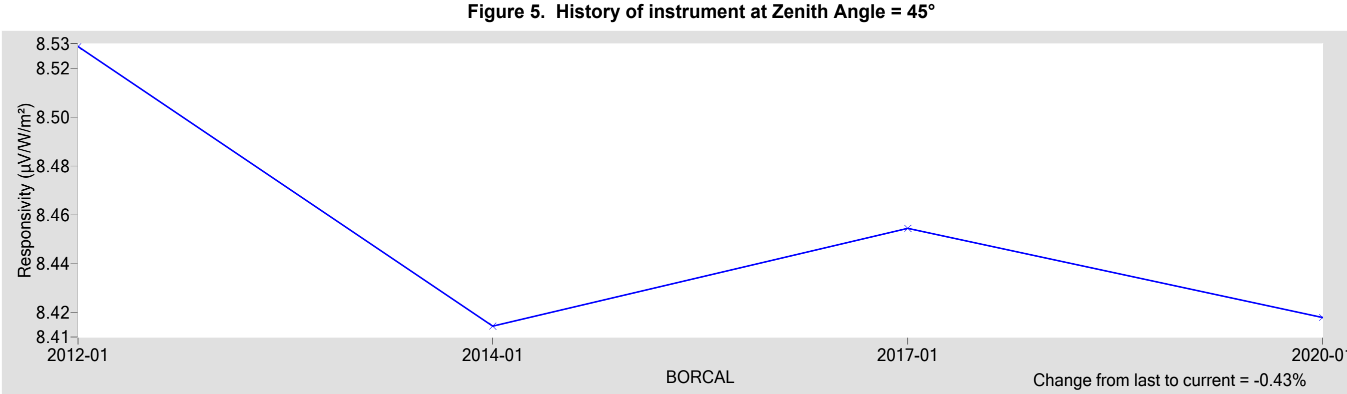
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4180	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.78 / -0.42
Expanded Uncertainty, U (%)	+1.4 / -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:**	37303F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

37303F3 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

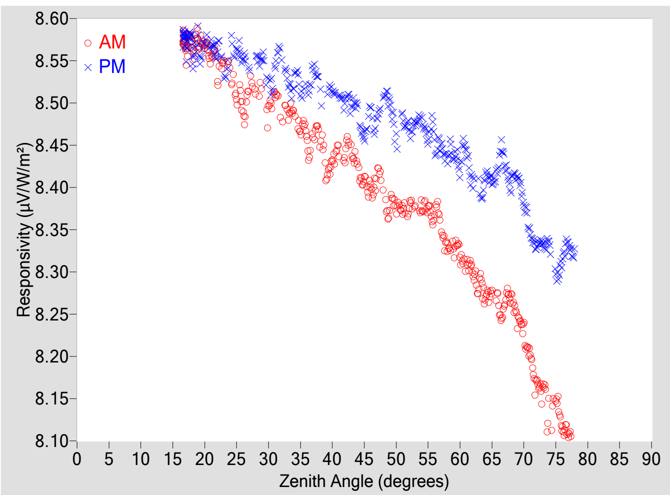


Figure 2. Responsivity vs Local Standard Time

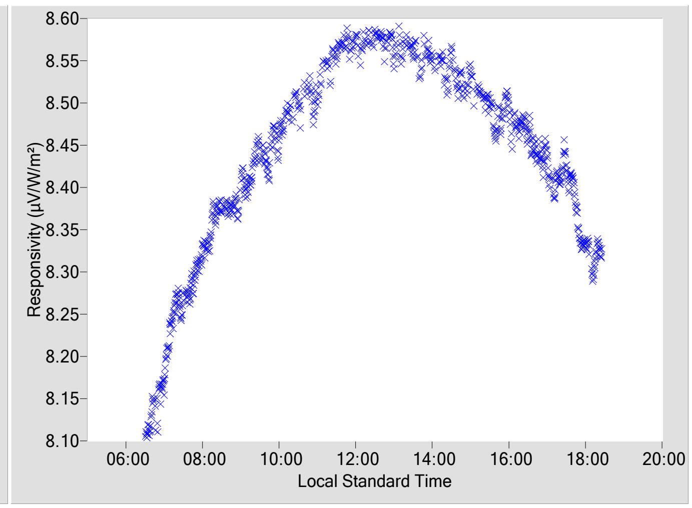


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3995	0.34	97.23	8.4950	0.33	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3969	0.34	95.57	8.5076	0.34	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3787	0.35	93.91	8.4544	0.34	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3750	0.35	92.33	8.4703	0.35	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3742	0.36	90.79	8.4778	0.36	269.35
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3660	0.37	89.35	8.4553	0.37	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3313	0.38	87.89	8.4359	0.38	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3224	0.39	86.46	8.4240	0.39	273.65
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3000	0.40	85.07	8.4091	0.41	275.04
18	8.5670	0.30	154.88	8.5671	0.30	204.05	64	8.2703	0.42	83.61	8.4139	0.43	276.48
20	8.5690	0.30	142.66	8.5754	0.30	217.84	66	8.2617	0.44	82.22	8.4253	0.45	277.85
22	8.5363	0.30	134.57	8.5661	0.30	225.45	68	8.2683	0.46	80.88	8.4044	0.47	279.21
24	8.5341	0.30	128.38	8.5751	0.30	232.17	70	8.2276	N/A	79.51	8.3806	0.51	280.60
26	8.4905	0.31	123.60	8.5527	0.31	236.58	72	8.1673	N/A	78.15	8.3305	N/A	282.01
28	8.5134	0.31	119.63	8.5534	0.31	240.96	74	8.1355	N/A	76.86	8.3314	N/A	283.37
30	8.4916	0.31	115.85	8.5289	0.31	244.18	76	8.1153	N/A	75.33	8.3160	N/A	284.82
32	8.4804	0.31	112.65	8.5576	0.31	247.26	78	N/A	N/A	N/A	8.3220	N/A	286.10
34	8.4885	0.31	110.04	8.5282	0.31	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4556	0.32	107.39	8.5160	0.32	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4572	0.32	105.05	8.5146	0.32	255.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4317	0.32	102.95	8.5144	0.32	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4396	0.33	100.93	8.5006	0.33	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4225	0.33	98.99	8.4902	0.33	261.06	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

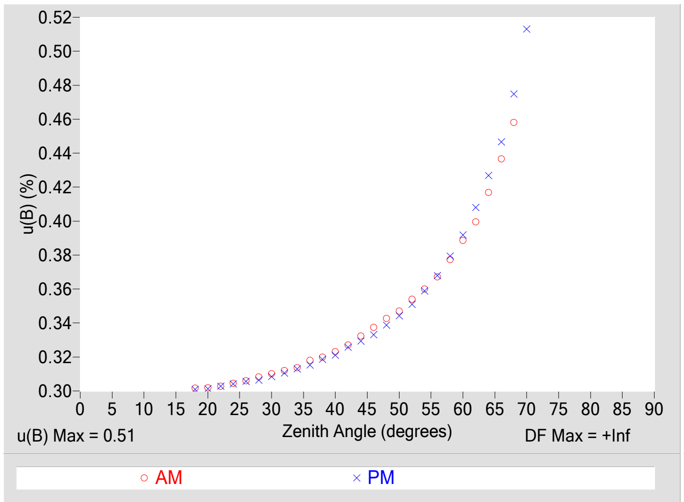


Figure 4. Residuals from Spline Interpolation

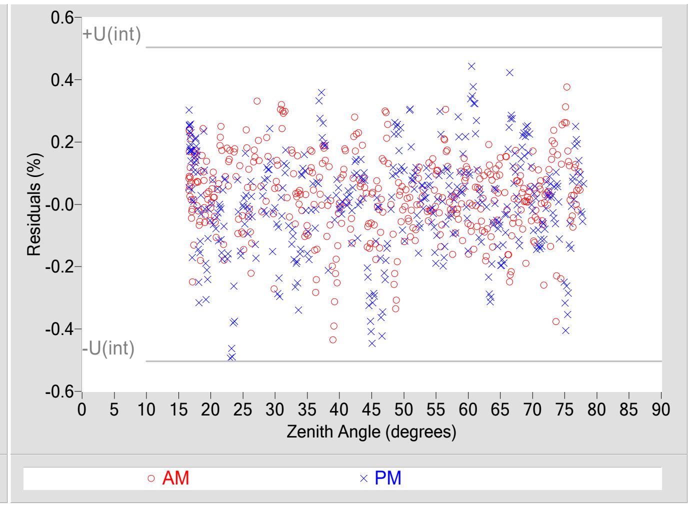


Table 3. Uncertainty using Spline Interpolation ‡

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)	19519
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

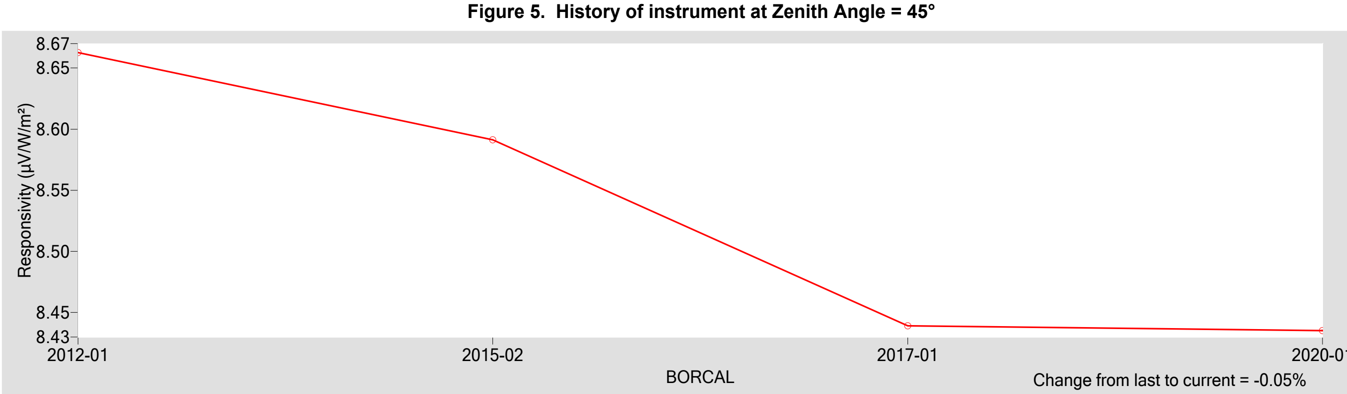
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4353	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.77
Offset Uncertainty, U(off) (%)	+1.4 / -1.3
Expanded Uncertainty, U (%)	+2.2 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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: 37304F3

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: NSA

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

37304F3 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

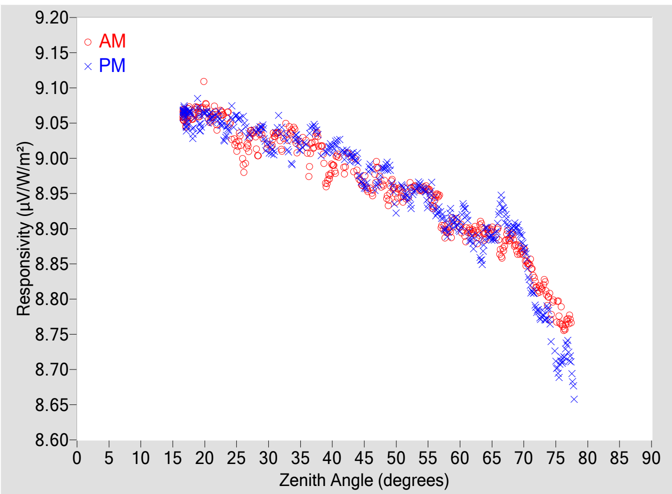


Figure 2. Responsivity vs Local Standard Time

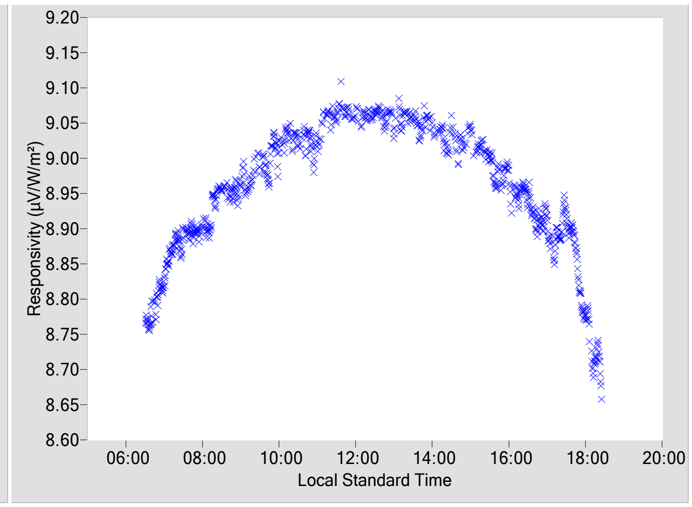


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.9516	0.33	97.13	8.9870	0.33	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9643	0.34	95.53	8.9856	0.34	264.60
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9474	0.34	93.96	8.9285	0.34	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9559	0.35	92.24	8.9443	0.35	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9552	0.35	90.85	8.9585	0.36	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9384	0.36	89.30	8.9301	0.36	270.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8987	0.37	87.86	8.9002	0.38	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9013	0.38	86.39	8.9019	0.39	273.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8948	0.39	85.04	8.8808	0.40	275.01
18	9.0568	0.30	155.62	9.0491	0.30	204.78	64	8.8909	0.41	83.67	8.8932	0.42	276.45
20	9.0841	0.30	142.82	9.0653	0.30	217.24	66	8.8871	0.42	82.28	8.9167	0.44	277.86
22	9.0438	0.30	134.99	9.0593	0.30	225.71	68	8.8894	0.44	80.86	8.8939	0.47	279.22
24	9.0421	0.30	128.26	9.0573	0.30	231.68	70	8.8655	N/A	79.52	8.8765	0.50	280.57
26	8.9901	0.30	123.41	9.0497	0.30	236.56	72	8.8158	N/A	78.12	8.7859	N/A	281.98
28	9.0218	0.31	119.35	9.0384	0.31	240.58	74	8.7926	N/A	76.70	8.7691	N/A	283.38
30	9.0166	0.31	116.13	9.0164	0.31	244.30	76	8.7669	N/A	75.34	8.7139	N/A	284.79
32	9.0160	0.31	112.74	9.0396	0.31	247.36	78	N/A	N/A	N/A	8.6673	N/A	286.08
34	9.0376	0.31	109.91	9.0302	0.31	250.45	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0162	0.32	107.41	9.0198	0.31	252.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0220	0.32	105.14	9.0188	0.32	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9882	0.32	102.91	9.0123	0.32	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9901	0.32	100.92	9.0066	0.32	259.16	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9762	0.33	99.03	8.9930	0.33	261.01	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

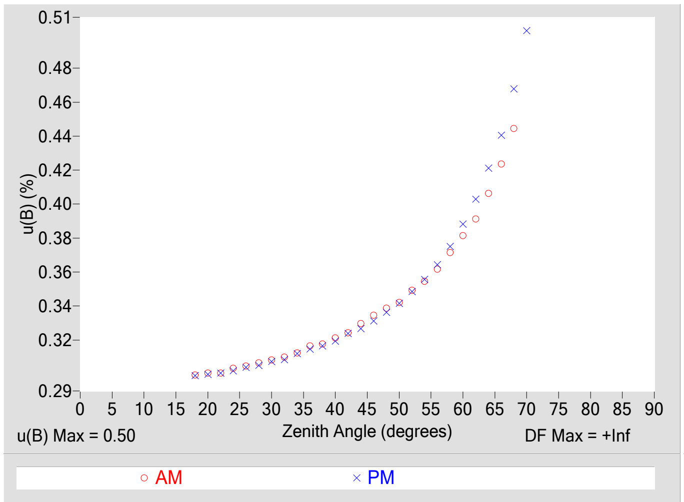


Figure 4. Residuals from Spline Interpolation

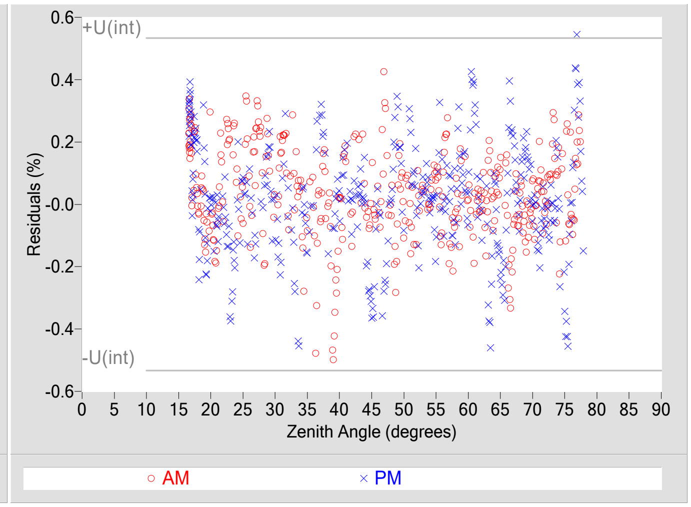


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.50
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	14765
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

