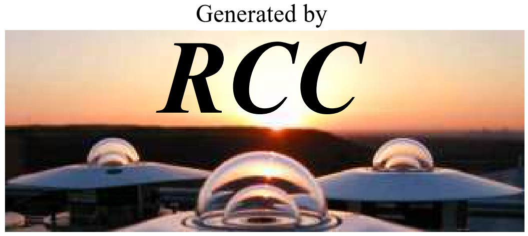
Broadband Outdoor Radiometer Calibration
Shortwave

BORCAL-SW
2022-01

Generated by



Radiometer Calibration and Characterization

Calibration Facility

Southern Great Plains

Latitude: 36.605°N

Longitude: 97.488°W

Elevation: 317.0 meters AMSL

Time Zone: -6.0

Calibration date

04/30/2022 to 05/07/2022

Report Date

July 20, 2022

NOTICE

Broadband Outdoor Radiometer Calibration Report

Table of contents

Introduction

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

This report includes these sections:

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

BORCAL Notes or Comments

NIP 31120E6 historical trend outlier this BORCAL but kept in for MAS/control tracking
PSP 31631F3, NIP 37360E6, sNIP 37945E6 removed from BORCAL due to unusual PM Rs results

Control Instrument History

Figure 1. Eppley NIP Control Instrument History

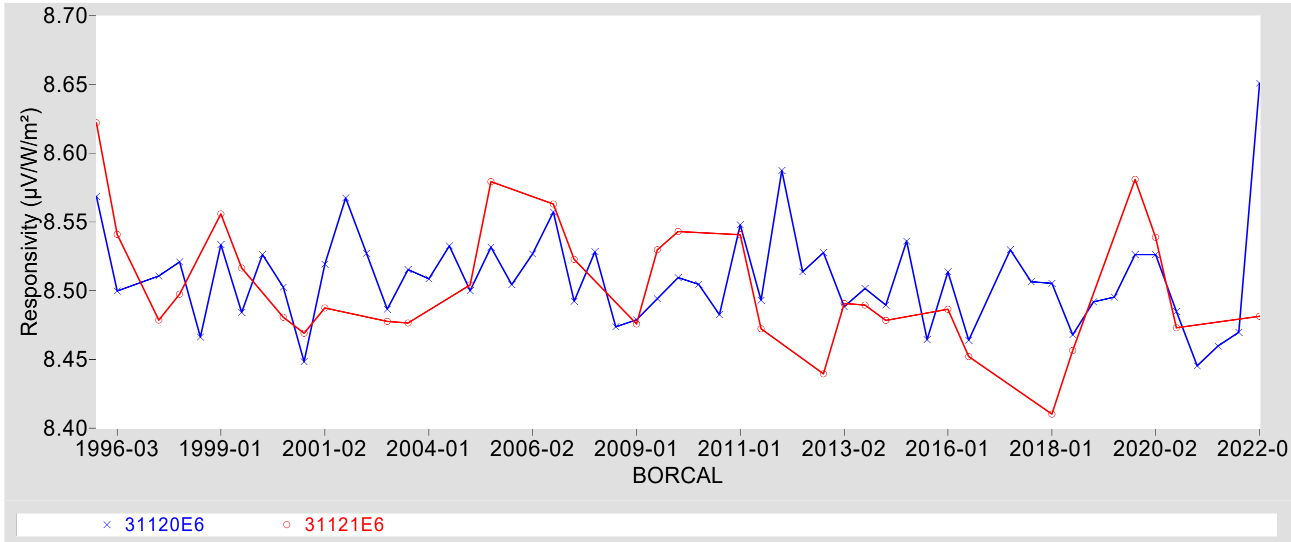


Figure 2. Eppley PSP Control Instrument History

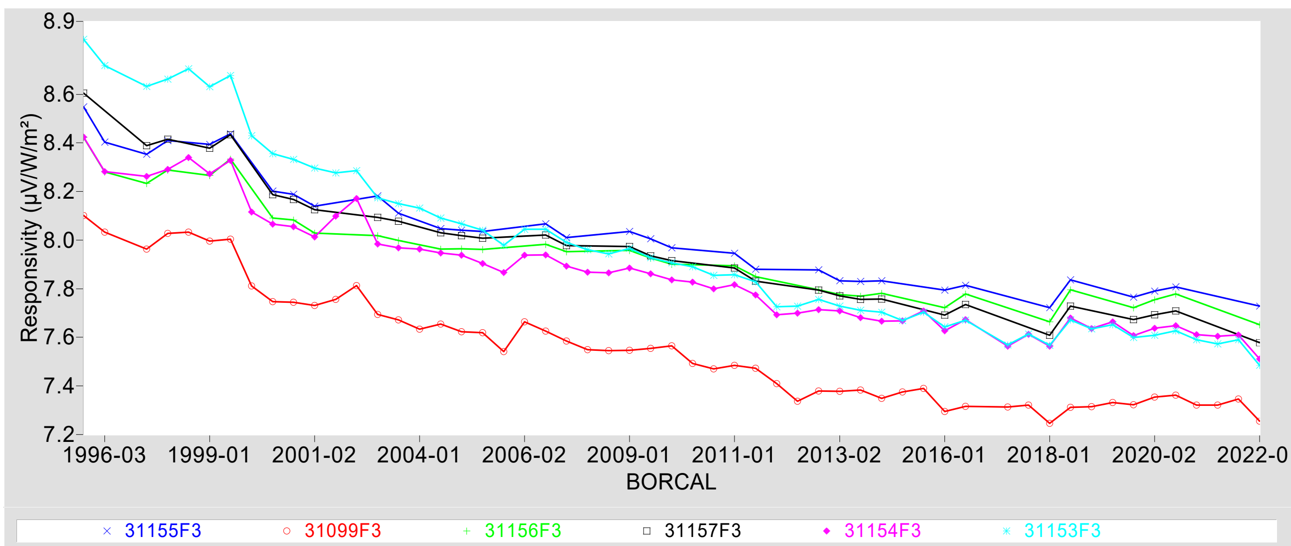
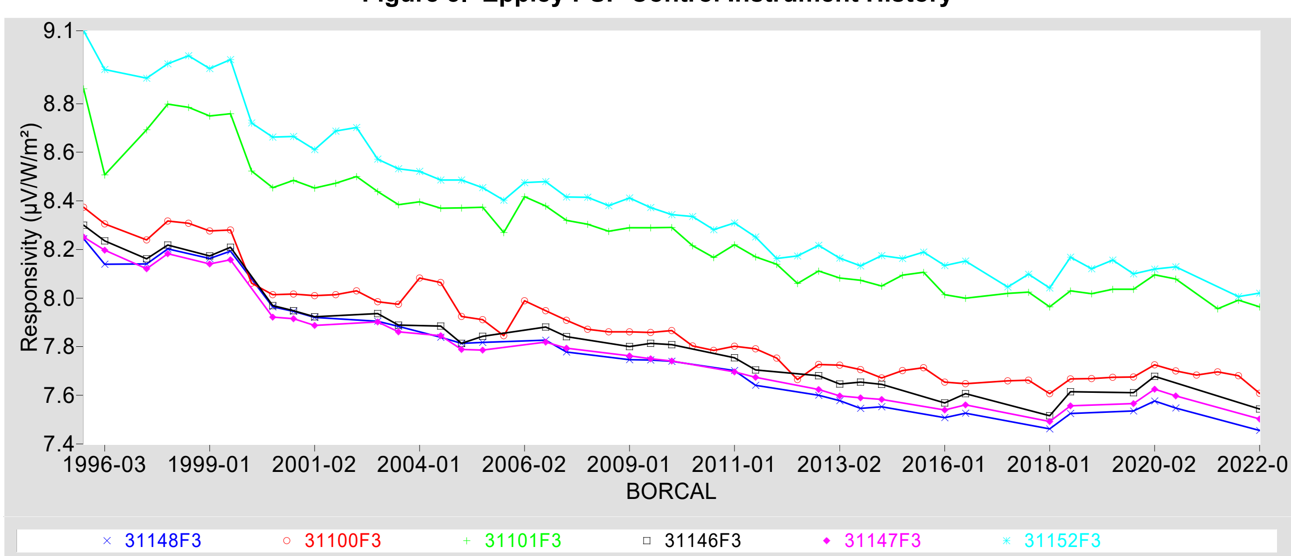
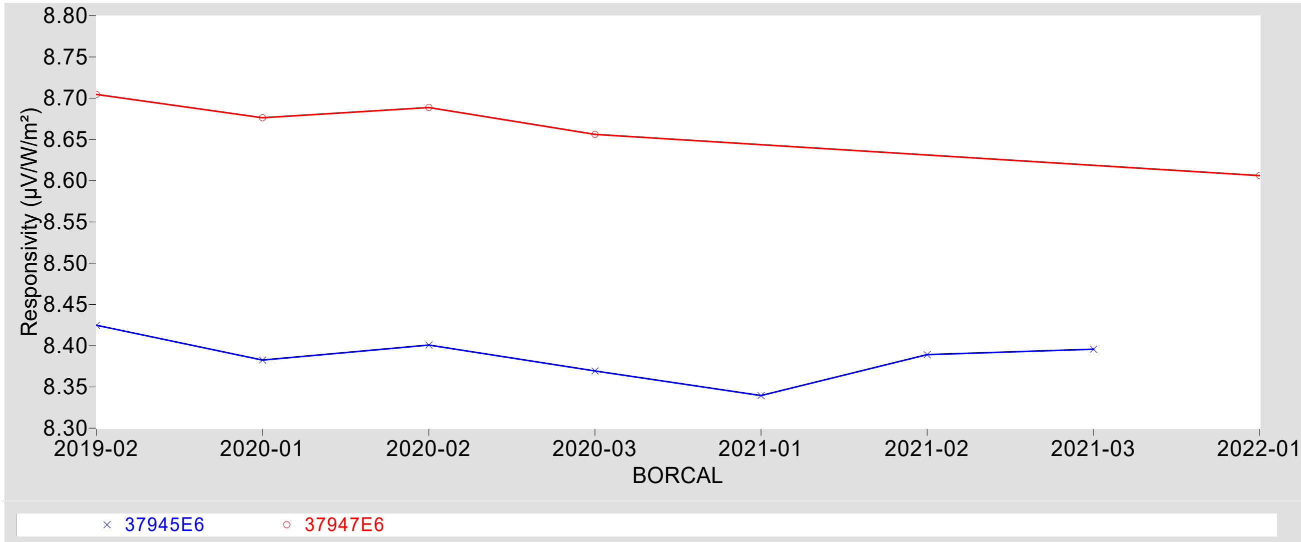