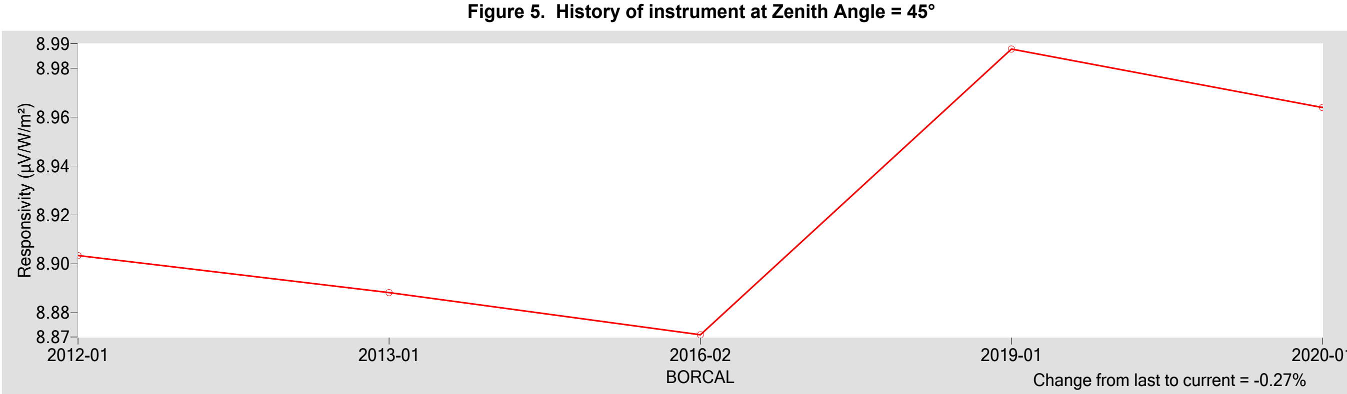
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.9639	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.76
Offset Uncertainty, U(off) (%)	+0.85 / -0.73
Expanded Uncertainty, U (%)	+1.6 / -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:**	37314F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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
37314F3 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

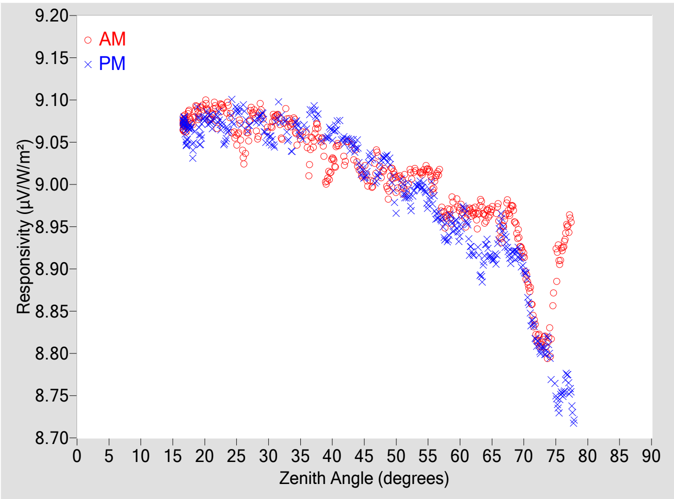


Figure 2. Responsivity vs Local Standard Time

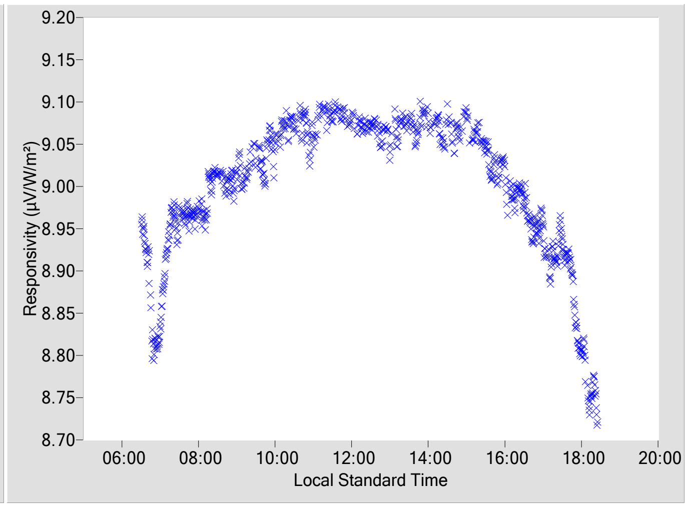


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.9995	0.33	97.13	9.0327	0.33	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0171	0.34	95.53	9.0316	0.34	264.60
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0014	0.34	93.96	8.9725	0.34	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0108	0.35	92.24	8.9867	0.35	267.77
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.0136	0.35	90.85	8.9986	0.36	269.29
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.0016	0.36	89.30	8.9713	0.36	270.82
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9645	0.37	87.86	8.9394	0.37	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9703	0.38	86.39	8.9429	0.39	273.66
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9662	0.39	85.04	8.9201	0.40	275.01
18	9.0745	0.30	155.62	9.0526	0.30	204.78	64	8.9618	0.41	83.67	8.9233	0.42	276.45
20	9.0945	0.30	142.82	9.0797	0.30	217.24	66	8.9619	0.42	82.28	8.9367	0.44	277.86
22	9.0707	0.30	134.99	9.0798	0.30	225.71	68	8.9718	0.44	80.86	8.9132	0.47	279.22
24	9.0747	0.30	128.26	9.0821	0.30	231.68	70	8.9131	N/A	79.52	8.9012	0.50	280.57
26	9.0322	0.30	123.41	9.0837	0.30	236.56	72	8.8215	N/A	78.12	8.8145	N/A	281.98
28	9.0709	0.31	119.35	9.0744	0.30	240.58	74	8.8152	N/A	76.70	8.7986	N/A	283.38
30	9.0652	0.31	116.13	9.0548	0.31	244.30	76	8.9216	N/A	75.34	8.7524	N/A	284.79
32	9.0598	0.31	112.74	9.0777	0.31	247.36	78	N/A	N/A	N/A	8.7193	N/A	286.08
34	9.0723	0.31	109.91	9.0711	0.31	250.45	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0524	0.32	107.41	9.0655	0.31	252.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0574	0.32	105.14	9.0676	0.32	255.00	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0269	0.32	102.91	9.0598	0.32	257.24	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0336	0.32	100.92	9.0527	0.32	259.16	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0218	0.33	99.03	9.0409	0.33	261.01	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

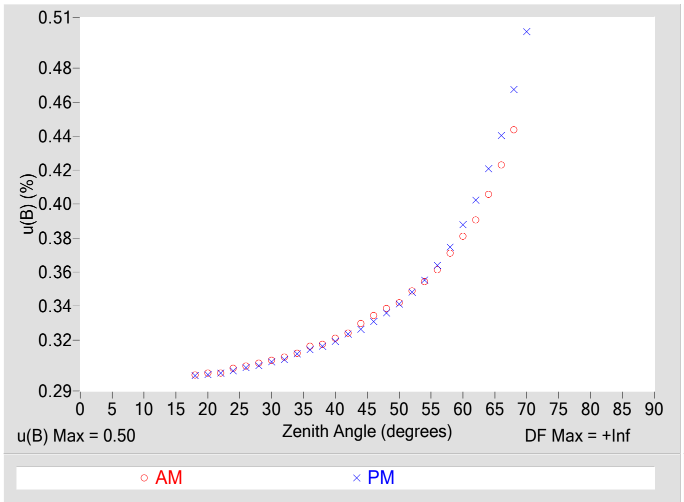


Figure 4. Residuals from Spline Interpolation

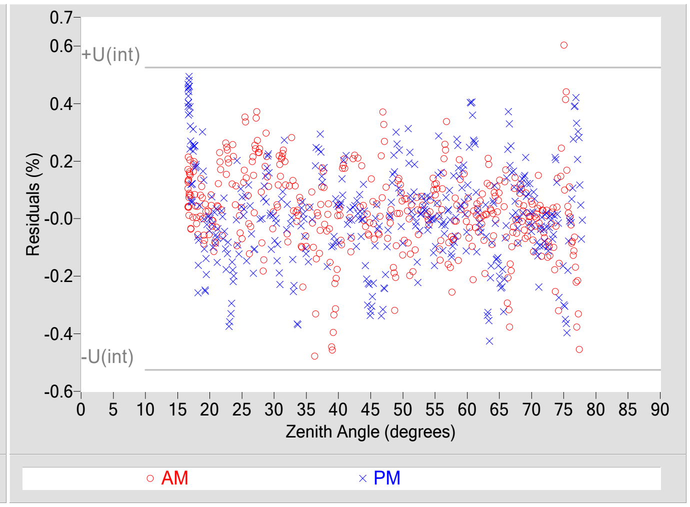


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.50
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.57
Effective degrees of freedom, DF(c)	15356
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

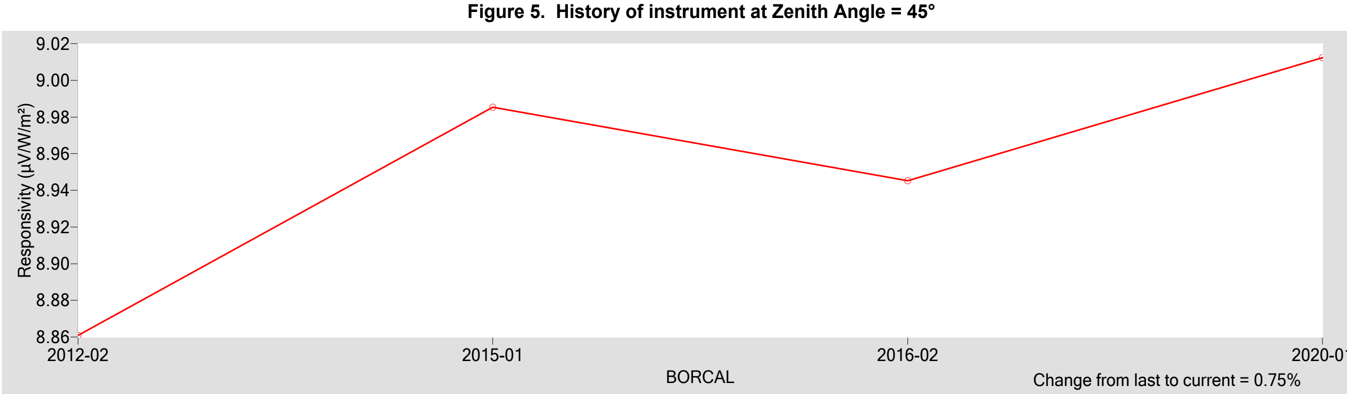
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0123	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.76
Offset Uncertainty, U(off) (%)	+0.73 / -0.81
Expanded Uncertainty, U (%)	+1.5 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	37317F3
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/02/2019	04/02/2021

† 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

37317F3 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

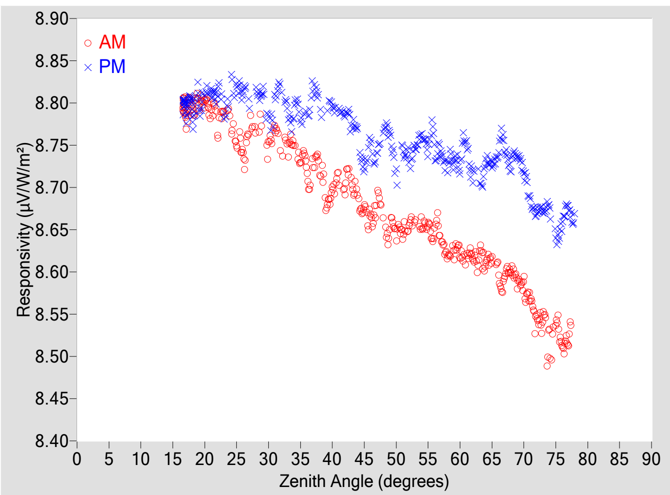


Figure 2. Responsivity vs Local Standard Time

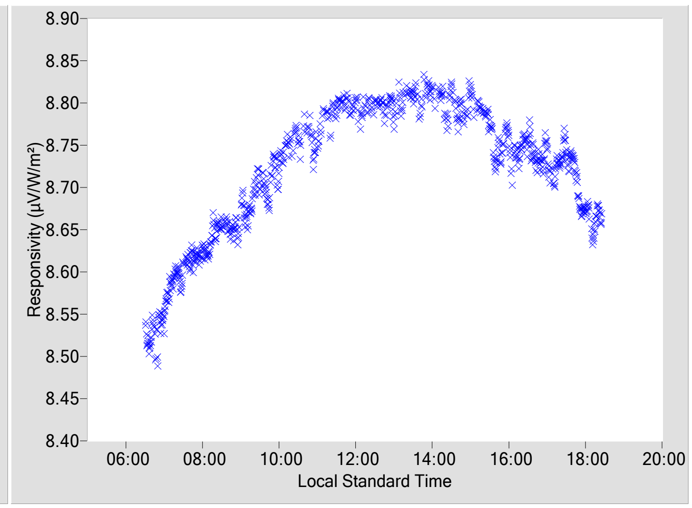


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	8.6652	0.34	97.23	8.7558	0.33	262.79
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6642	0.34	95.57	8.7679	0.34	264.63
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6493	0.35	93.91	8.7138	0.34	266.15
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6542	0.35	92.33	8.7356	0.35	267.72
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6539	0.36	90.79	8.7598	0.36	269.35
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6460	0.37	89.35	8.7500	0.37	270.75
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6205	0.38	87.89	8.7271	0.38	272.28
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6243	0.39	86.46	8.7253	0.39	273.65
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6169	0.40	85.07	8.7177	0.40	275.04
18	8.7918	0.30	154.88	8.7938	0.30	204.05	64	8.6094	0.41	83.61	8.7294	0.42	276.48
20	8.8017	0.30	142.66	8.8141	0.30	217.84	66	8.5977	0.43	82.22	8.7419	0.44	277.85
22	8.7732	0.30	134.57	8.8128	0.30	225.45	68	8.6009	0.45	80.88	8.7276	0.47	279.21
24	8.7772	0.30	128.38	8.8307	0.30	232.17	70	8.5801	N/A	79.51	8.7182	0.51	280.60
26	8.7374	0.31	123.60	8.8126	0.30	236.58	72	8.5422	N/A	78.15	8.6698	N/A	282.01
28	8.7682	0.31	119.63	8.8135	0.31	240.96	74	8.5151	N/A	76.78	8.6740	N/A	283.37
30	8.7506	0.31	115.85	8.7856	0.31	244.18	76	8.5129	N/A	75.33	8.6594	N/A	284.82
32	8.7404	0.31	112.65	8.8174	0.31	247.26	78	N/A	N/A	N/A	8.6635	N/A	286.10
34	8.7513	0.31	110.04	8.7928	0.31	250.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7191	0.32	107.39	8.7876	0.31	252.73	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7196	0.32	105.05	8.7951	0.32	255.09	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6965	0.32	102.95	8.7964	0.32	257.18	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7027	0.33	100.93	8.7863	0.32	259.20	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6870	0.33	98.99	8.7608	0.33	261.06	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

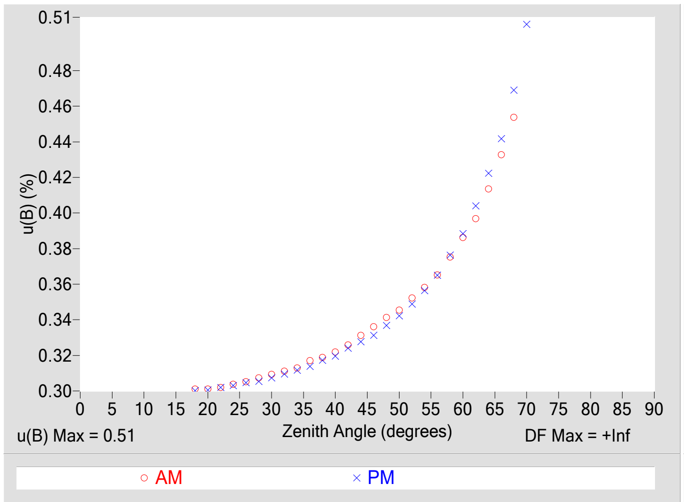


Figure 4. Residuals from Spline Interpolation

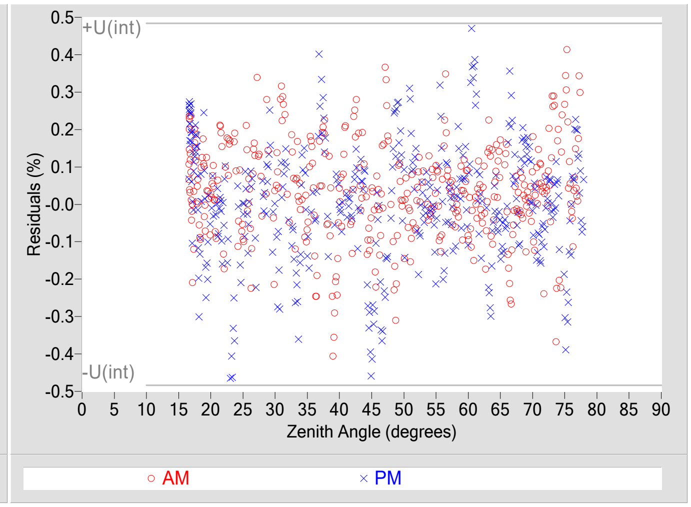


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.51
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.56
Effective degrees of freedom, DF(c)	21318
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

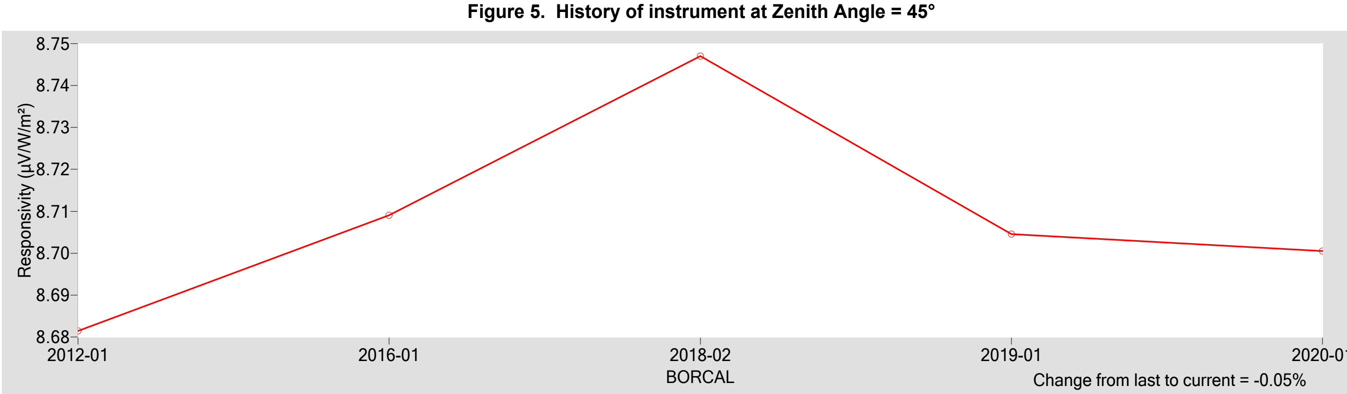
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7005	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.76
Offset Uncertainty, U(off) (%)	+1.3 / -0.92
Expanded Uncertainty, U (%)	+2.1 / -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).

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:**	37359E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

37359E6 Eppley NIP

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

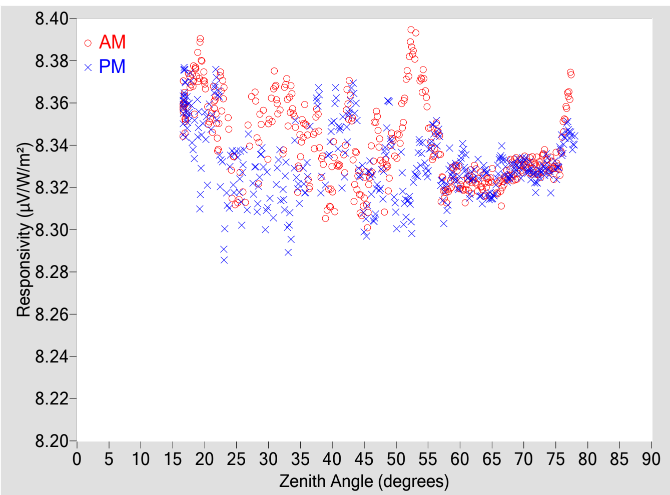


Figure 2. Responsivity vs Local Standard Time

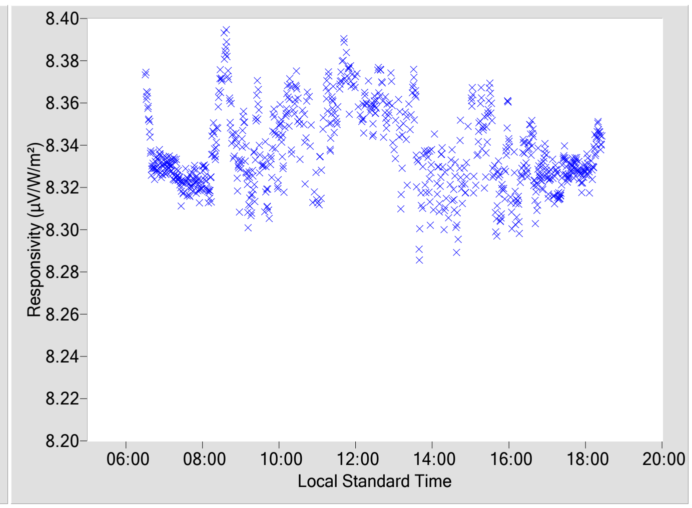


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3279	0.29	97.28	8.3256	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3255	0.29	95.51	8.3296	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3380	0.29	93.88	8.3072	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3797	0.29	92.35	8.3119	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3709	0.29	90.83	8.3372	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3383	0.30	89.32	8.3455	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3168	0.30	87.88	8.3183	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3227	0.30	86.42	8.3293	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3237	0.30	85.02	8.3254	0.29	275.04
18	8.3709	0.28	155.08	8.3565	0.28	204.18	64	8.3197	0.30	83.65	8.3277	0.30	276.48
20	8.3702	0.28	143.00	8.3505	0.28	217.45	66	8.3205	0.30	82.26	8.3298	0.30	277.84
22	8.3482	0.28	134.77	8.3654	0.28	225.40	68	8.3280	0.30	80.88	8.3276	0.30	279.25
24	8.3303	0.29	128.29	8.3282	0.28	231.62	70	8.3306	N/A	79.51	8.3325	0.30	280.64
26	8.3179	0.29	123.59	8.3222	0.28	236.36	72	8.3296	N/A	78.10	8.3221	N/A	281.96
28	8.3565	0.29	119.34	8.3201	0.28	240.85	74	8.3301	N/A	76.77	8.3267	N/A	283.36
30	8.3453	0.29	115.82	8.3175	0.28	244.14	76	8.3430	N/A	75.32	8.3390	N/A	284.77
32	8.3462	0.29	112.65	8.3236	0.28	247.35	78	N/A	N/A	N/A	8.3417	N/A	286.10
34	8.3536	0.29	109.96	8.3410	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3419	0.29	107.35	8.3249	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3412	0.29	105.10	8.3518	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3285	0.29	102.88	8.3495	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3451	0.29	100.86	8.3366	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3251	0.29	99.04	8.3414	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

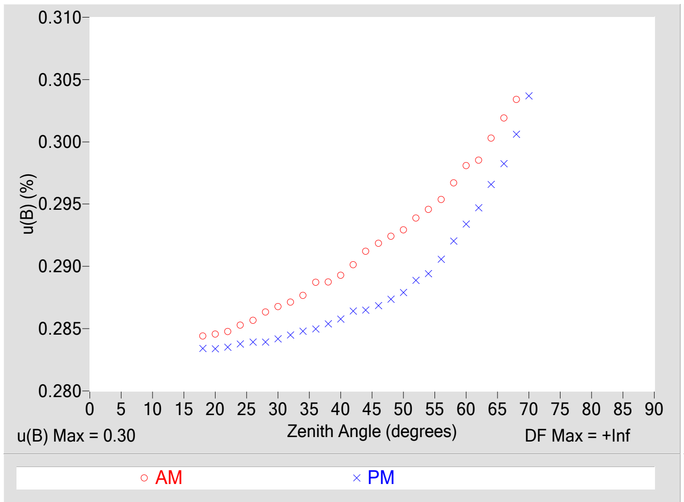


Figure 4. Residuals from Spline Interpolation

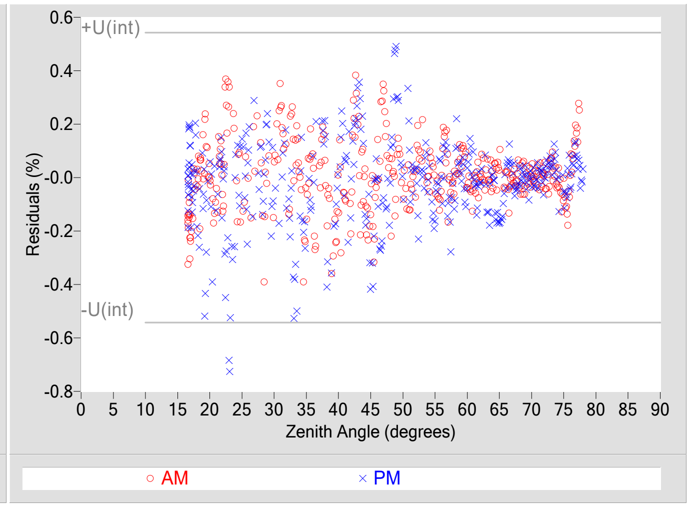


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.27
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	3622
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.80
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

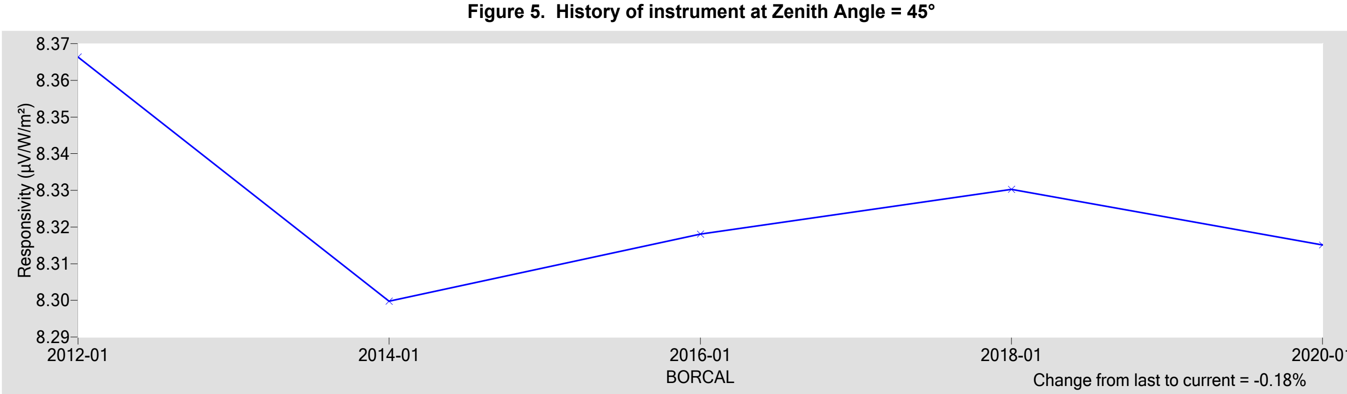
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3151	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.78 / -0.095
Expanded Uncertainty, U (%)	+1.4 / -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: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 37361E6

Calibration Date: 5/19/2020

Due Date: 5/19/2021

Customer: NSA

Environmental Conditions: see page 4

Test Dates: 5/19

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

37361E6 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

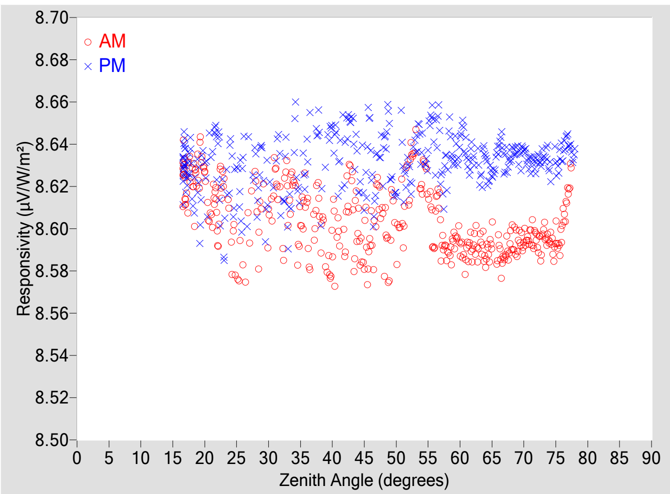


Figure 2. Responsivity vs Local Standard Time

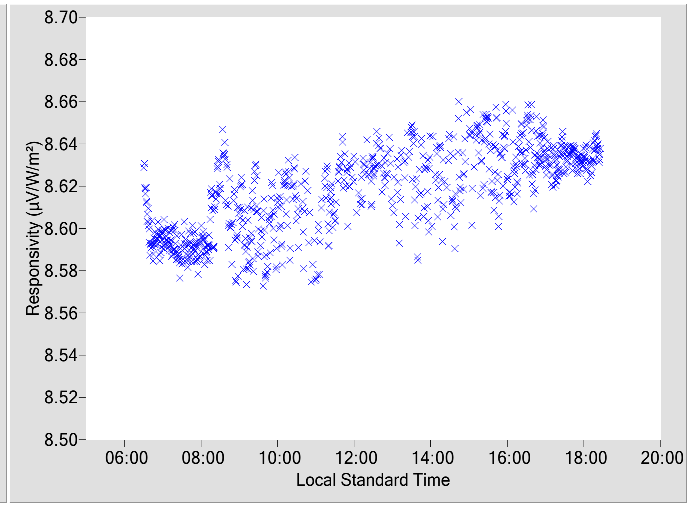


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5954	0.29	97.28	8.6381	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6011	0.29	95.51	8.6364	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5959	0.29	93.88	8.6166	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6219	0.29	92.35	8.6264	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6216	0.29	90.83	8.6392	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5954	0.30	89.32	8.6424	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5886	0.30	87.88	8.6324	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5937	0.30	86.42	8.6419	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5908	0.30	85.02	8.6352	0.29	275.04
18	8.6243	0.28	155.08	8.6273	0.28	204.18	64	8.5864	0.30	83.65	8.6338	0.30	276.48
20	8.6269	0.28	143.00	8.6310	0.28	217.45	66	8.5895	0.30	82.26	8.6382	0.30	277.84
22	8.6037	0.28	134.77	8.6409	0.28	225.40	68	8.5937	0.30	80.88	8.6350	0.30	279.25
24	8.5939	0.29	128.29	8.6334	0.28	231.62	70	8.5933	N/A	79.51	8.6372	0.30	280.64
26	8.5829	0.29	123.59	8.6216	0.28	236.36	72	8.5940	N/A	78.10	8.6307	N/A	281.96
28	8.6192	0.29	119.34	8.6231	0.28	240.85	74	8.5955	N/A	76.77	8.6299	N/A	283.36
30	8.6023	0.29	115.82	8.6219	0.28	244.14	76	8.6015	N/A	75.32	8.6349	N/A	284.77
32	8.6052	0.29	112.65	8.6186	0.28	247.35	78	N/A	N/A	N/A	8.6352	N/A	286.10
34	8.6215	0.29	109.96	8.6494	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6069	0.29	107.35	8.6333	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6076	0.29	105.10	8.6369	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5971	0.29	102.88	8.6441	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6017	0.29	100.86	8.6380	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6027	0.29	99.04	8.6290	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

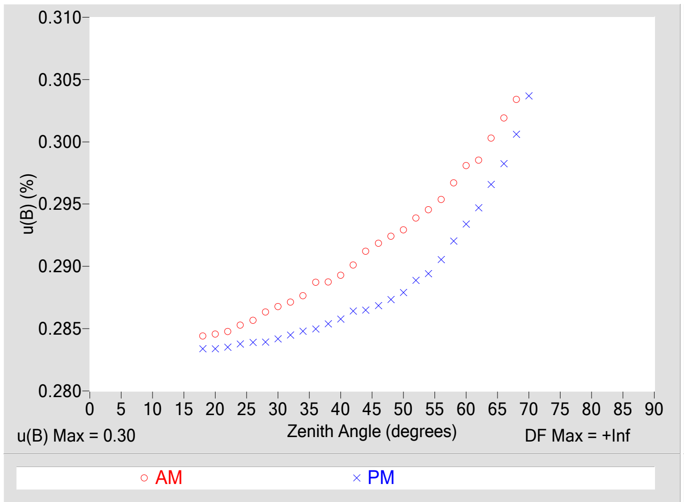


Figure 4. Residuals from Spline Interpolation

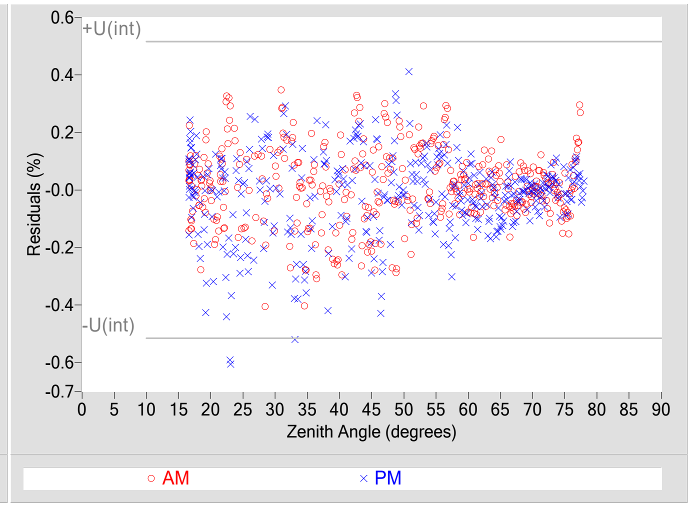


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.26
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	4058
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

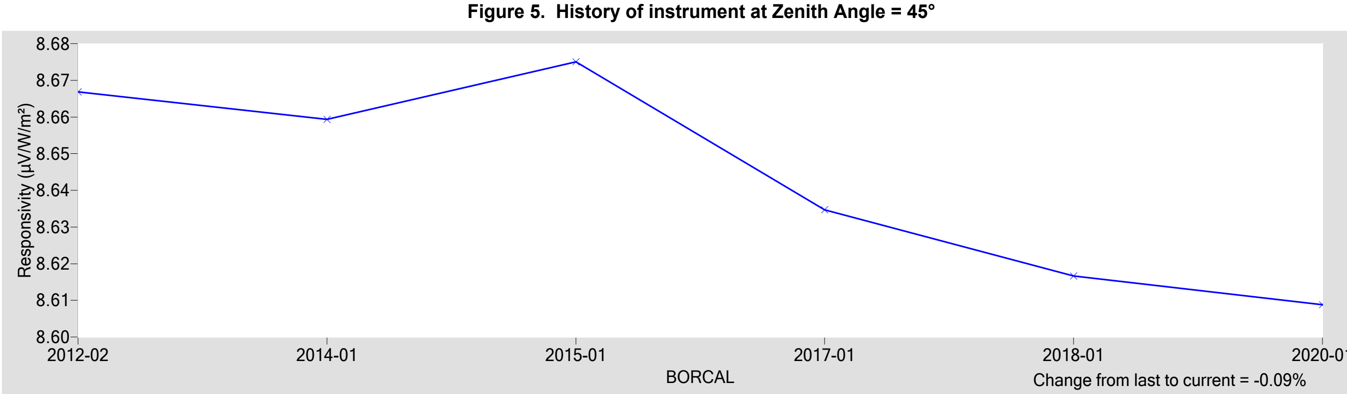
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6088	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.47 / -0.23
Expanded Uncertainty, U (%)	+1.1 / -0.82
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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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:

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

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

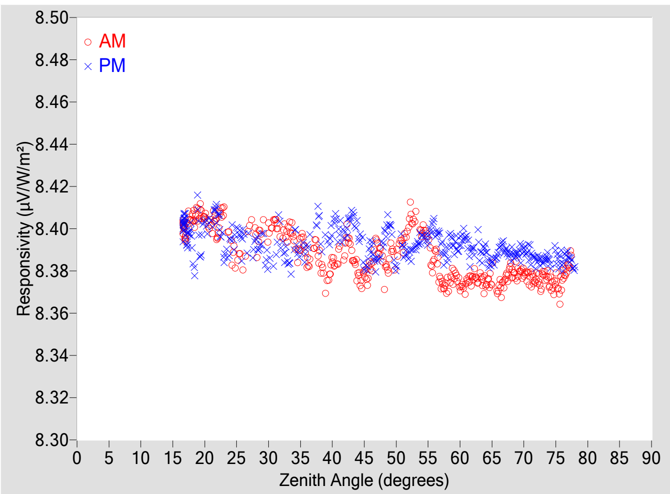


Figure 2. Responsivity vs Local Standard Time

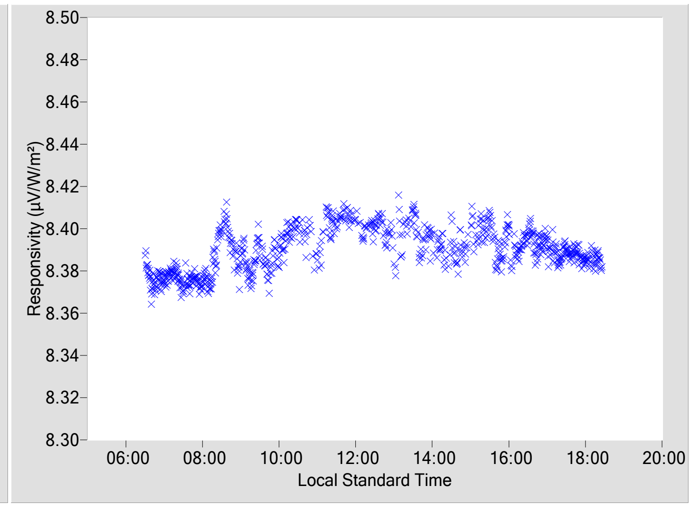


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3823	0.29	97.28	8.3919	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3812	0.29	95.51	8.3957	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3859	0.29	93.88	8.3816	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4041	0.29	92.35	8.3874	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3990	0.29	90.83	8.3962	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3873	0.30	89.32	8.4009	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3727	0.30	87.88	8.3894	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3732	0.30	86.42	8.3929	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3769	0.30	85.02	8.3900	0.29	275.04
18	8.4052	0.28	155.08	8.3947	0.28	204.18	64	8.3733	0.30	83.65	8.3902	0.30	276.48
20	8.4057	0.28	143.00	8.4026	0.28	217.45	66	8.3719	0.30	82.26	8.3889	0.30	277.84
22	8.3991	0.28	134.77	8.4075	0.28	225.40	68	8.3802	0.30	80.88	8.3881	0.30	279.25
24	8.3919	0.29	128.29	8.3948	0.28	231.62	70	8.3786	N/A	79.51	8.3895	0.30	280.64
26	8.3805	0.29	123.59	8.3945	0.28	236.36	72	8.3757	N/A	78.10	8.3849	N/A	281.96
28	8.3946	0.29	119.34	8.3939	0.28	240.85	74	8.3759	N/A	76.77	8.3848	N/A	283.36
30	8.3981	0.29	115.82	8.3856	0.28	244.14	76	8.3761	N/A	75.32	8.3839	N/A	284.77
32	8.3958	0.29	112.65	8.3962	0.28	247.35	78	N/A	N/A	N/A	8.3812	N/A	286.10
34	8.3946	0.29	109.96	8.3963	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3848	0.29	107.35	8.3905	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3848	0.29	105.10	8.4038	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3844	0.29	102.88	8.4010	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3927	0.29	100.86	8.3981	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3794	0.29	99.04	8.3983	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

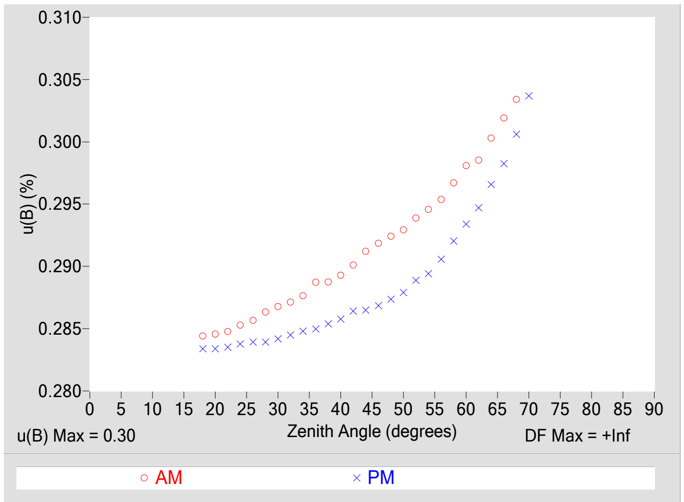


Figure 4. Residuals from Spline Interpolation

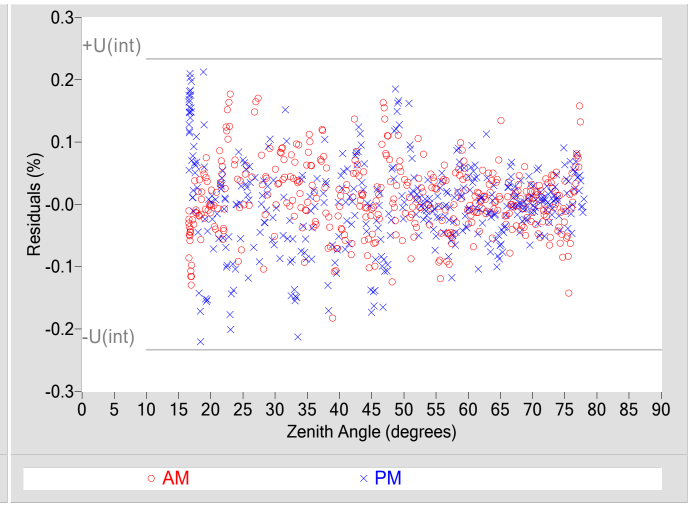


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.12
Combined Standard Uncertainty, u(c) (%)	±0.33
Effective degrees of freedom, DF(c)	43110
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.64
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

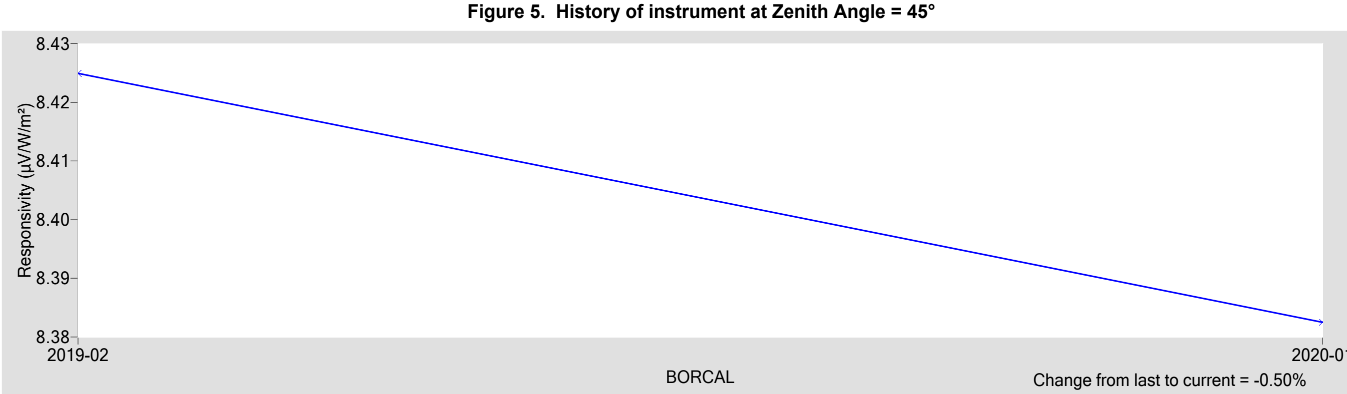
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3825	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.26 / -0.12
Expanded Uncertainty, U (%)	+0.84 / -0.70
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:**	37947E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

37947E6 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

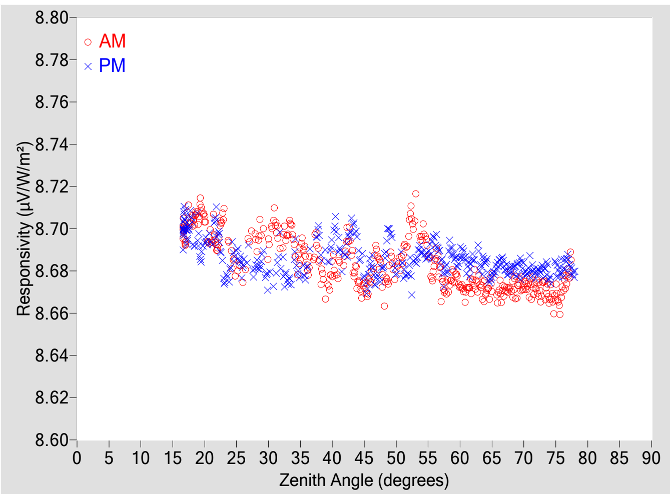


Figure 2. Responsivity vs Local Standard Time

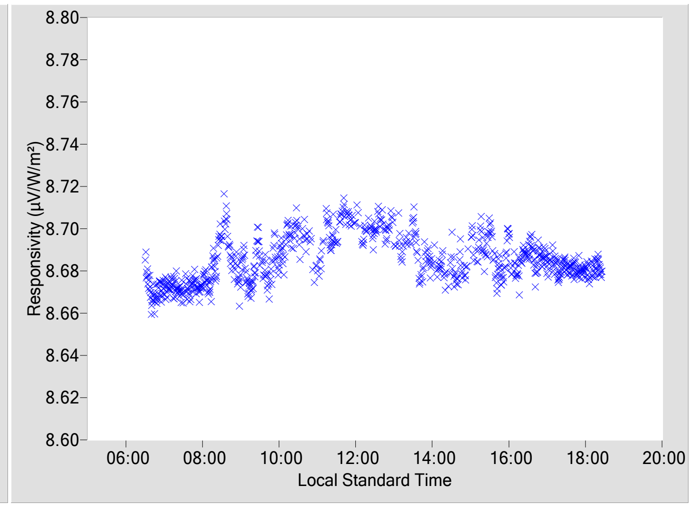


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6762	0.29	97.28	8.6839	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6722	0.29	95.51	8.6845	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6809	0.29	93.88	8.6794	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6998	0.29	92.35	8.6807	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6968	0.29	90.83	8.6895	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6832	0.30	89.32	8.6954	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6724	0.30	87.88	8.6826	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6729	0.30	86.42	8.6869	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6749	0.30	85.02	8.6854	0.29	275.04
18	8.7035	0.28	155.08	8.7030	0.28	204.18	64	8.6701	0.30	83.65	8.6845	0.30	276.48
20	8.7052	0.28	143.00	8.6938	0.28	217.45	66	8.6699	0.30	82.26	8.6836	0.30	277.84
22	8.6921	0.28	134.77	8.7009	0.28	225.40	68	8.6727	0.30	80.88	8.6814	0.30	279.25
24	8.6881	0.29	128.29	8.6828	0.28	231.62	70	8.6723	N/A	79.51	8.6803	0.30	280.64
26	8.6746	0.29	123.59	8.6821	0.28	236.36	72	8.6712	N/A	78.10	8.6789	N/A	281.96
28	8.6939	0.29	119.34	8.6825	0.28	240.85	74	8.6693	N/A	76.77	8.6772	N/A	283.36
30	8.6911	0.29	115.82	8.6765	0.28	244.14	76	8.6716	N/A	75.32	8.6804	N/A	284.77
32	8.6907	0.29	112.65	8.6886	0.28	247.35	78	N/A	N/A	N/A	8.6788	N/A	286.10
34	8.6928	0.29	109.96	8.6898	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6820	0.29	107.35	8.6799	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6834	0.29	105.10	8.6963	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6816	0.29	102.88	8.6951	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6907	0.29	100.86	8.6894	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6757	0.29	99.04	8.6924	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

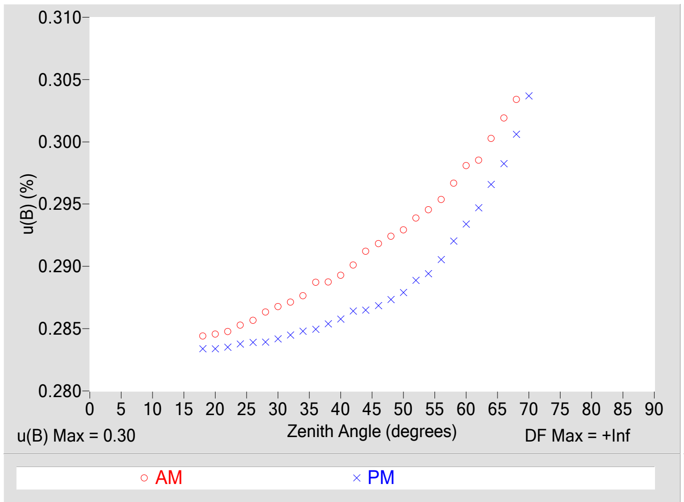


Figure 4. Residuals from Spline Interpolation

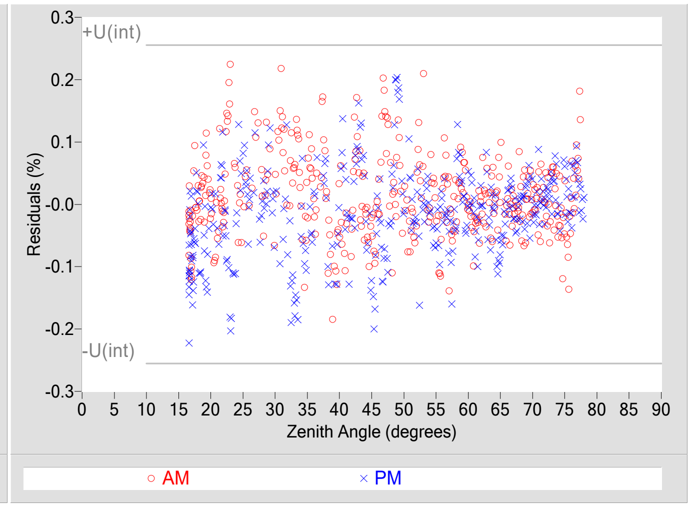


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.33
Effective degrees of freedom, DF(c)	31520
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.65
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

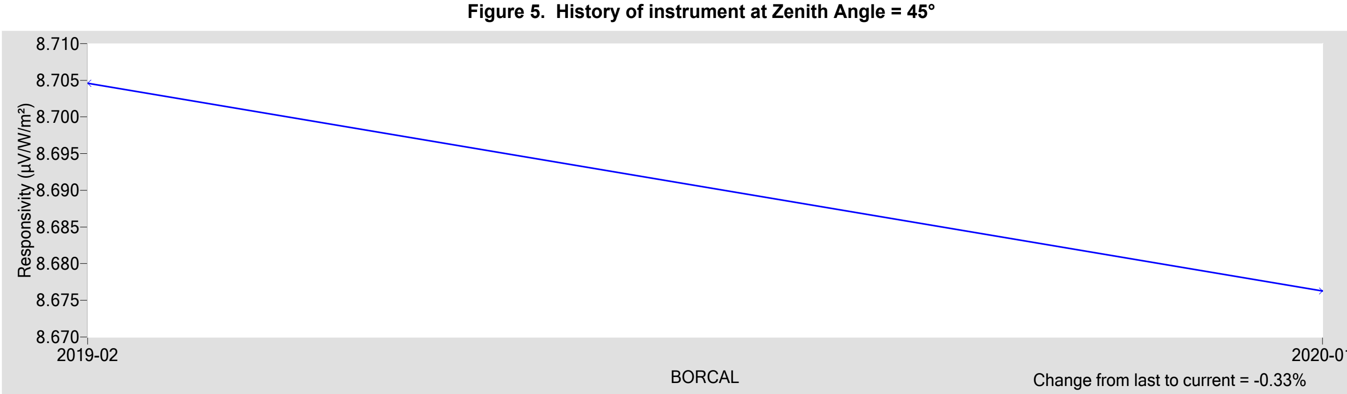
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6763	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.27 / -0.047
Expanded Uncertainty, U (%)	+0.86 / -0.63
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:**	37959E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