Figure 3. Eppley PSP Control Instrument History



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
13011F3	TWP	8.6428	+2.6 / -1.5	0.60000	A1-2
18289F3	Nels Laulainen	8.1638	+1.8 / -2.4	0.60000	A1-5
18637E6	TWP	7.9941	+1.0 / -0.99	0	A1-8
20018F3	TWP	9.7815	+2.2 / -3.9	0.60000	A1-11
200692	SGP	9.2313	+1.3 / -1.4	0.087000	A1-14
200693	SGP	10.093	+1.4 / -1.4	0.087000	A1-17
200804	SGP	8.3841	+0.85 / -0.71	0	A1-20
20620F3	TWP	9.6152	+2.5 / -3.5	0.60000	A1-23
29010E6	SGP	8.7016	+0.78 / -0.93	0	A1-26
29011E6	SGP	8.3160	+1.1 / -0.96	0	A1-29
29278F3	SGP	7.6729	+2.5 / -3.6	0.56800	A1-32
29541E6	SGP	7.8685	+0.92 / -0.88	0	A1-35
29608F3	SGP	7.8252	+2.8 / -3.4	0.57100	A1-38
29609F3	SGP	8.0696	+2.7 / -3.5	0.63600	A1-41
29738E6	SGP	8.1904	+0.79 / -1.0	0	A1-44
29848E6	SGP	8.0827	+0.76 / -1.0	0	A1-47
29911F3	SGP	7.4660	+2.4 / -3.7	0.59755	A1-50
29917F3	TWP	7.9544	+2.2 / -2.7	0.58000	A1-53
29935E6	SGP	8.0372	+0.84 / -1.0	0	A1-56
29937E6	TWP	7.8683	+0.85 / -0.94	0	A1-59
30584E6	SGP	8.6247	+0.90 / -0.84	0	A1-62
30615F3	SGP	8.7248	+2.7 / -4.5	0.68534	A1-65
30666F3	SGP	7.8835	+2.7 / -4.1	0.69195	A1-68
30667F3	SGP	8.4982	+2.9 / -4.5	0.62861	A1-71
30674F3	SGP	8.9695	+2.7 / -3.2	0.61487	A1-74
30720E6	SGP	8.2482	+0.96 / -1.0	0	A1-77
30797F3	SGP	8.6572	+2.5 / -2.5	0.58912	A1-80
30811F3	SGP	7.9920	+2.0 / -3.3	0.55500	A1-83
30887F3	SGP	8.5931	+2.8 / -3.8	0.64358	A1-86
30890F3	SGP	7.5005	+2.2 / -3.1	0.59445	A1-89
30894F3	SGP	7.9602	+1.9 / -2.4	0.64666	A1-92
30895F3	SGP	8.3749	+2.3 / -2.8	0.54800	A1-95
30897F3	SGP	7.9249	+2.0 / -2.9	0.59840	A1-98
30899F3	SGP	7.4560	+2.3 / -2.9	0.52200	A1-101
30901F3	SGP	8.0605	+1.9 / -2.3	0.52300	A1-104
30903F3	SGP	7.6166	+1.8 / -2.7	0.58651	A1-107
30929F3	SGP	7.5343	+2.5 / -4.0	0.63036	A1-110
30934F3	SGP	7.2004	+2.1 / -3.5	0.53000	A1-113
30940F3	SGP	7.2557	+2.1 / -2.7	0.61870	A1-116
30944F3	SGP	7.1157	+2.2 / -3.1	0.56695	A1-119
30945F3	SGP	7.5944	+2.9 / -3.1	0.53402	A1-122
30946F3	SGP	7.5358	+2.3 / -3.6	0.66251	A1-125
30947F3	SGP	8.0758	+2.5 / -2.7	0.54900	A1-128
30951F3	SGP	8.4356	+2.0 / -2.6	0.64270	A1-131
30952F3	SGP	8.6289	+2.6 / -2.5	0.58666	A1-134
30954F3	SGP	8.5232	+2.5 / -3.2	0.63330	A1-137
30958F3	SGP	9.0433	+2.1 / -2.8	0.61540	A1-140
31099F3	Calibration System	7.2548	+2.6 / -3.5	0.57866	A1-143
31100F3	Calibration System	7.6086	+2.3 / -3.3	0.64729	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
31101F3	Calibration System	7.9640	+2.6 / -3.1	0.64834	A1-149
31120E6	Calibration System	8.6510	+0.74 / -0.95	0	A1-152
31121E6	Calibration System	8.4813	+0.91 / -0.90	0	A1-155
31146F3	Calibration System	7.5435	+2.1 / -2.8	0.54900	A1-158
31147F3	Calibration System	7.5028	+2.2 / -3.2	0.55100	A1-161
31148F3	Calibration System	7.4548	+2.1 / -2.8	0.53300	A1-164
31152F3	Calibration System	8.0209	+2.6 / -3.5	0.63390	A1-167
31153F3	Calibration System	7.4851	+3.6 / -5.2	0.64286	A1-170
31154F3	Calibration System	7.5111	+2.6 / -3.8	0.56158	A1-173
31155F3	Calibration System	7.7282	+2.2 / -2.7	0.52400	A1-176
31156F3	Calibration System	7.6520	+2.3 / -2.7	0.53200	A1-179
31157F3	Calibration System	7.5785	+2.6 / -4.0	0.49000	A1-182
31275F3	TWP	7.6135	+2.3 / -2.6	0.59150	A1-185
31277F3	TWP	7.3153	+2.1 / -3.4	0.50400	A1-188
31280F3	TWP	6.8794	+2.8 / -3.7	0.49700	A1-191
31281F3	TWP	7.5452	+2.3 / -3.0	0.54100	A1-194
31287F3	TWP	7.4814	+3.3 / -3.9	0.62407	A1-197
31288F3	TWP	8.4128	+2.9 / -4.6	0.57800	A1-200
31344E6	NSA	8.2434	+0.96 / -1.1	0	A1-203
31627F3	SGP	7.9367	+1.9 / -3.1	0.61800	A1-206
31632F3	SGP	7.6052	+2.9 / -3.2	0.60000	A1-209
31635F3	SGP	8.3841	+2.2 / -2.6	0.61365	A1-212
31746E6	SGP	8.3620	+0.83 / -0.91	0	A1-215
31759E6	NSA	8.2269	+0.79 / -0.98	0	A1-218
31866E6	TWP	8.1110	+0.93 / -1.1	0	A1-221
32015F3	NSA	8.8807	+2.0 / -2.6	0.42210	A1-224
32017F3	NSA	8.8710	+1.6 / -2.4	0.59100	A1-227
32018F3	NSA	8.4980	+2.2 / -2.7	0.60555	A1-230
33237	SGP	8.3133	+2.9 / -2.4	0	A1-233
33239	SGP	9.6744	+3.8 / -1.9	0	A1-236
33242	SGP	9.0328	+3.3 / -2.3	0	A1-239
33243	TWP	9.0981	+3.4 / -2.3	0	A1-242
33259	NSA	8.7331	+3.6 / -2.5	0	A1-245
33261	SGP	8.7483	+3.4 / -2.6	0	A1-248
33269	SGP	8.3932	+5.3 / -2.3	0	A1-251
33271	TWP	8.6877	+3.2 / -1.8	0	A1-254
33274	SGP	8.8083	+4.4 / -2.1	0	A1-257
33277	SGP	9.2406	+5.2 / -2.1	0	A1-260
33282	TWP	8.6531	+4.9 / -2.1	0	A1-263
33376	TWP	8.8171	+4.1 / -2.1	0	A1-266
33379	TWP	8.7143	+3.3 / -1.8	0	A1-269
33551E6	TWP	7.9657	+0.90 / -0.97	0	A1-272
33784	SGP	9.7630	+3.7 / -2.1	0	A1-275
33785	SGP	9.3326	+3.6 / -1.9	0	A1-278
33860E6	AMF	7.8436	+0.81 / -0.94	0	A1-281
34066	AMF	8.5222	+4.3 / -2.3	0	A1-284
34504E6	SGP	8.1115	+0.87 / -1.2	0	A1-287
34505E6	SGP	7.9688	+0.80 / -1.1	0	A1-290
34506E6	SGP	7.6435	+0.85 / -1.5	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
34580	SGP	9.8965	+4.0 / -2.1	0	A1-296
35751	AMF#2	9.5536	+3.1 / -2.6	0	A1-299
35834F3	AMF#2	8.0534	+1.9 / -3.1	0.54922	A1-302
37166	NSA	8.7387	+3.5 / -1.9	0	A1-305
37285E6	AMF	8.4238	+0.84 / -0.91	0	A1-308
37298F3	NSA	8.8344	+1.7 / -2.0	0.60000	A1-311
37299F3	NSA	8.6965	+1.2 / -1.8	0.60000	A1-314
37303F3	AMF	8.4127	+2.1 / -2.8	0.60000	A1-317
37317F3	AMF	8.5401	+2.2 / -2.5	0.60000	A1-320
37319F3	AMF	8.1755	+2.1 / -2.9	0.60000	A1-323
37361E6	NSA	8.6025	+0.80 / -0.83	0	A1-326
37392	NSA	8.5541	+3.5 / -2.5	0	A1-329
37947E6	SGP	8.6060	+1.1 / -1.1	0	A1-332
37959E6	SGP	7.8197	+1.8 / -1.2	0	A1-335