37959E6 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

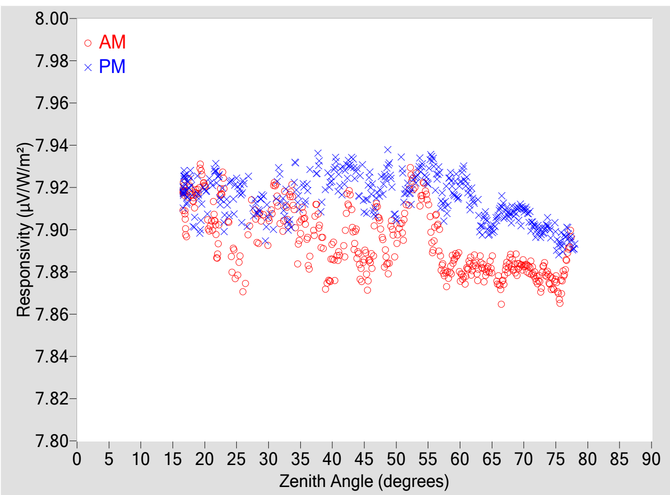


Figure 2. Responsivity vs Local Standard Time

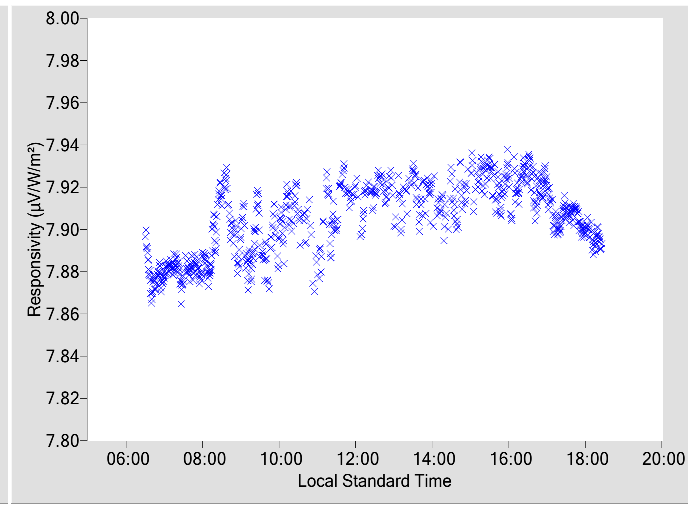


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8852	0.29	97.28	7.9221	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8911	0.29	95.51	7.9224	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8927	0.29	93.88	7.9056	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9201	0.29	92.28	7.9177	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9161	0.29	90.83	7.9306	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8982	0.30	89.32	7.9272	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8774	0.30	87.88	7.9155	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8805	0.30	86.42	7.9217	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8827	0.30	85.02	7.9154	0.29	275.04
18	7.9159	0.28	155.08	7.9182	0.28	204.18	64	7.8793	0.30	83.65	7.9061	0.30	276.48
20	7.9212	0.28	143.00	7.9190	0.28	217.45	66	7.8751	0.30	82.26	7.9073	0.30	277.84
22	7.8939	0.28	134.77	7.9263	0.28	225.40	68	7.8847	0.30	80.88	7.9075	0.30	279.25
24	7.8902	0.29	128.29	7.9188	0.28	231.62	70	7.8830	N/A	79.51	7.9096	0.30	280.64
26	7.8707	0.29	123.59	7.9164	0.28	236.36	72	7.8761	N/A	78.10	7.8995	N/A	281.96
28	7.9028	0.29	119.34	7.9107	0.28	240.85	74	7.8772	N/A	76.77	7.9007	N/A	283.36
30	7.9008	0.29	115.82	7.9084	0.28	244.14	76	7.8760	N/A	75.32	7.8934	N/A	284.77
32	7.9011	0.29	112.65	7.9180	0.28	247.35	78	N/A	N/A	N/A	7.8917	N/A	286.10
34	7.9094	0.29	109.96	7.9287	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8944	0.29	107.35	7.9179	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9005	0.29	105.10	7.9269	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8890	0.29	102.88	7.9255	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9008	0.29	100.86	7.9268	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8897	0.29	99.04	7.9221	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

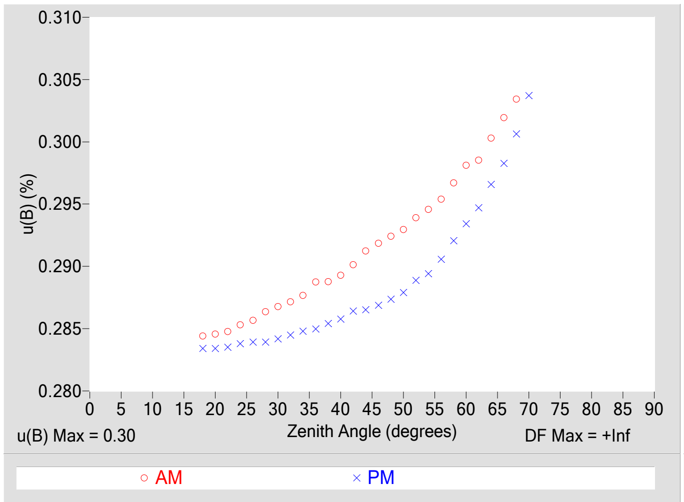


Figure 4. Residuals from Spline Interpolation

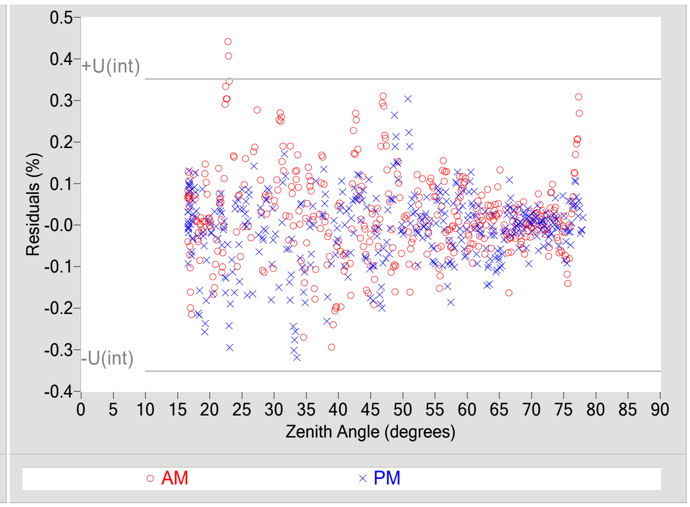


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	11302
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

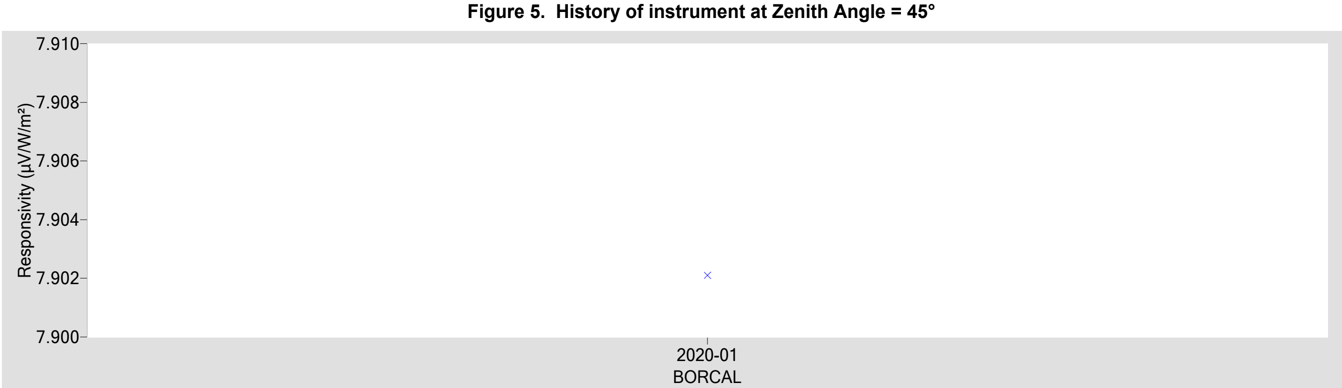
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9021	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.36 / -0.31
Expanded Uncertainty, U (%)	+0.94 / -0.90
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:**	37961E6
Calibration Date:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021

† 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

37961E6 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),
= $Win - Wout$ = $Win - \sigma * Tc^4$
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

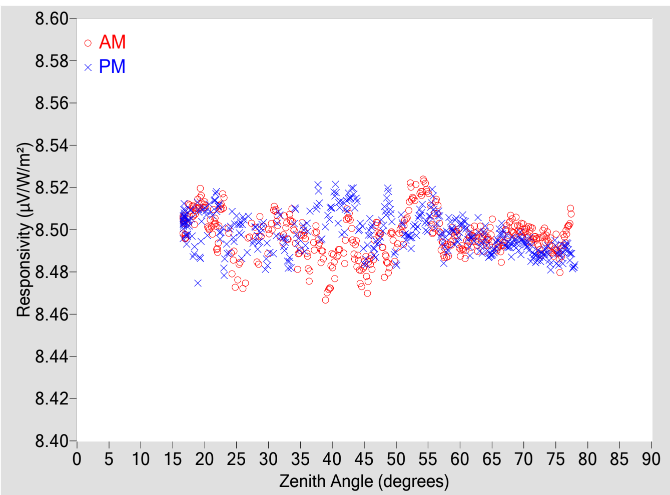


Figure 2. Responsivity vs Local Standard Time

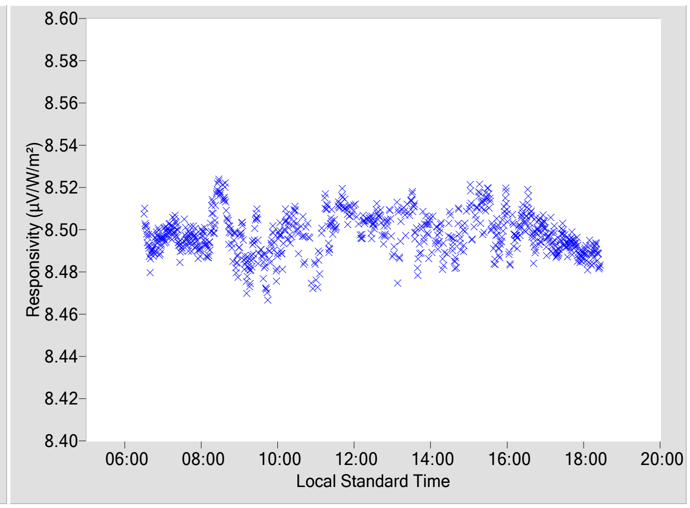


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4847	0.29	97.28	8.5012	0.29	262.84
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4871	0.29	95.51	8.5053	0.29	264.62
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4899	0.29	93.88	8.4855	0.29	266.13
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5125	0.29	92.35	8.4958	0.29	267.80
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5187	0.29	90.83	8.5091	0.29	269.21
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5051	0.30	89.32	8.5086	0.29	270.80
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4898	0.30	87.88	8.4962	0.29	272.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4924	0.30	86.42	8.5005	0.29	273.68
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4969	0.30	85.02	8.4961	0.29	275.04
18	8.5086	0.28	155.08	8.5016	0.28	204.18	64	8.4939	0.30	83.65	8.4968	0.30	276.48
20	8.5115	0.28	143.00	8.5089	0.28	217.45	66	8.4922	0.30	82.26	8.4961	0.30	277.84
22	8.4959	0.28	134.77	8.5130	0.28	225.40	68	8.5029	0.30	80.88	8.4925	0.30	279.25
24	8.4888	0.29	128.29	8.4999	0.28	231.62	70	8.4994	N/A	79.51	8.4940	0.30	280.64
26	8.4722	0.29	123.59	8.4994	0.28	236.36	72	8.4947	N/A	78.10	8.4873	N/A	281.96
28	8.4942	0.29	119.34	8.4977	0.28	240.85	74	8.4944	N/A	76.77	8.4863	N/A	283.36
30	8.4956	0.29	115.82	8.4887	0.28	244.14	76	8.4922	N/A	75.32	8.4883	N/A	284.77
32	8.4952	0.29	112.65	8.4999	0.28	247.35	78	N/A	N/A	N/A	8.4826	N/A	286.10
34	8.4993	0.29	109.96	8.5076	0.28	250.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4884	0.29	107.35	8.4983	0.28	252.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4915	0.29	105.10	8.5118	0.29	254.93	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4853	0.29	102.88	8.5129	0.29	257.13	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4965	0.29	100.86	8.5074	0.29	259.21	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4863	0.29	99.04	8.5070	0.29	261.03	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

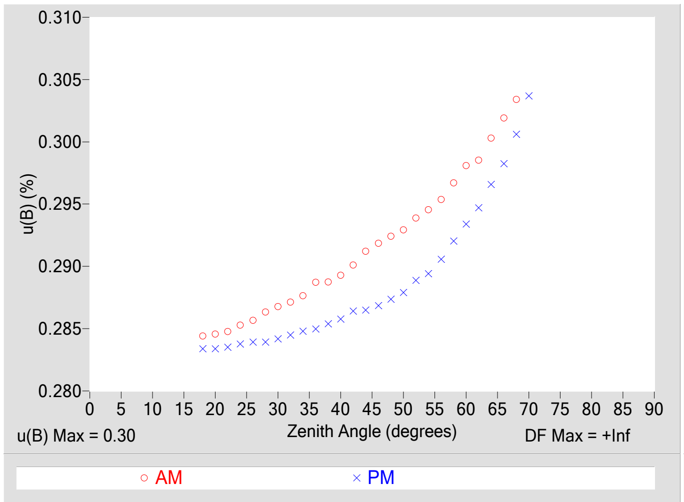


Figure 4. Residuals from Spline Interpolation

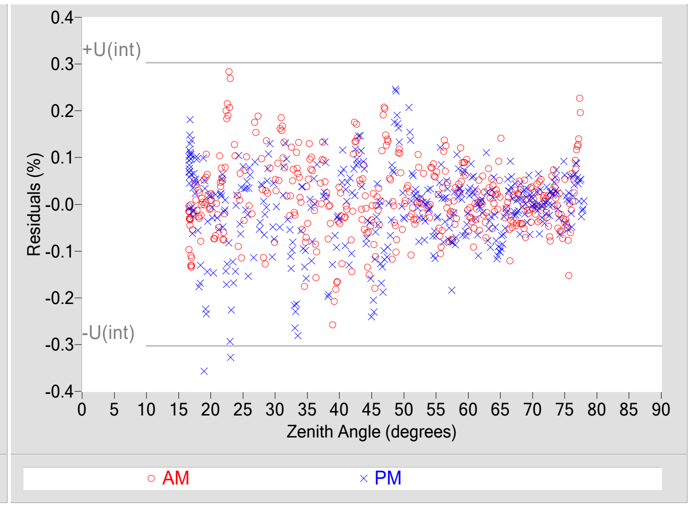


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.30
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.34
Effective degrees of freedom, DF(c)	17911
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.67
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

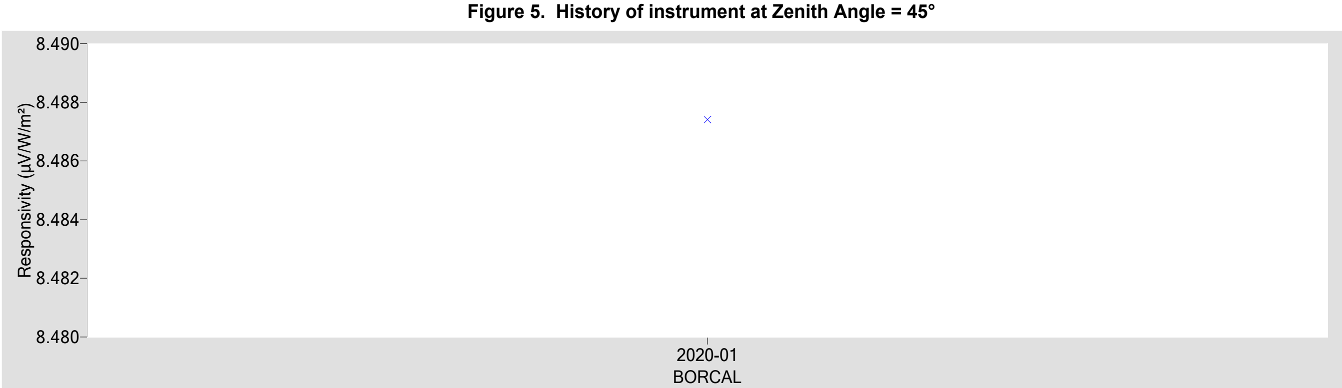
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4874	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.58
Offset Uncertainty, U(off) (%)	+0.37 / -0.032
Expanded Uncertainty, U (%)	+0.95 / -0.62
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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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

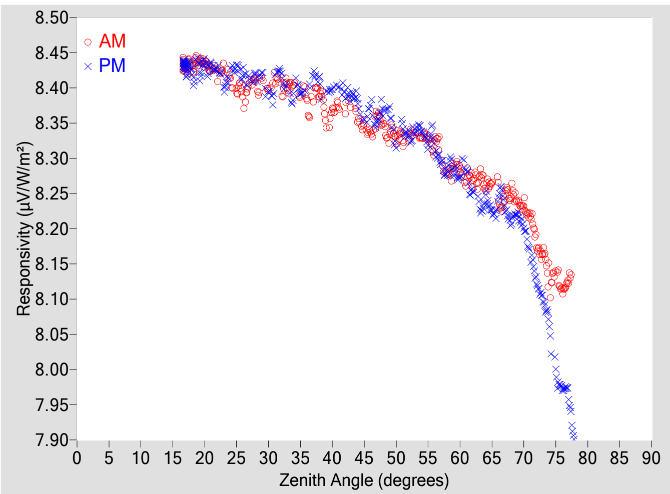


Figure 2. Responsivity vs Local Standard Time

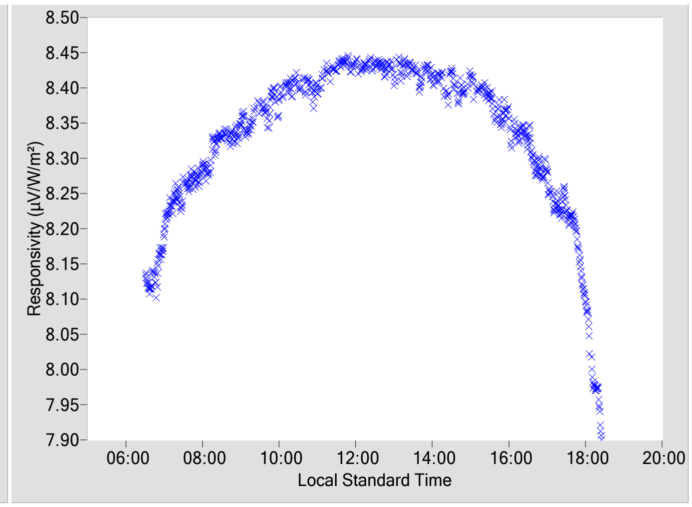


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.3358	0.32	97.20	8.3723	0.31	262.87
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3478	0.32	95.51	8.3665	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3277	0.32	93.94	8.3193	0.31	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3309	0.33	92.28	8.3325	0.32	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3298	0.33	90.81	8.3401	0.32	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3186	0.34	89.30	8.3151	0.33	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2783	0.35	87.82	8.2828	0.34	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2821	0.36	86.44	8.2732	0.35	273.65
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2694	0.36	85.05	8.2537	0.36	275.02
18	8.4292	0.29	154.61	8.4205	0.29	204.76	64	8.2591	0.38	83.67	8.2417	0.37	276.46
20	8.4365	0.29	142.92	8.4363	0.29	216.89	66	8.2530	0.39	82.24	8.2438	0.38	277.86
22	8.4092	0.29	134.55	8.4258	0.29	225.88	68	8.2493	0.41	80.86	8.2096	0.40	279.23
24	8.4116	0.29	128.43	8.4281	0.29	231.71	70	8.2323	N/A	79.53	8.2028	0.43	280.58
26	8.3843	0.29	123.66	8.4180	0.29	236.43	72	8.1785	N/A	78.13	8.1232	N/A	281.99
28	8.4069	0.30	119.47	8.4172	0.29	240.64	74	8.1235	N/A	76.71	8.0568	N/A	283.39
30	8.3984	0.30	116.05	8.3955	0.29	244.44	76	8.1133	N/A	75.35	7.9732	N/A	284.79
32	8.3877	0.30	112.44	8.4182	0.29	247.39	78	N/A	N/A	N/A	7.9036	N/A	286.08
34	8.4041	0.30	110.03	8.3962	0.29	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3841	0.30	107.42	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3923	0.30	105.10	8.4058	0.30	255.01	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3680	0.31	102.85	8.3992	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3712	0.31	100.84	8.3901	0.30	259.24	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3565	0.31	99.04	8.3820	0.30	261.01	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