[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 A1-338.

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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	13011F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

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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

13011F3 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

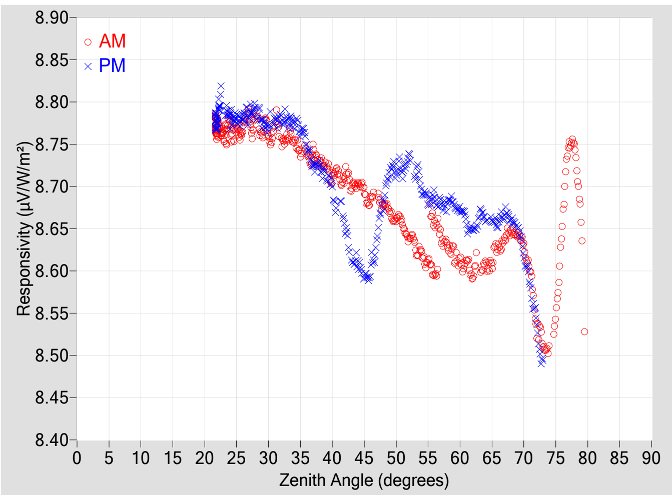


Figure 2. Responsivity vs Local Standard Time

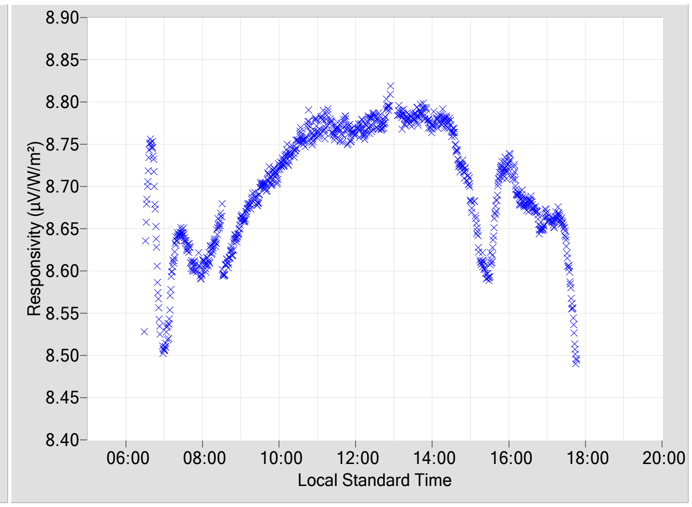


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6848	0.44	105.78	8.6048	0.41	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6782	0.44	103.70	8.6809	0.46	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6610	0.45	101.87	8.7158	0.46	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6381	0.45	99.99	8.7341	0.47	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6206	0.45	98.29	8.6946	0.47	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6302	0.47	94.96	8.6866	0.48	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6307	0.47	92.11	8.6787	0.50	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6106	0.48	90.59	8.6722	0.53	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5955	0.51	89.08	8.6492	0.57	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6070	0.54	87.62	8.6603	0.60	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6268	0.56	86.23	8.6555	0.63	271.28
22	8.7692	0.38	170.79	8.7792	0.37	189.59	68	8.6466	0.60	84.76	8.6593	N/A	272.74
24	8.7699	0.41	151.42	8.7826	0.39	208.63	70	8.6284	N/A	83.36	8.6153	N/A	274.23
26	8.7699	0.37	142.24	8.7827	0.37	218.00	72	8.5345	N/A	81.97	8.5355	N/A	275.66
28	8.7823	0.39	135.70	8.7882	0.40	224.64	74	8.5068	N/A	80.63	N/A	N/A	N/A
30	8.7626	0.42	130.25	8.7697	0.38	229.82	76	8.6541	N/A	79.10	N/A	N/A	N/A
32	8.7530	0.37	125.50	8.7795	0.41	234.40	78	8.7396	N/A	77.67	N/A	N/A	N/A
34	8.7539	0.39	121.90	8.7725	0.39	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7393	0.38	118.43	8.7477	0.39	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7286	0.38	115.42	8.7231	0.40	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7108	0.39	112.76	8.6961	0.41	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7126	0.41	110.30	8.6521	0.40	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7016	0.42	107.87	8.6101	0.46	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