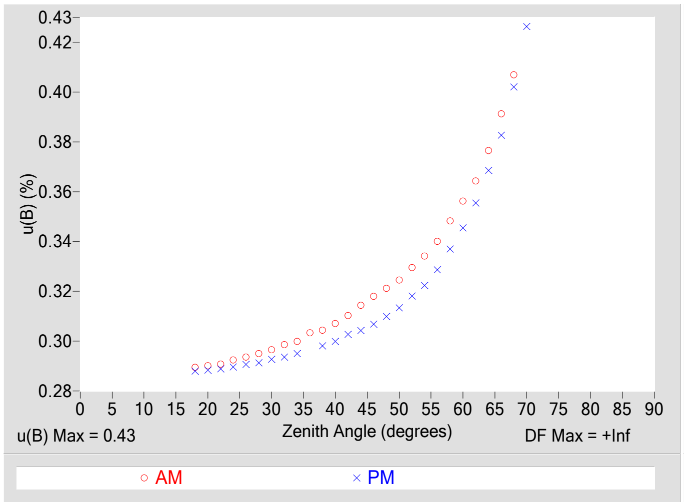


Figure 4. Residuals from Spline Interpolation

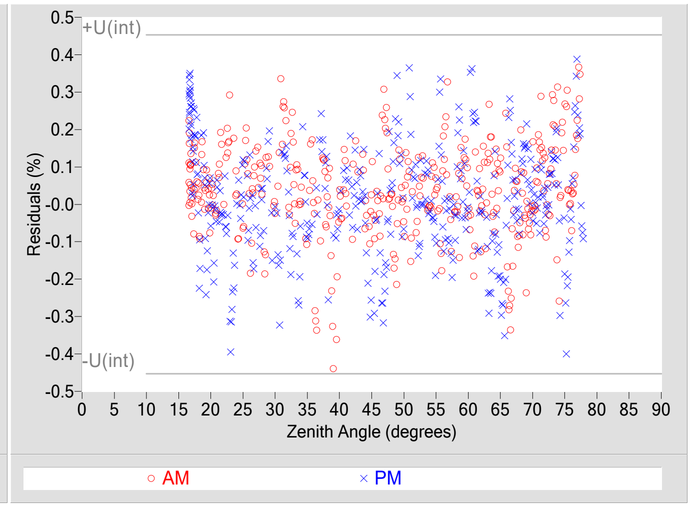


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.48
Effective degrees of freedom, DF(c)	14454
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.95
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

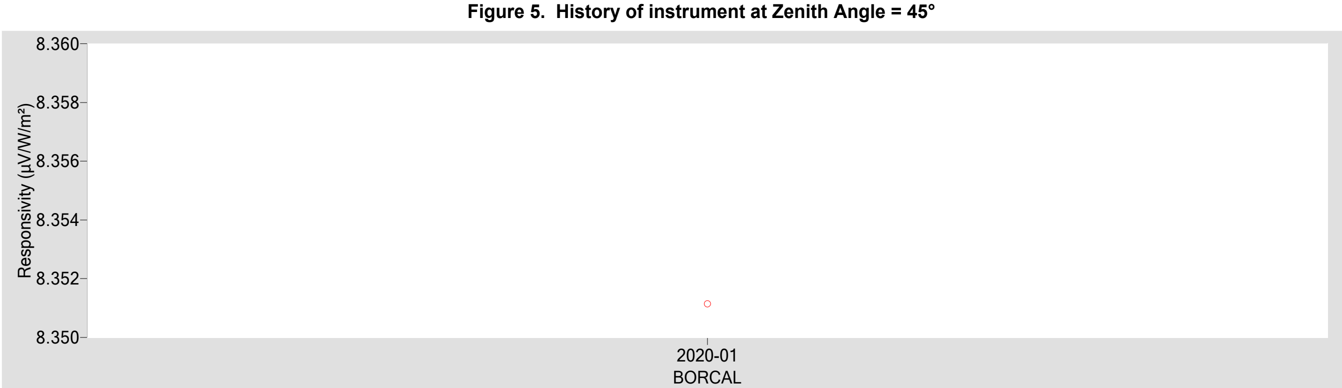
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3511	0.22000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.70
Offset Uncertainty, U(off) (%)	+0.80 / -0.93
Expanded Uncertainty, U (%)	+1.5 / -1.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/19/2020	**Due Date:**	5/19/2021
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	5/19		

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	09/23/2020
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	09/23/2019	09/23/2020
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	05/03/2019	05/03/2021
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	05/03/2019	05/03/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	05/14/2020	05/14/2021
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	05/14/2020	05/14/2021
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/02/2019	04/02/2021

† 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:

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

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

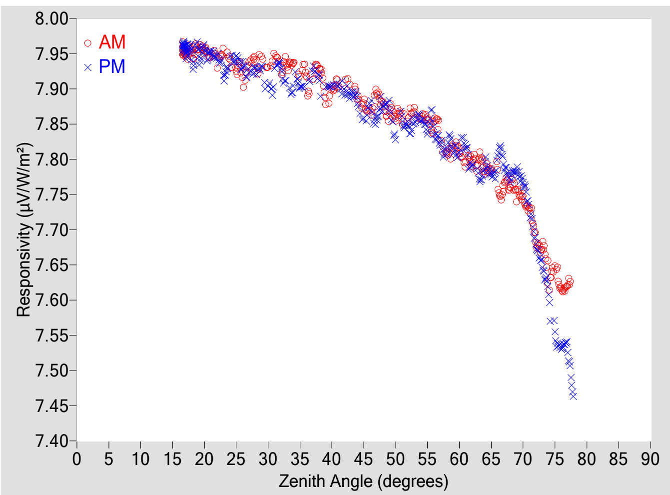


Figure 2. Responsivity vs Local Standard Time

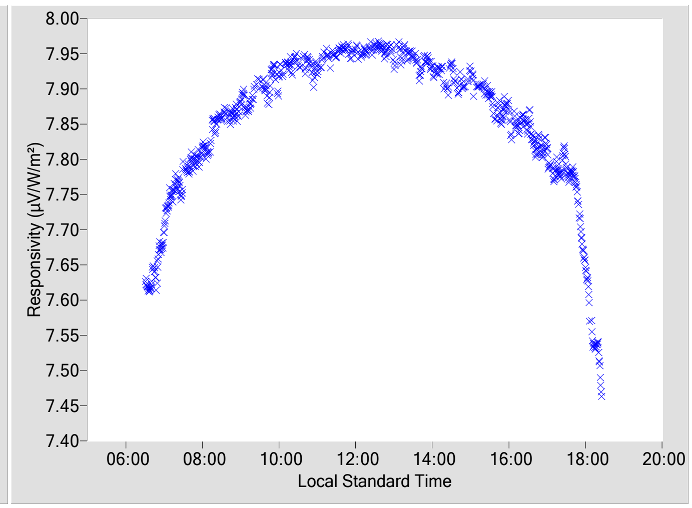


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8682	0.32	97.20	7.8756	0.31	262.87
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8797	0.32	95.51	7.8743	0.31	264.54
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8603	0.32	93.94	7.8324	0.31	266.05
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8621	0.33	92.28	7.8468	0.32	267.73
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8592	0.33	90.81	7.8572	0.32	269.27
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8482	0.34	89.30	7.8408	0.33	270.78
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8084	0.35	87.82	7.8150	0.34	272.23
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8108	0.36	86.44	7.8087	0.35	273.65
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7968	0.36	85.05	7.7920	0.36	275.02
18	7.9498	0.29	154.61	7.9454	0.29	204.76	64	7.7845	0.38	83.67	7.7911	0.37	276.46
20	7.9564	0.29	142.92	7.9578	0.29	216.89	66	7.7729	0.39	82.24	7.8027	0.38	277.86
22	7.9295	0.29	134.55	7.9449	0.29	225.88	68	7.7653	0.41	80.86	7.7724	0.40	279.23
24	7.9406	0.29	128.43	7.9463	0.29	231.71	70	7.7471	N/A	79.53	7.7680	0.43	280.58
26	7.9137	0.29	123.66	7.9315	0.29	236.43	72	7.6854	N/A	78.13	7.6797	N/A	281.99
28	7.9394	0.30	119.47	7.9279	0.29	240.64	74	7.6316	N/A	76.71	7.6042	N/A	283.39
30	7.9305	0.30	116.05	7.9061	0.29	244.44	76	7.6154	N/A	75.35	7.5331	N/A	284.79
32	7.9218	0.30	112.44	7.9283	0.29	247.39	78	N/A	N/A	N/A	7.4665	N/A	286.08
34	7.9360	0.30	110.03	7.9078	0.30	250.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9168	0.30	107.42	N/A	N/A	N/A	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9259	0.30	105.10	7.9113	0.30	255.01	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9003	0.31	102.85	7.9047	0.30	257.12	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9068	0.31	100.84	7.8956	0.30	259.24	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8901	0.31	99.04	7.8847	0.30	261.01	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

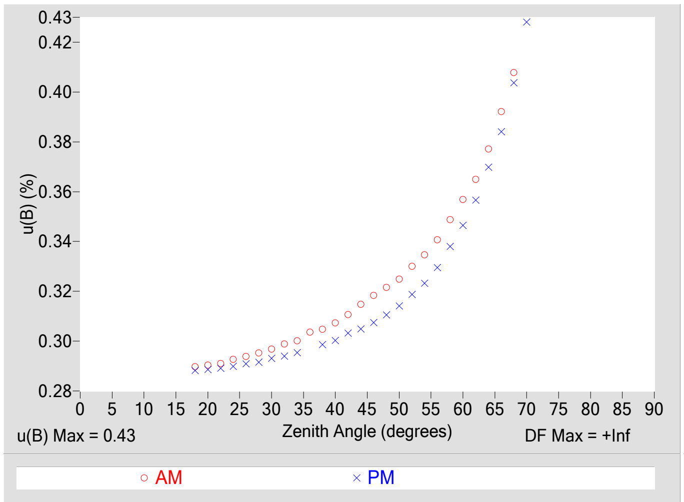


Figure 4. Residuals from Spline Interpolation

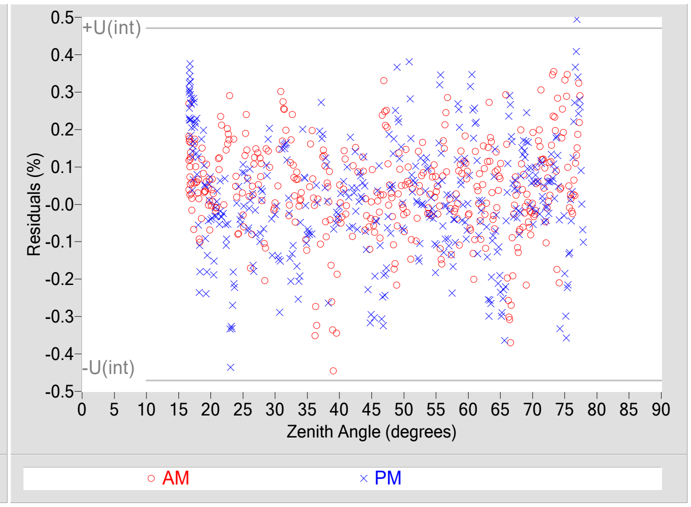


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.43
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.49
Effective degrees of freedom, DF(c)	12979
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.96
AM Valid zenith angle range	18° to 68°
PM Valid zenith angle range	18° to 70°

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

Table 4. Calibration Label Values

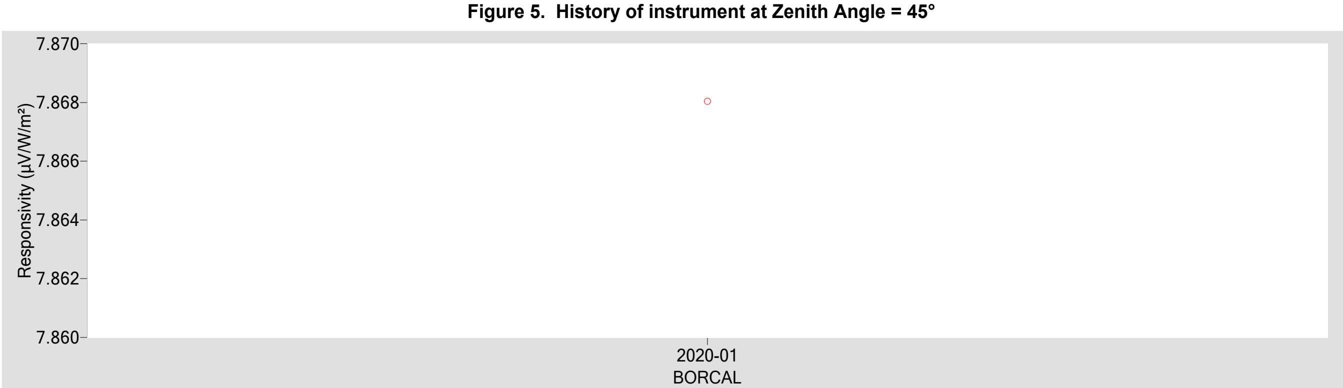
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8680	0.22000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.70
Offset Uncertainty, U(off) (%)	+0.86 / -0.76
Expanded Uncertainty, U (%)	+1.6 / -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).

Environmental and Sky Conditions for BORCAL-SW 2020-01

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

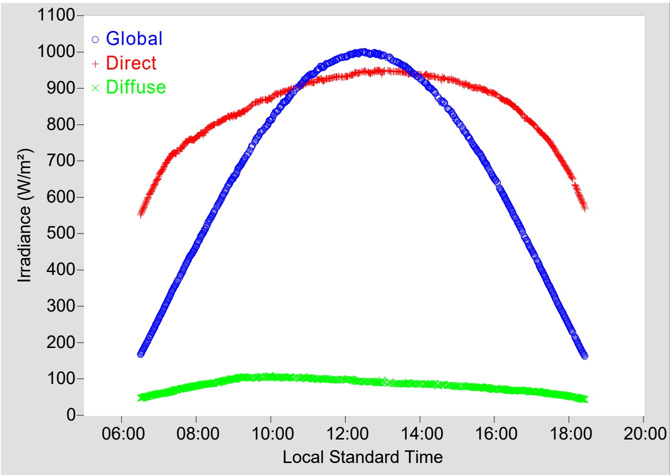
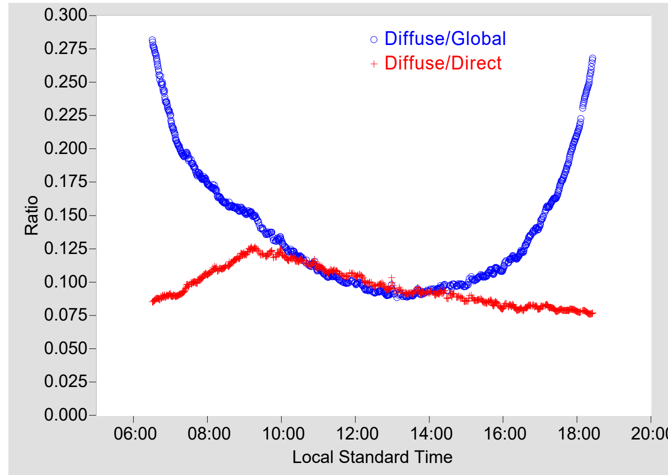