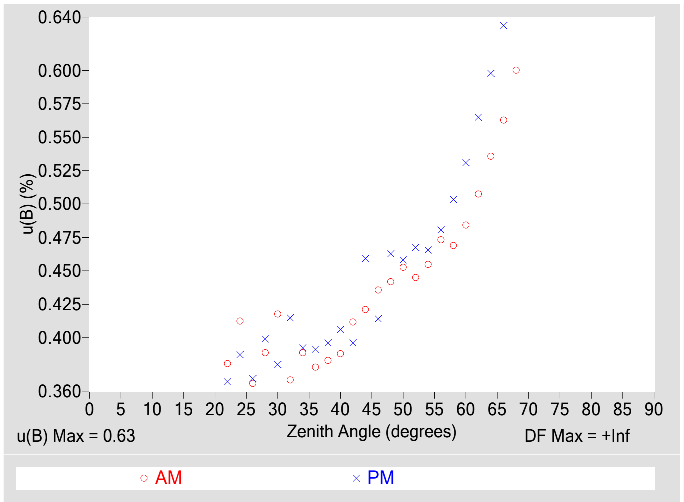


Figure 4. Residuals from Spline Interpolation

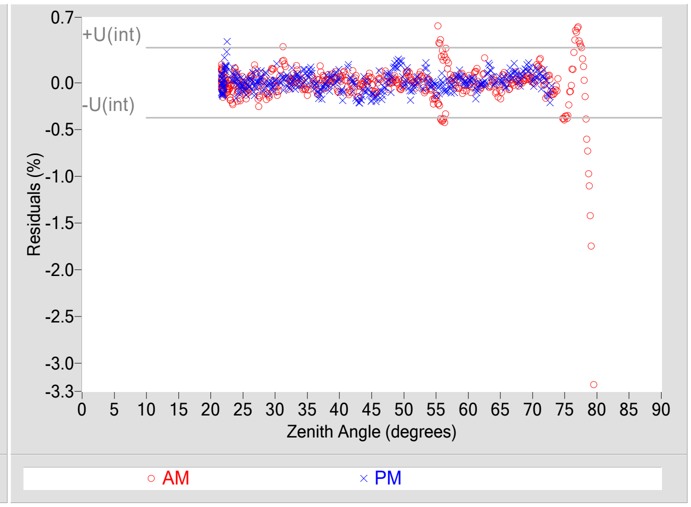


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	123275
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

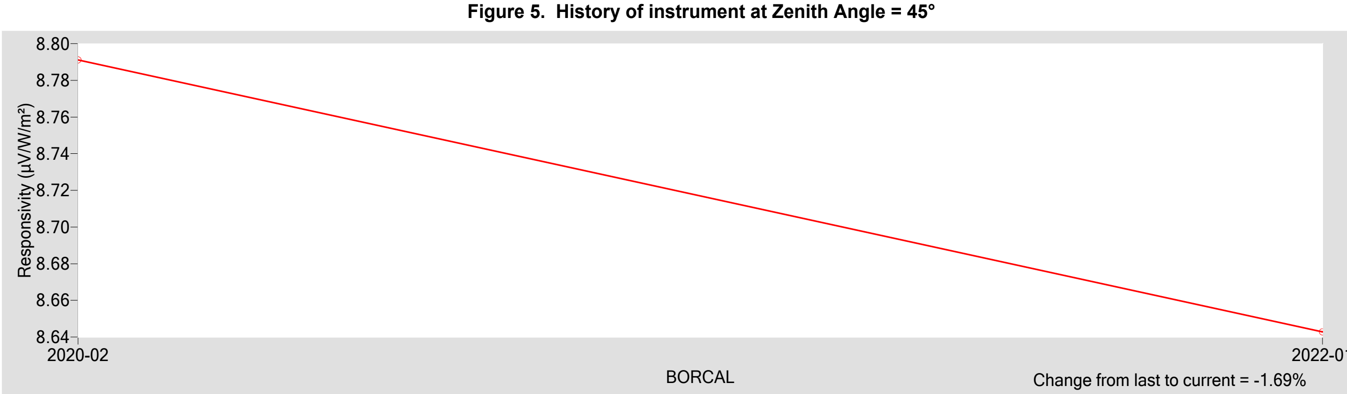
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6428	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.6 / -0.44
Expanded Uncertainty, U (%)	+2.6 / -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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	18289F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Nels Laulainen	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