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

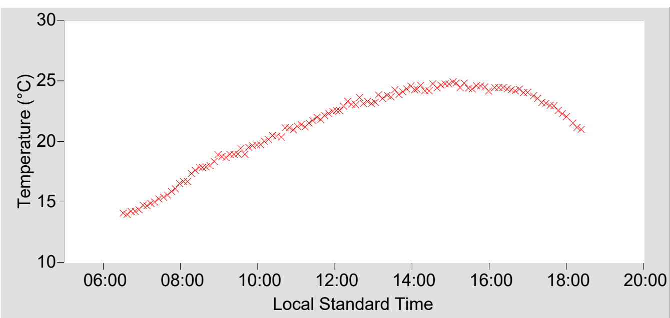


Figure 9. Humidity

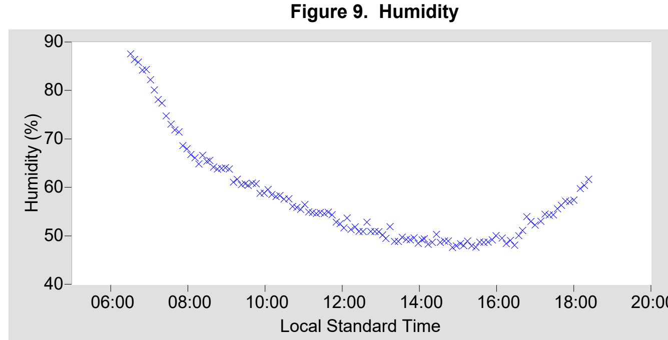


Figure 10. Pressure

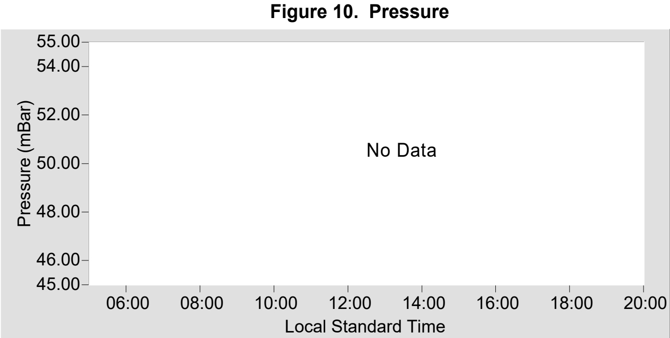


Figure 11. Effective Net Infrared

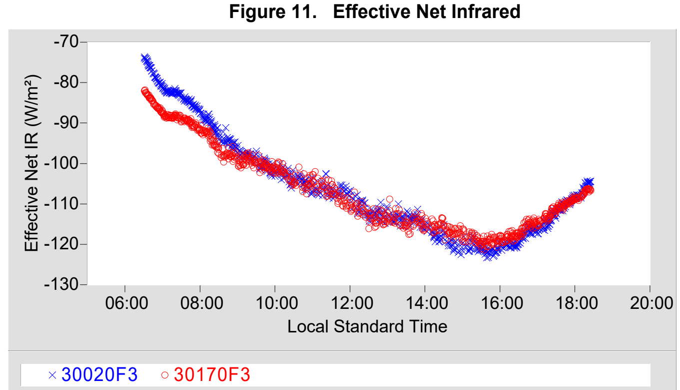


Figure 12. Estimated Broadband Aerosol Optical Depth

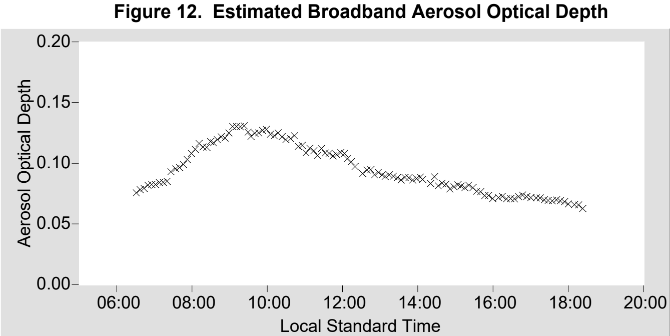


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	21.26	13.95	24.93
Humidity (%)	57.52	47.57	87.57
Pressure (mBar)	N/A	N/A	N/A
Est. Aerosol Optical Depth (BB)	0.095	0.063	0.131

For other information about the calibration facility visit: http://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).

29738E6 Eppley NIP
Comments:
Sent back to Eppley for repair and the old cal factor was 7.72 uV/W/m^2 new one is 8.26uV/W/m^2. (First BORCAL after repair: 2001-02)

29914F3 Eppley PSP
Comments:
IAW with sticker on radiometer factory cali should be 8.97, I don't have a cali sheet with this instrument came in from TWP. C Webb.

Eppley issued new calibration certificate (repaired?) in May of 2004. Previous cal was 8.27 (Oct 1997 and Nov 1993). New cal is 8.97.
S. Wilcox

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

---

30895F3 Eppley PSP
Comments:
Factory cal was 9.040 but the cal sheet from Eppley Inc. was 9.050.

30938F3 Eppley PSP
Comments:
Sent to Eppley for repair. Old Factory cal was 8.23, new factory cal is 8..44. First BORCAL after repair is 2001-01.

31388E6 Eppley NIP
Comments:
Instrument repaired June 2011. New factory cal of 7.895 assigned. Old cal 8.73.

33242 Eppley 8-48
Comments:
Old cal factory was 8.340, Eppley recalibrated on Nov 4,2002 due to paint lefting off the sensor surface. new cal factoris 9.20.

Appendix 3
Session Configuration Audit Report

Latest Session Configuration Audit Report for the BORCAL

BORCAL 2020-01 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
+	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: PY22692 Licor LI200	60		2	2
ASR 2: None				

METEOROLOGICAL INSTRUMENTS

	Channel	Junction Box	Cable	Location	Scale	Offset
Temperature: E0710025T Vaisala HMP155 T	239		AT	AT	100	-40
Humidity: E0710025H 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 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	2009-1206 NREL RAP-DAQ	MY42002863 Agilent 34420A

	Unit 1	Unit 2	Unit 3	Unit 0
Cal Date	05/14/2020	05/14/2020	05/14/2020	05/14/2020
Cal Due Date	05/14/2021	05/14/2021	05/14/2021	05/14/2021
System Offsets: Volts DC (µV)	0.34	0.34	0.34	0.34
2-Wire Res. (mOhms)	2672.00	2672.00	2672.00	2672.00
4-Wire Res. (mOhms)	0.00	0.00	0.00	0.00

Communications

	Unit	Type	Addr.	Board	Parity	Stop	Data
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
DMM	0	GPIB	21	0	0	0	0
Relay	0	GPIB	24	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	09/23/2020	09/23/2020

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	✔	✔

	Unit 1	Unit 2
Cavity Head	29222 Eppley HF	30495 Eppley HF
Control Unit	US37037985 NREL Reda	US37037994 NREL Reda
Digital Multi Meter	US37037985 Hewlett Packard 34970A	US37037994 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	09/04/2019	09/04/2019
Cal Due Date	09/04/2020	09/04/2020

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 2020-01 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: 2550 Hukseflux SR25-T2	8.722	05/03/2019	05/03/2021	6.2	70.0	5.1	1.20	0.0	50	177		T4	T4	☐	✓
Diffuse 1: Case NONE Temperature										n/a	n/a	n/a			
Diffuse 1: Dome NONE Temperature										n/a	n/a	n/a			
Diffuse 2: 2549 Hukseflux SR25-T2	9.094	05/03/2019	05/03/2021	6.2	70.0	5.1	1.30	0.0	50	176		T3	T3	☐	✓
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: 30170F3 Eppley PIR	04/02/2019	04/02/2021	-5.30000	0.23381	0.99290	-3.79000	7.04400E-4	2.70	9	208		30	30	✓
Pyrgeometer 1: Case 10K Temperature										216		30		
Pyrgeometer 1: Dome 10K Temperature										224		30		
Pyrgeometer 2: 30020F3 Eppley PIR-V (Ventilated)	04/02/2019	04/02/2021	-1.90000	0.24287	1.00440	-3.99000	7.04400E-4	2.80	9	146		74	83	✓
Pyrgeometer 2: Case 10K Temperature										154		74		
Pyrgeometer 2: Dome 10K Temperature										34		54		

BORCAL 2020-01 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	Global	50	Eppley 8-48	Eppley 8-48	none	9
3	Direct	50	Eppley NIP	Eppley NIP	none	10
4	Direct	50	Eppley NIP	Eppley NIP	none	10
5	Direct	50	Eppley NIP	Eppley NIP	none	5
			Eppley sNIP			4
6	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
7	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
8	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	7
			Eppley SPP			2
9	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	10
10	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	10
11	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	10
12	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	3
Total						110

BORCAL 2020-01 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
16256F3 ©	PSP	TWP	6	1	133		51	No	Yes	Yes	TOT	51	12
17933F3 ©	PSP	TWP	6	2	125		48	No	Yes	Yes	TOT	48	12
17934F3 ©	PSP	Nels Laulainen	6	3	124		47	No	Yes	Yes	TOT	47	12
18289F3 ©	PSP	Nels Laulainen	9	1	0		4	No	Yes	No	TOT	4	12
18350E6	NIP	TWP	3	1	254		T36	No	Yes	No	DIR	T36	12
27973F3 ©	PSP	TWP	9	2	61		3	No	Yes	No	TOT	3	12
29554E6	NIP	SGP	3	2	242		T29	No	Yes	No	DIR	T29	12
29608F3 ©	PSP	SGP	9	3	9		8	No	Yes	No	TOT	8	12
29612F3 ©	PSP	SGP	9	4	10		9	No	Yes	No	TOT	9	12
29618F3 ©	PSP	SGP	9	5	16		16	No	Yes	No	TOT	16	12
29738E6	NIP	SGP	3	3	244		T18	No	Yes	No	DIR	T18	12
29743E6	NIP	SGP	3	4	194		T27	No	Yes	No	DIR	T27	12
29848E6	NIP	SGP	3	5	250		T31	No	Yes	No	DIR	T31	12
29856E6	NIP	SGP	3	6	210		T32	No	Yes	No	DIR	T32	12
29913F3 ©	PSP	TWP	9	6	109		33	No	Yes	No	TOT	33	12
29914F3 ©	PSP	TWP	6	4	164		76	No	Yes	Yes	TOT	76	12
29916F3 ©	PSP	TWP	6	5	165		77	No	Yes	Yes	TOT	77	12
29937E6	NIP	TWP	3	7	209		T28	No	Yes	No	DIR	T28	12
29939E6	NIP	SGP	3	8	236		T17	No	Yes	No	DIR	T17	12
30614F3 ©	PSP	SGP	9	7	17		17	No	Yes	No	TOT	17	12
30620F3 ©	PSP	SGP	9	8	12		25	No	Yes	No	TOT	25	12
30663F3 ©	PSP	SGP	9	9	13		26	No	Yes	No	TOT	26	12
30666F3 ©	PSP	SGP	6	6	117		41	No	Yes	Yes	TOT	41	12
30667F3 ©	PSP	SGP	9	10	65		13	No	Yes	No	TOT	13	12
30673F3 ©	PSP	SGP	10	1	96		31	No	Yes	No	TOT	31	12
30674F3 ©	PSP	SGP	10	2	92		20	No	Yes	No	TOT	20	12
30720E6	NIP	SGP	3	9	241		T21	No	Yes	No	DIR	T21	12
30722E6	NIP	SGP	3	10	238		T25	No	Yes	No	DIR	T25	12
30797F3 ©	PSP	SGP	10	3	14		27	No	Yes	No	TOT	27	12
30802F3 ©	PSP	SGP	-	-	1		5	No	Yes	No	TOT	5	12
30811F3 ©	PSP	SGP	6	7	116		40	No	Yes	Yes	TOT	40	12
30825F3 ©	PSP	SGP	6	8	149		67	No	Yes	Yes	TOT	67	12
30890F3 ©	PSP	SGP	6	9	118		42	No	Yes	Yes	TOT	42	12
30895F3 ©	PSP	SGP	10	4	66		14	No	Yes	No	TOT	14	12
30897F3 ©	PSP	SGP	10	5	78		15	No	Yes	No	TOT	15	12
30899F3 ©	PSP	SGP	6	10	144		65	No	Yes	Yes	TOT	65	12
30902F3 ©	PSP	SGP	10	6	97		32	No	Yes	No	TOT	32	12
30929F3 ©	PSP	SGP	7	1	110		38	No	Yes	Yes	TOT	38	12
30938F3 ©	PSP	SGP	7	2	156		66	No	Yes	Yes	TOT	66	12
30939F3 ©	PSP	SGP	10	7	5		23	No	Yes	No	TOT	23	12
30946F3 ©	PSP	SGP	7	3	108		39	No	Yes	Yes	TOT	39	12
30951F3 ©	PSP	SGP	10	8	2		6	No	Yes	No	TOT	6	12
30954F3 ©	PSP	SGP	10	9	4		22	No	Yes	No	TOT	22	12
30958F3 ©	PSP	SGP	10	10	93		21	No	Yes	No	TOT	21	12
31097F3 ©	PSP	SGP	11	1	18		18	No	Yes	No	TOT	18	12
31099F3 ‡©	PSP	Calibration System	7	4	130		64	No	Yes	Yes	TOT	64	12
		(Case 10K Temperature)			138		64						
31100F3 ‡©	PSP	Calibration System	7	5	145		73	No	Yes	Yes	TOT	73	12
		(Case 10K Temperature)			153		73						

‡ Control Instrument © Effective Net IR Corrected Instrument

BORCAL 2020-01 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
31101F3 ‡©	PSP	Calibration System	7	6	160		82	No	Yes	Yes	TOT	82	12
		(Case 10K Temperature)			168		82						
31120E6 ‡	NIP	Calibration System	4	1	225		T7	No	Yes	No	DIR	T7	12
31121E6 ‡	NIP	Calibration System	4	2	245		T26	No	Yes	No	DIR	T26	12
31146F3 ‡©	PSP	Calibration System	7	7	98		37	No	Yes	Yes	TOT	37	12
		(Case 10K Temperature)			106		37						
31147F3 ‡©	PSP	Calibration System	7	8	112		46	No	Yes	Yes	TOT	46	12
		(Case 10K Temperature)			120		46						
31148F3 ‡©	PSP	Calibration System	7	9	113		55	No	Yes	Yes	TOT	55	12
		(Case 10K Temperature)			121		55						
31152F3 ‡©	PSP	Calibration System	11	2	80		19	No	Yes	No	TOT	19	12
		(Case 10K Temperature)			88		19						
31153F3 ‡©	PSP	Calibration System	11	3	81		28	No	Yes	No	TOT	28	12
		(Case 10K Temperature)			89		28						
31154F3 ‡©	PSP	Calibration System	11	4	82		29	No	Yes	No	TOT	29	12
		(Case 10K Temperature)			90		29						
31155F3 ‡©	PSP	Calibration System	11	5	48		1	No	Yes	No	TOT	1	12
		(Case 10K Temperature)			56		1						
31156F3 ‡©	PSP	Calibration System	11	6	49		10	No	Yes	No	TOT	10	12
		(Case 10K Temperature)			57		10						
31157F3 ‡©	PSP	Calibration System	11	7	50		11	No	Yes	No	TOT	11	12
		(Case 10K Temperature)			58		11						
31278F3 ©	PSP	TWP	11	8	64		12	No	Yes	No	TOT	12	12
31281F3 ©	PSP	TWP	7	10	158		75	No	Yes	Yes	TOT	75	12
31284F3 ©	PSP	TWP	11	9	20		34	No	Yes	No	TOT	34	12
31291F3 ©	PSP	TWP	11	10	21		35	No	Yes	No	TOT	35	12
31293F3 ©	PSP	TWP	8	1	166		78	No	Yes	Yes	TOT	78	12
31388E6	NIP	SGP	4	3	249		T30	No	Yes	No	DIR	T30	12
31631F3 ©	PSP	SGP	12	1	6		24	No	Yes	No	TOT	24	12
31827E6	NIP	TWP	4	4	212		T9	No	Yes	No	DIR	T9	12
31866E6	NIP	TWP	4	5	229		T8	No	Yes	No	DIR	T8	12
32015F3 ©	PSP	NSA	-	-	128		57	No	Yes	Yes	TOT	57	12
32016F3 ©	PSP	NSA	8	2	129		58	No	Yes	Yes	TOT	58	12
32017F3 ©	PSP	NSA	8	3	141		59	No	Yes	Yes	TOT	59	12
32018F3 ©	PSP	NSA	8	4	162		85	No	Yes	Yes	TOT	85	12
32039F3 ©	PSP	NSA	-	-	161		84	No	Yes	Yes	TOT	84	12
32882	8-48	TWP	1	1	36		79	No	Yes	Yes	TOT	79	12
32989F3 ©	PSP	TWP	8	5	126		49	No	Yes	Yes	TOT	49	12
32991F3 ©	PSP	TWP	-	-	132		50	No	Yes	Yes	TOT	50	12
33239	8-48	SGP	1	2	25		44	No	Yes	Yes	TOT	44	12
33242	8-48	SGP	1	3	28		70	No	Yes	Yes	TOT	70	12
33247	8-48	SGP	1	4	29		71	No	Yes	Yes	TOT	71	12
33259	8-48	NSA	1	5	40		61	No	Yes	Yes	TOT	61	12
33261	8-48	SGP	1	6	30		72	No	Yes	Yes	TOT	72	12
33271	8-48	TWP	1	7	32		52	No	Yes	Yes	TOT	52	12
33274	8-48	SGP	1	8	46		90	No	Yes	Yes	TOT	90	12
33277	8-48	SGP	1	9	45		89	No	Yes	Yes	TOT	89	12
33279	8-48	SGP	1	10	142		60	No	Yes	Yes	TOT	60	12
33374	8-48	TWP	2	1	37		80	No	Yes	Yes	TOT	80	12
33375	8-48	NSA	2	2	41		62	No	Yes	Yes	TOT	62	12