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

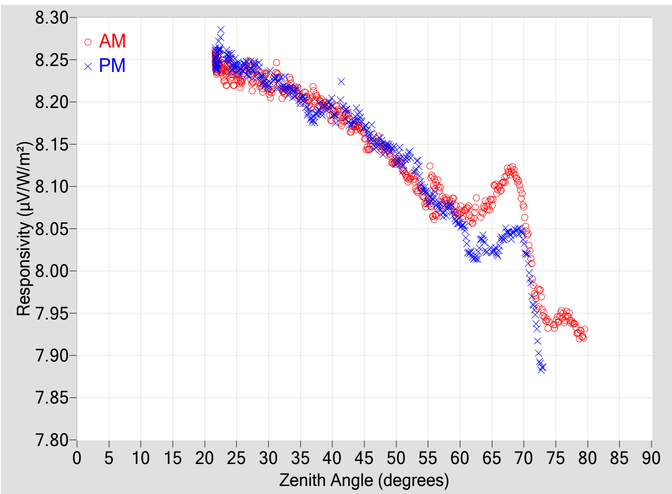


Figure 2. Responsivity vs Local Standard Time

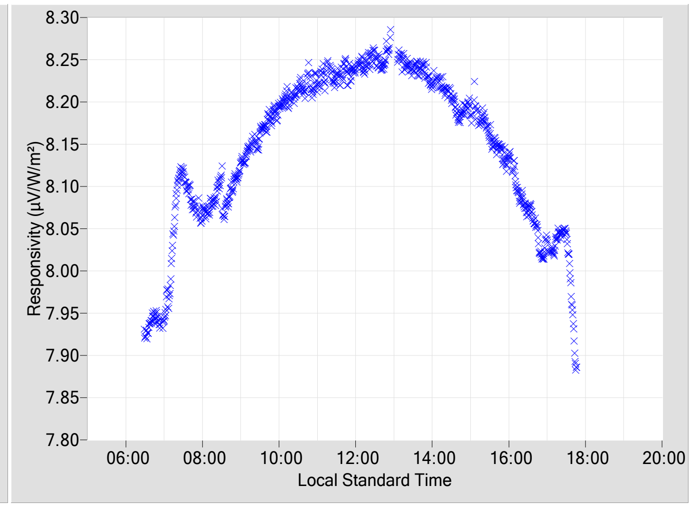


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1501	0.44	105.78	8.1608	0.42	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1456	0.44	103.70	8.1460	0.47	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1289	0.46	101.87	8.1298	0.46	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1085	0.45	99.99	8.1370	0.47	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0939	0.46	98.29	8.1002	0.47	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0869	0.48	94.96	8.0866	0.49	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0818	0.47	92.11	8.0727	0.51	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0708	0.49	90.59	8.0560	0.54	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0615	0.51	89.08	8.0160	0.57	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0767	0.54	87.62	8.0256	0.61	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0968	0.57	86.23	8.0227	0.64	271.28
22	8.2449	0.38	170.79	8.2490	0.37	189.59	68	8.1193	0.61	84.76	8.0421	N/A	272.74
24	8.2387	0.41	151.42	8.2488	0.39	208.63	70	8.0723	N/A	83.36	8.0310	N/A	274.23
26	8.2318	0.37	142.24	8.2408	0.37	218.00	72	7.9681	N/A	81.97	7.9274	N/A	275.66
28	8.2371	0.39	135.70	8.2387	0.40	224.64	74	7.9360	N/A	80.63	N/A	N/A	N/A
30	8.2180	0.42	130.25	8.2193	0.38	229.82	76	7.9472	N/A	79.10	N/A	N/A	N/A
32	8.2106	0.37	125.50	8.2222	0.42	234.40	78	7.9345	N/A	77.67	N/A	N/A	N/A
34	8.2154	0.39	121.90	8.2093	0.39	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2051	0.38	118.43	8.1917	0.39	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1993	0.39	115.42	8.1903	0.40	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1842	0.39	112.76	8.1930	0.41	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1837	0.41	110.30	8.1895	0.40	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1695	0.42	107.87	8.1844	0.46	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

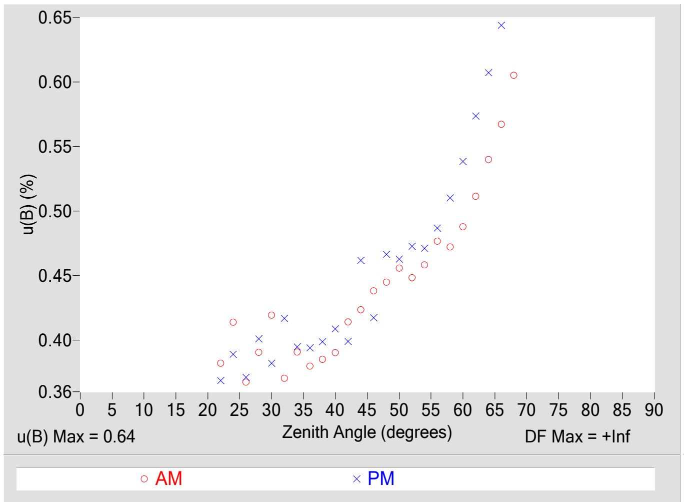


Figure 4. Residuals from Spline Interpolation

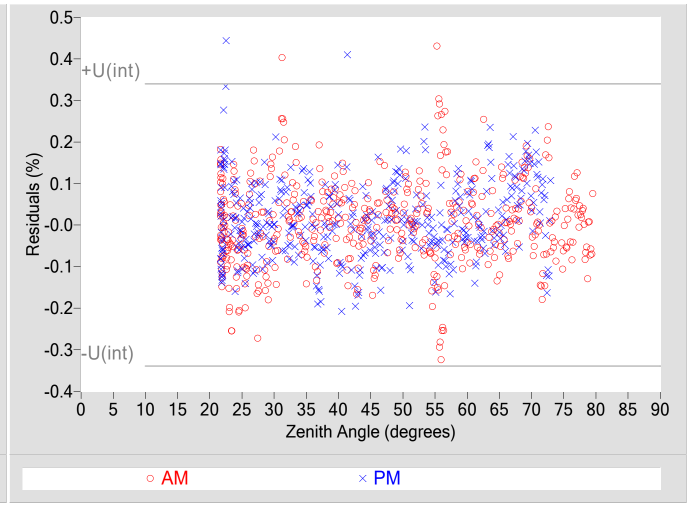


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	189358
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

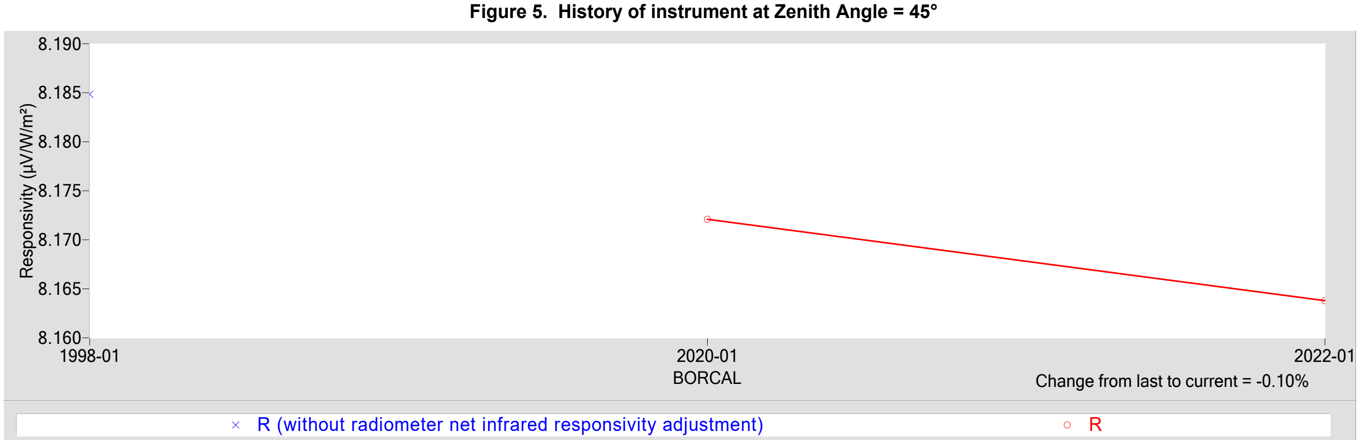
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1638	0.60000

† Rnet determination date: 05/18/2019

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.1
Offset Uncertainty, U(off) (%)	+0.72 / -1.3
Expanded Uncertainty, U (%)	+1.8 / -2.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	18637E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