‡ Control Instrument

© Effective Net IR Corrected Instrument

BORCAL 2020-01 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
33551E6	NIP	TWP	4	6	222		T33	No	Yes	No	DIR	T33	12
33784	8-48	SGP	2	3	42		63	No	Yes	Yes	TOT	63	12
33785	8-48	SGP	2	4	26		45	No	Yes	Yes	TOT	45	12
33860E6	NIP	AMF	4	7	246		T34	No	Yes	No	DIR	T34	12
34066	8-48	AMF	2	5	38		81	No	Yes	Yes	TOT	81	12
34135E6	NIP	AMF	4	8	253		T35	No	Yes	No	DIR	T35	12
34281	8-48	TWP	2	6	33		53	No	Yes	Yes	TOT	53	12
34504E6	NIP	SGP	4	9	192		T13	No	Yes	No	DIR	T13	12
34505E6	NIP	SGP	4	10	234		T20	No	Yes	No	DIR	T20	12
34506E6	NIP	SGP	5	1	226		T15	No	Yes	No	DIR	T15	12
34580	8-48	SGP	2	7	24		43	No	Yes	Yes	TOT	43	12
35751	8-48	AMF#2	2	8	44		88	No	Yes	Yes	TOT	88	12
35804E6	NIP	AMF#2	5	2	213		T10	No	Yes	No	DIR	T10	12
35864	8-48	SGP	2	9	173		87	No	Yes	Yes	TOT	87	12
37285E6	NIP	AMF	5	3	214		T11	No	Yes	No	DIR	T11	12
37303F3 ©	PSP	AMF	12	2	8		7	No	Yes	No	TOT	7	12
37304F3 ©	PSP	NSA	8	6	174		86	No	Yes	Yes	TOT	86	12
37314F3 ©	PSP	NSA	8	7	114		56	No	Yes	Yes	TOT	56	12
37317F3 ©	PSP	AMF	12	3	22		36	No	Yes	No	TOT	36	12
37359E6	NIP	NSA	5	4	237		T24	No	Yes	No	DIR	T24	12
37361E6	NIP	NSA	5	5	205		T23	No	Yes	No	DIR	T23	12
37945E6 ‡	sNIP	SGP	5	6	178		T12	No	Yes	No	DIR	T12	12
37947E6 ‡	sNIP	SGP	5	7	193		T22	No	Yes	No	DIR	T22	12
37959E6	sNIP	SGP	5	8	204		T14	No	Yes	No	DIR	T14	12
37961E6	sNIP	SGP	5	9	230		T16	No	Yes	No	DIR	T16	12
38909F3 ©	SPP	SGP	8	8	150		68	No	Yes	Yes	TOT	68	12
38910F3 ©	SPP	SGP	8	9	157		69	No	Yes	Yes	TOT	69	12

‡ Control Instrument

© Effective Net IR Corrected Instrument

BORCAL 2020-01 Session Configuration Audit Report

Effective Net IR Corrected Instruments

Instrument	Vent	Correcting Pyrgeometer	Inst. RSnet	RSnet uncert.	RSnet Date
16256F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
17933F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
17934F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	05/18/2019
18289F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	05/18/2019
27973F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
29608F3 Eppley PSP	No	30170F3 Eppley PIR	0.5710	10.0000	04/06/2006
29612F3 Eppley PSP	No	30170F3 Eppley PIR	0.5710	10.0000	04/06/2006
29618F3 Eppley PSP	No	30170F3 Eppley PIR	0.6750	10.0000	06/29/2005
29913F3 Eppley PSP	No	30170F3 Eppley PIR	0.5390	10.0000	03/31/2006
29914F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6510	10.0000	06/29/2005
29916F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5470	10.0000	04/03/2006
30614F3 Eppley PSP	No	30170F3 Eppley PIR	0.6312	10.0000	06/06/2006
30620F3 Eppley PSP	No	30170F3 Eppley PIR	0.6691	10.0000	07/10/2006
30663F3 Eppley PSP	No	30170F3 Eppley PIR	0.5943	10.0000	04/04/2006
30666F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6919	10.0000	06/07/2006
30667F3 Eppley PSP	No	30170F3 Eppley PIR	0.6286	10.0000	04/06/2006
30673F3 Eppley PSP	No	30170F3 Eppley PIR	0.5741	10.0000	04/26/2007
30674F3 Eppley PSP	No	30170F3 Eppley PIR	0.6149	10.0000	04/26/2007
30797F3 Eppley PSP	No	30170F3 Eppley PIR	0.6140	10.0000	06/29/2005
30802F3 Eppley PSP	No	30170F3 Eppley PIR	0.6870	10.0000	04/25/2007
30811F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5550	10.0000	04/05/2006
30825F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6380	10.0000	06/28/2005
30890F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5945	10.0000	06/07/2006
30895F3 Eppley PSP	No	30170F3 Eppley PIR	0.5480	10.0000	04/04/2006
30897F3 Eppley PSP	No	30170F3 Eppley PIR	0.5984	10.0000	04/06/2006
30899F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5220	10.0000	04/07/2006
30902F3 Eppley PSP	No	30170F3 Eppley PIR	0.5504	10.0000	07/10/2006
30929F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6304	10.0000	06/07/2006
30938F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5520	10.0000	04/07/2006
30939F3 Eppley PSP	No	30170F3 Eppley PIR	0.5831	10.0000	04/26/2007
30946F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6625	10.0000	04/24/2007
30951F3 Eppley PSP	No	30170F3 Eppley PIR	0.6427	10.0000	07/06/2006
30954F3 Eppley PSP	No	30170F3 Eppley PIR	0.6333	10.0000	06/06/2006
30958F3 Eppley PSP	No	30170F3 Eppley PIR	0.6154	10.0000	06/06/2006
31097F3 Eppley PSP	No	30170F3 Eppley PIR	0.4872	10.0000	04/26/2007
31099F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5787	10.0000	05/08/2006
31100F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6473	10.0000	05/09/2006
31101F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6483	10.0000	05/09/2006
31146F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5490	10.0000	03/30/2006
31147F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5510	10.0000	03/30/2006
31148F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5330	10.0000	03/30/2006
31152F3 Eppley PSP	No	30170F3 Eppley PIR	0.6339	10.0000	05/09/2006
31153F3 Eppley PSP	No	30170F3 Eppley PIR	0.6429	10.0000	05/09/2006
31154F3 Eppley PSP	No	30170F3 Eppley PIR	0.5616	10.0000	05/09/2006
31155F3 Eppley PSP	No	30170F3 Eppley PIR	0.5240	10.0000	03/30/2006
31156F3 Eppley PSP	No	30170F3 Eppley PIR	0.5320	10.0000	03/30/2006
31157F3 Eppley PSP	No	30170F3 Eppley PIR	0.4900	10.0000	03/30/2006
31278F3 Eppley PSP	No	30170F3 Eppley PIR	0.5610	10.0000	06/29/2005
31281F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5410	10.0000	06/29/2005
31284F3 Eppley PSP	No	30170F3 Eppley PIR	0.5460	10.0000	03/31/2006

BORCAL 2020-01 Session Configuration Audit Report

Effective Net IR Corrected Instruments

Instrument	Vent	Correcting Pyrgeometer	Inst. RSnet	RSnet uncert.	RSnet Date
31291F3 Eppley PSP	No	30170F3 Eppley PIR	0.6184	10.0000	04/26/2007
31293F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6255	10.0000	04/26/2007
31631F3 Eppley PSP	No	30170F3 Eppley PIR	0.6599	10.0000	04/25/2007
32015F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.4221	10.0000	03/25/2009
32016F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6405	10.0000	06/13/2006
32017F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5910	10.0000	04/03/2006
32018F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6055	10.0000	06/13/2006
32039F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6577	10.0000	06/13/2006
32989F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
32991F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
37303F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
37304F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
37314F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
37317F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
38909F3 Eppley SPP	Yes	30020F3 Eppley PIR-V	0.2200	20.0000	Estimated
38910F3 Eppley SPP	Yes	30020F3 Eppley PIR-V	0.2200	20.0000	Estimated

Appendix 4
Operator Session Logs

Operator session logs for the BORCAL

BORCAL 2020-01 Operator Session Log

Session: 1

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	10:22:27	10:43:51	29222	05:00	970.4	970.3

Observations: [None]

Session: 2

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	11:25:22	11:31:26	29222	05:00	969.8	969.8
			30495	05:00	956.4	956.3

Observations: [None]

Session: 3

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	11:43:28	12:18:46	29222	05:00	969.8	969.5
			30495	05:00	956.4	955.9

Observations: [None]

Session: 4

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	12:39:10	13:39:13	29222	5:00	969.0	968.8
			30495	5:00	955.6	955.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:59:29	18.31	Blue	929.4	9.8	Craig Webb

Comments:
getting a few alarms at this time. wnd 330 @ 6 mph, temp -25C, hum -40%, hpa 977, some light cirrus to the east.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:21:06	20.63	Green	936.8	9.2	Craig Webb

Comments:
bugs around 34506E6 clear with small cirrus to the east, temp 24C, hum 41%, hpa 977

Session: 5

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	13:39:13	14:39:14	29222	5:00	968.8	968.2
			30495	5:00	955.5	955.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:44:04	23.89	Blue	937.7	8.8	Craig Webb

Comments:
clear, wnds 340 @ 4 mph, temp 26, hum 38%, hpa 977,

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:04:43	27.27	Blue	930.1	8.8	Craig Webb

Comments:
a few alarms clear, wnd 045 @ 5 mpn, temp 25C, hum 41%, hpa 976.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:33:33	32.42	Blue	921.7	9.4	Craig Webb

Comments:
no change in conditions,

BORCAL 2020-01 Operator Session Log

Session: 6

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	14:39:14	15:32:17	29222	5:00	968.2	967.9
			30495	5:00	955.4	954.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:54:18	36.32	Green	915.2	9.4	Craig Webb

Comments:
clear with a small line of cirrus to the NE wnd 010 @ 3 mph, temp 26C, hum 40%, hpa 976.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:16:42	40.68	Brown	899.3	10.0	Craig Webb

Comments:
no change in sky conditions, temp 27C, hum 38%, hpa 975, wnd 230 @ 2 mph.

Session: 7

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	15:32:17	16:32:18	29222	5:00	967.9	967.5
			30495	5:00	954.7	954.7

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:41:11	45.49	Blue	879.7	10.7	Craig Webb

Comments:
clear with some cirrus to the NE, temp 27C, hum 37, hpa 975 some small errors.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:05:08	50.28	Blue	858.6	11.8	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:25:14	54.30	Blue	836.2	12.8	Craig Webb

Comments:
clear, temp 27C, hum 35%, hpa 975, wnd 030 @ 7 mph, a few bugs around radiometers.

Session: 8

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	16:32:18	17:32:21	29222	5:00	967.5	967.5
			30495	5:00	954.7	954.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:45:25	58.35	Blue	804.7	14.0	Craig Webb

Comments:
clear, temp 27C, hum 38%, hpa 975, wnd 020 @ 4 mph. a few alarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:07:23	62.74	Green	766.7	15.9	Craig Webb

Comments:
several more alarms, temp 27C, hum 40%, hpa 975 wnd 010 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:27:46	66.79	Blue	725.2	17.7	Craig Webb

BORCAL 2020-01 Operator Session Log

Comments:
light cirrus forming to the west, temp 26C, hum 43%, hpa 974 several alarms.

Session: 9

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-18-2020	17:32:21	18:30:00	29222	5:00	967.5	967.8
			30495	5:00	954.5	955.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:48:26	70.87	Blue	670.2	20.5	Craig Webb

Comments:
STD 31157F3 going into alarm, temp 26C, hum 41%, hpa 974 some cirus on west horzin.

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:09:27	74.96	Blue	601.1	24.3	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:23:16	77.64	Blue	547.0	27.9	Craig Webb

Comments:
quiting at end of this session.

Session: 10

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	06:30:07	07:33:07	29222	06:00	971.4	973.1
			30495	06:00	957.6	958.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
06:52:08	73.24	Blue	633.3	23.5	Craig Webb

Comments:
some considation on domes, temp 15C, hum 85%, hpa 976, wnd dir 065 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:13:12	69.10	Blue	697.9	20.2	Craig Webb

Comments:
clear with haze on the horzion, temp 15C, hum 80%, hpa 976, wnd dir 095 @ 5 mph. some alarms.

Session: 11

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	07:33:07	08:33:10	29222	06:00	973.1	972.6
			30495	06:00	958.8	959.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:33:22	65.10	Blue	726.3	19.2	Craig Webb

Comments:
clear, temp 15C, hum 74%, hpa 976, wnd dir 070 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:53:44	61.04	Blue	757.5	17.7	Craig Webb

Comments:
clear no change in sky conditions.

BORCAL 2020-01 Operator Session Log

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:13:57	57.00	Green	772.8	17.1	Craig Webb

Comments:
birds in area causing alarms, temp 17C, hum 66%, hpa 977 wnd dir 060 @ 4 mph.

Session: 12

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	08:33:10	09:33:10	29222	06:00	972.6	971.9
			30495	06:00	959.0	957.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:37:04	52.37	Green	807.1	15.7	Craig Webb

Comments:
clear, temp 18C, hum 66%, hpa 977, wnd dir 075 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:57:30	48.26	Green	825.0	15.3	Craig Webb

Comments:
no change in conditions.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:22:55	43.21	Brown	843.2	14.5	Craig Webb

Comments:
clear with some light cirrus to the south/east. temp19C, hum 61%, hpa 977, wnd dir 050 @ 10 mph.

Session: 13

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	09:33:10	10:36:13	29222	06:00	971.9	971.3
			30495	06:00	957.8	957.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:43:04	39.25	Blue	866.8	13.7	Craig Webb

Comments:
clear some cirrus to the SE, temp 198C, hum 61%, hpa 977, wnd dir 095 @ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:05:21	34.95	Blue	881.4	12.6	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:25:24	31.21	Blue	891.6	11.9	Craig Webb

Comments:
bird on 31157F3, temp 21C, hum 58%, hpa 977, wnd dir 027 @ 5 mph.

Session: 14

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	10:36:13	11:13:13	29222	06:00	971.3	970.9
			30495	06:00	957.3	957.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:59:18	25.28	Blue	919.2	10.9	Craig Webb

Comments:
a few birds in the area, temp 21C, hum 56%, hpa 977, wnd dir 110 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:10:07	23.56	Blue	917.5	10.6	Craig Webb

Comments:
calibrating early to get ready for solar noon.

Session: 15

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	11:13:13	12:06:47	29222	06:00	970.9	970.1
			30495	06:00	957.1	956.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:30:17	20.69	Green	926.4	10.4	Craig Webb

Comments:
clear, temp 22C, hum 55%, hpa 976, wnd dir 056 @ 7 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:50:25	18.40	Green	932.2	10.1	Craig Webb

Comments:
no change in conditions.

Session: 16

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	12:06:47	13:06:51	29222	06:00	970.1	969.6
			30495	06:00	956.5	955.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:10:35	16.98	Blue	938.0	9.8	Craig Webb

Comments:
this will be the solar noon run, temp 22C, hum 54%, hpa 976, wnd dir 045 @ 5 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:30:45	16.64	Green	946.8	9.2	Craig Webb

Comments:
almost solar noon, temp 23C, hum 51%, hpa 976, wnd dir 055 @ 8 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:51:04	17.46	Blue	950.2	9.0	Craig Webb

Comments:
no change.

Session: 17

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	13:06:51	14:06:53	29222	06:00	969.6	969.4
			30495	06:00	955.9	955.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:11:11	19.25	Blue	947.7	9.2	Craig Webb

Comments:
clear, a few birds in area, temp 24C, hum 50%, hoa 975, wnd dir 070 @ 10 mph.

BORCAL 2020-01 Operator Session Log

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:31:20	21.83	Blue	945.7	9.0	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:51:58	24.98	Blue	941.2	9.1	Craig Webb

Comments:
clear sky, temp 24C, hum 50, hpa 975, wnd dir 090 @ 6 mph.bugs on 34506E6

Session: 18

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	14:06:53	15:07:54	29222	06:00	969.4	969.0
			30495	06:00	955.6	955.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:12:02	28.38	Blue	937.3	9.4	Craig Webb

Comments:
clear sky, temp 25C, hum 50%, hpa 975, wnd dir 090 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:32:19	32.06	Green	931.3	9.5	Craig Webb

Comments:
no change

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:52:42	35.90	Green	921.6	9.8	Craig Webb

Comments:
clear, temp 25C, hum 47%, hpa 974, wnd dir 050 @5 mph.

Session: 19

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	15:07:54	16:07:56	29222	06:00	969.0	969.2
			30495	06:00	955.6	955.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:13:46	39.98	Blue	912.1	10.2	Craig Webb

Comments:
clear

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:33:54	43.94	Blue	901.1	10.5	Craig Webb

Comments:
clear some haze on the horzin, temp 24C, hum 48%, hpa 974, wnd dir 0901 @ 4 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:54:00	47.93	Blue	890.7	10.9	Craig Webb

Comments:
no change.

BORCAL 2020-01 Operator Session Log

Session: 20

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	16:07:56	17:07:55	29222	06:00	969.2	969.1
			30495	06:00	955.4	955.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:14:13	51.98	Blue	868.9	11.8	Craig Webb

Comments:
clear, temp 25C, hum 49%, hpa 974, wnd dir 070 m@ 3 mph. a few alarms.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:34:36	56.06	Blue	846.7	12.6	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:54:53	60.10	Blue	812.1	14.0	Craig Webb

Comments:
clear temp 24C, hum 53%, hpa 974, wnd dir 050 @ 9 mph

Session: 21

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	17:07:55	18:09:00	29222	06:00	969.1	969.7
			30495	06:00	955.5	956.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:14:57	64.13	Blue	778.0	15.6	Craig Webb

Comments:
clear with a very light haze on the horzin, temp 24C, hum 55%, hpa 974, wnd dir 074 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:35:23	68.18	Blue	735.7	17.6	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
17:55:32	72.14	Blue	680.3	20.5	Craig Webb

Comments:
starting to get STD alarms(31157F3 &31146F3) temp 22C, hum 57%, hpa 974, wnd dir 090 @ 9 mph.

Session: 22

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-19-2020	18:09:00	18:28:13	29222	06:00	969.7	969.9
			30495	06:00	956.1	956.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:15:36	76.04	Blue	608.0	24.4	Craig Webb

Comments:
31146F3 & 31157F3 alarm every scan, temp 21C, hum 60%, hpa 974, wnd dir 252 n@ 3 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
18:25:18	77.91	Blue	569.0	26.8	Craig Webb

BORCAL 2020-01 Operator Session Log

Comments: [None]