18637E6 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

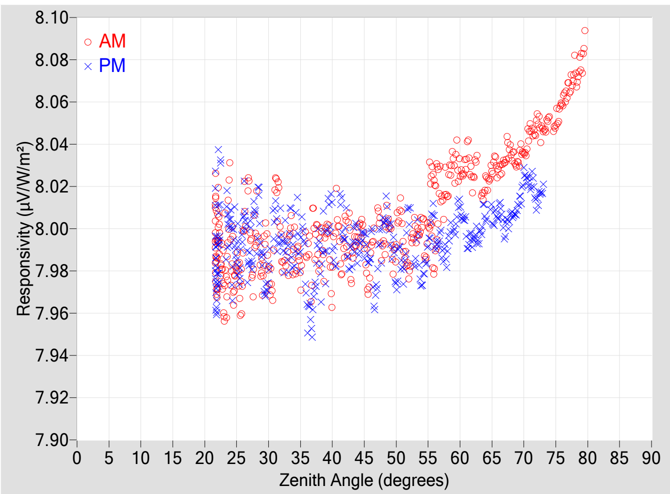


Figure 2. Responsivity vs Local Standard Time

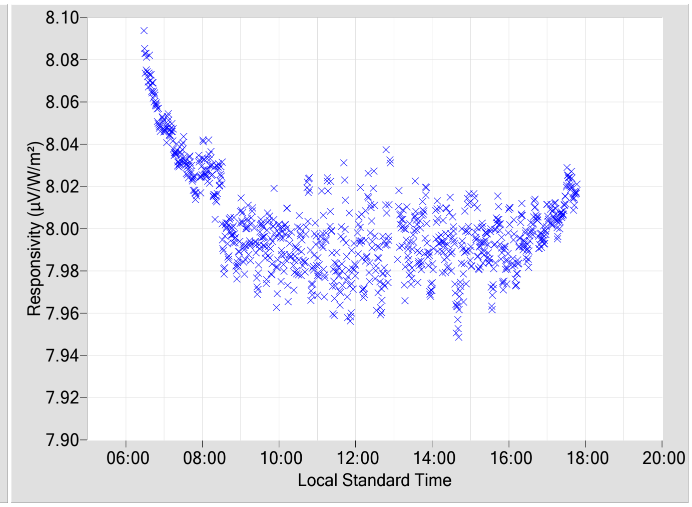


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9847	0.30	105.78	7.9908	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9903	0.30	103.76	8.0029	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9956	0.29	101.80	7.9738	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9810	0.30	100.04	8.0077	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0028	0.29	98.23	7.9749	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0012	0.29	95.28	7.9999	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0203	0.31	92.10	7.9883	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0270	0.29	90.59	8.0090	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0226	0.29	89.07	7.9949	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0211	0.30	87.67	8.0064	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0268	0.30	86.17	8.0080	0.30	271.28
22	7.9926	0.31	170.39	7.9811	0.31	189.69	68	8.0361	0.30	84.76	8.0062	N/A	272.74
24	7.9999	0.30	151.65	7.9990	0.31	208.46	70	8.0359	N/A	83.36	8.0240	N/A	274.18
26	7.9913	0.30	142.23	8.0046	0.30	217.99	72	8.0488	N/A	81.97	8.0126	N/A	275.61
28	8.0010	0.28	135.72	8.0016	0.33	224.55	74	8.0522	N/A	80.63	N/A	N/A	N/A
30	7.9817	0.31	130.12	7.9800	0.31	229.94	76	8.0596	N/A	79.15	N/A	N/A	N/A
32	7.9893	0.31	125.60	7.9966	0.31	234.51	78	8.0740	N/A	77.67	N/A	N/A	N/A
34	7.9869	0.30	121.84	7.9916	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9912	0.28	118.56	7.9643	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9893	0.30	115.50	7.9857	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9775	0.32	112.75	7.9990	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9956	0.30	110.22	7.9973	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9974	0.30	107.93	7.9911	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

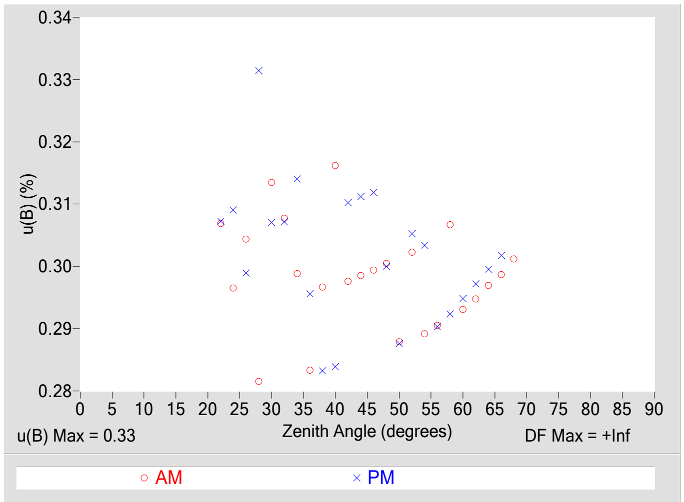


Figure 4. Residuals from Spline Interpolation

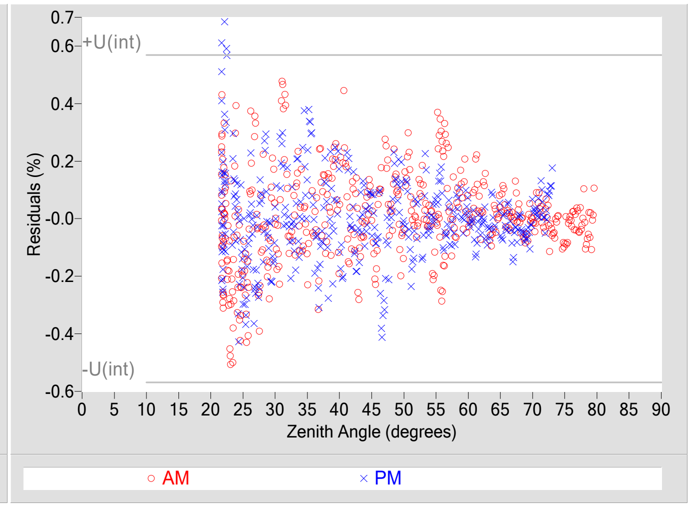


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.28
Combined Standard Uncertainty, u(c) (%)	±0.44
Effective degrees of freedom, DF(c)	4455
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.86
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

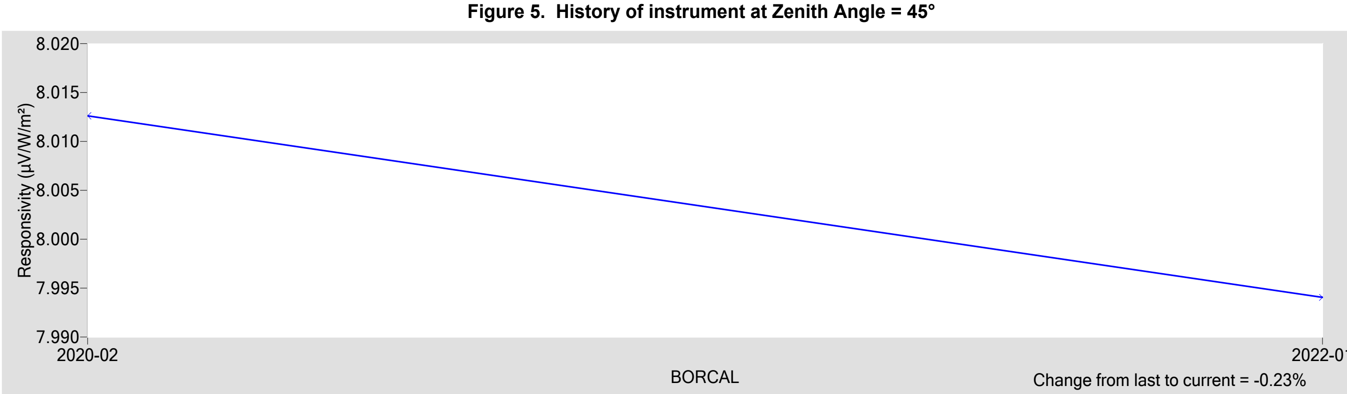
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9941	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.41 / -0.37
Expanded Uncertainty, U (%)	+1.0 / -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:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	20018F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

20018F3 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

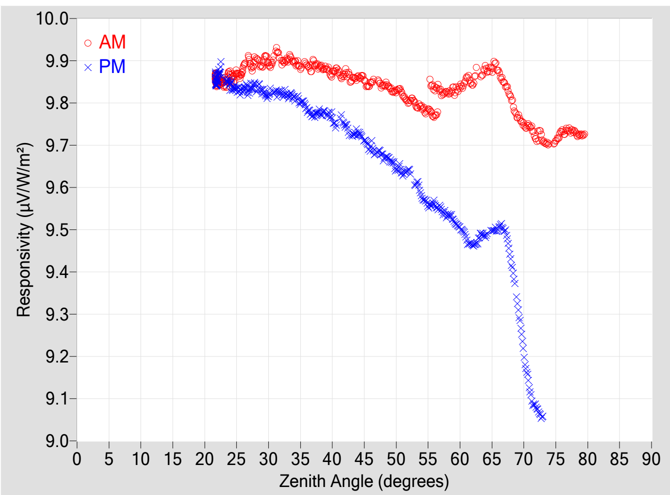


Figure 2. Responsivity vs Local Standard Time

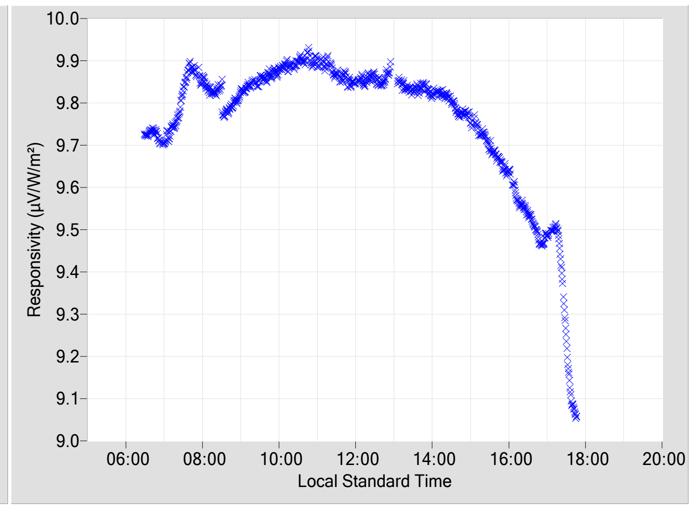


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.8463	0.43	105.78	9.6955	0.41	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8412	0.44	103.70	9.6718	0.46	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.8284	0.45	101.87	9.6418	0.45	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.8035	0.44	99.99	9.6395	0.46	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.7900	0.45	98.29	9.5780	0.46	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.8061	0.47	94.96	9.5605	0.47	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.8248	0.46	92.11	9.5334	0.50	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.8370	0.48	90.59	9.5041	0.52	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.8484	0.50	89.08	9.4636	0.56	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.8800	0.53	87.62	9.4865	0.59	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.8759	0.55	86.23	9.5030	0.62	271.28
22	9.8543	0.38	170.79	9.8539	0.36	189.59	68	9.8115	0.59	84.76	9.4246	N/A	272.74
24	9.8640	0.41	151.42	9.8438	0.38	208.63	70	9.7484	N/A	83.36	9.2006	N/A	274.23
26	9.8808	0.36	142.24	9.8320	0.37	218.00	72	9.7186	N/A	81.97	9.0771	N/A	275.66
28	9.9031	0.39	135.70	9.8376	0.40	224.64	74	9.7021	N/A	80.63	N/A	N/A	N/A
30	9.8958	0.42	130.25	9.8200	0.37	229.95	76	9.7315	N/A	79.10	N/A	N/A	N/A
32	9.8967	0.37	125.50	9.8232	0.41	234.40	78	9.7300	N/A	77.67	N/A	N/A	N/A
34	9.8984	0.39	121.90	9.8111	0.39	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.8894	0.37	118.43	9.7855	0.39	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.8855	0.38	115.42	9.7768	0.39	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.8691	0.38	112.76	9.7627	0.40	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8703	0.41	110.30	9.7480	0.39	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8597	0.42	107.87	9.7294	0.45	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

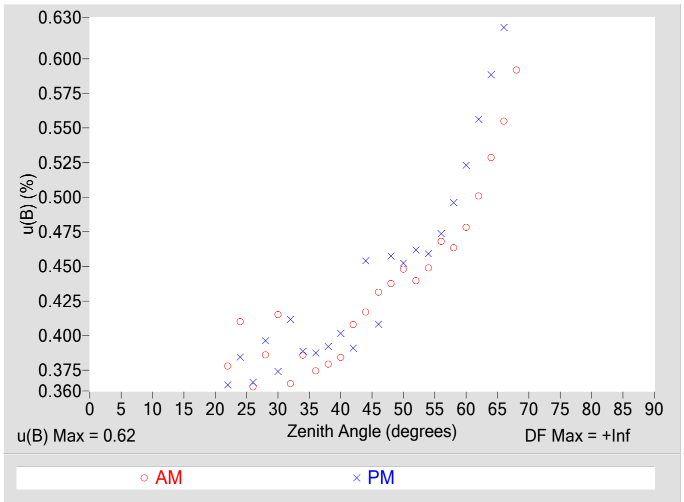


Figure 4. Residuals from Spline Interpolation

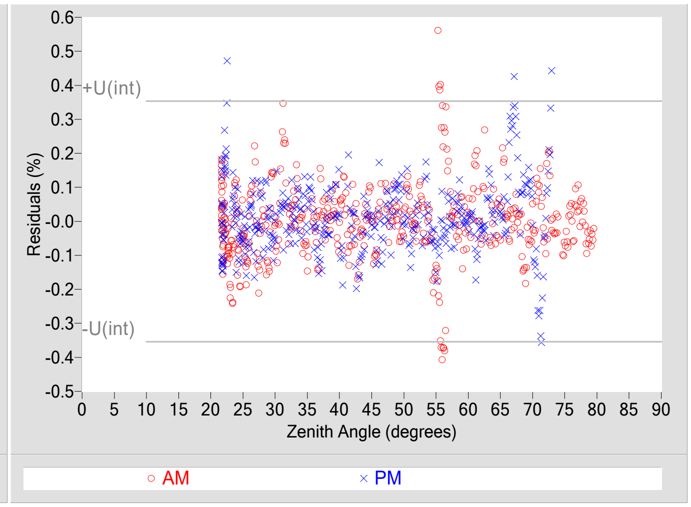


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	143259
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

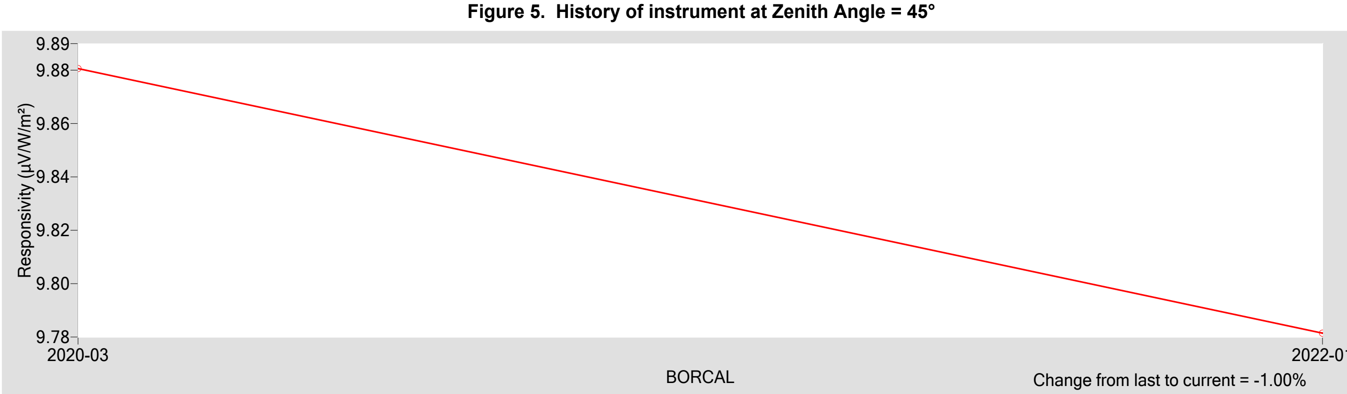
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.7815	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.2 / -2.8
Expanded Uncertainty, U (%)	+2.2 / -3.9
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	200692
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

200692 Kipp & Zonen CMP22

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

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

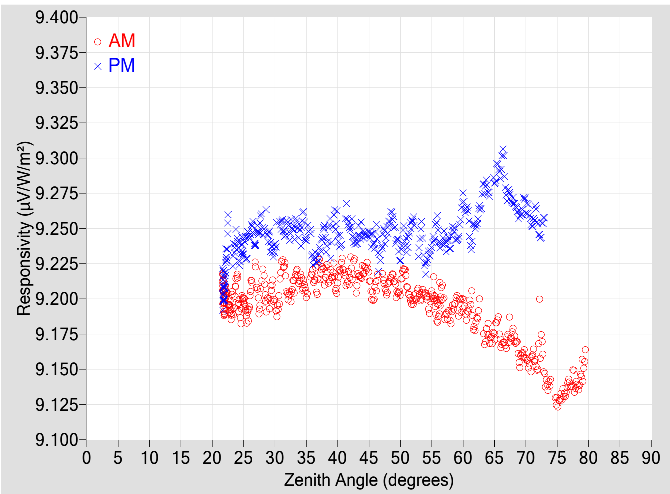


Figure 2. Responsivity vs Local Standard Time

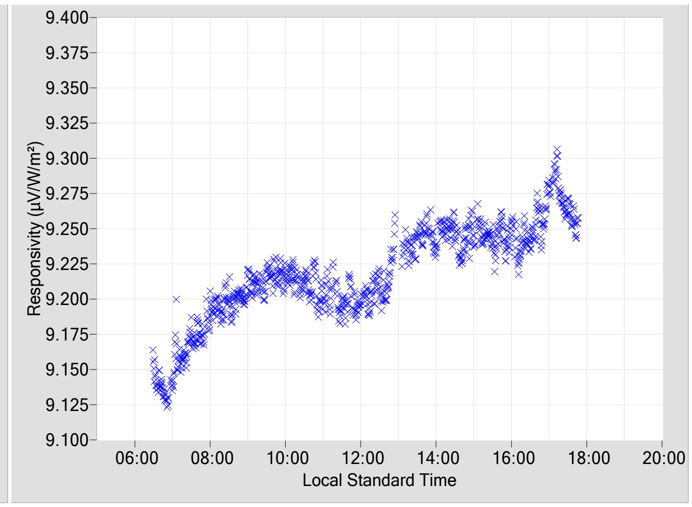


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle	(deg.)	(μV/W/m²)	± (%)	Angle	(μV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.2065	0.42	105.78	9.2437	0.41	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.2076	0.40	103.76	9.2497	0.44	256.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.2083	0.41	101.86	9.2322	0.45	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1980	0.42	99.98	9.2554	0.41	260.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.2025	0.43	98.29	9.2241	0.43	261.91
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1941	0.45	94.95	9.2477	0.44	263.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1871	0.45	92.10	9.2419	0.46	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1957	0.46	90.59	9.2682	0.48	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1827	0.48	89.07	9.2520	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.1757	0.51	87.66	9.2764	0.54	269.81
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.1698	0.53	86.22	9.2923	0.57	271.28
22	9.2012	0.36	170.62	9.2111	0.36	189.35	68	9.1747	0.56	84.76	9.2689	N/A	272.74
24	9.2062	0.36	151.41	9.2371	0.38	208.85	70	9.1585	N/A	83.36	9.2663	N/A	274.22
26	9.2007	0.36	142.23	9.2466	0.37	217.77	72	9.1667	N/A	81.96	9.2485	N/A	275.66
28	9.2144	0.34	135.58	9.2531	0.34	224.52	74	9.1404	N/A	80.63	N/A	N/A	N/A
30	9.1960	0.38	130.11	9.2385	0.35	229.93	76	9.1318	N/A	79.10	N/A	N/A	N/A
32	9.2028	0.38	125.65	9.2517	0.37	234.26	78	9.1377	N/A	77.72	N/A	N/A	N/A
34	9.2138	0.36	121.89	9.2467	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.2161	0.41	118.42	9.2317	0.37	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.2170	0.37	115.41	9.2444	0.41	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.2117	0.39	112.75	9.2477	0.37	247.37	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.2192	0.40	110.30	9.2525	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.2185	0.38	107.93	9.2470	0.40	252.18	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

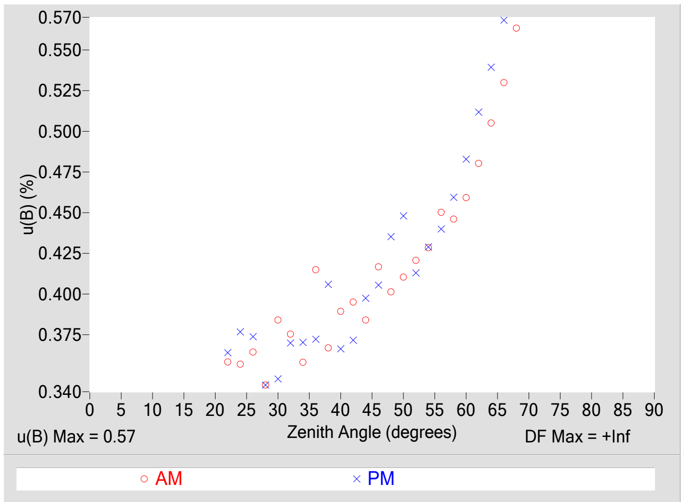


Figure 4. Residuals from Spline Interpolation

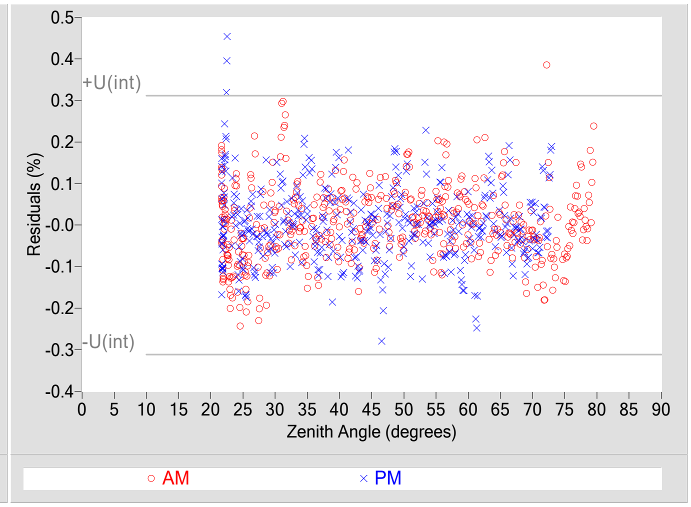


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	163850
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

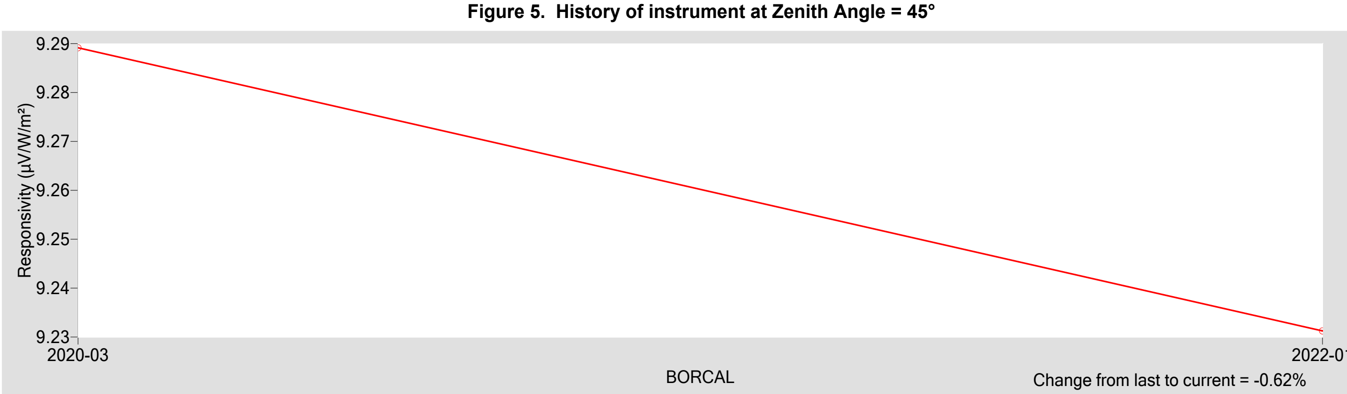
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.2313	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+0.40 / -0.48
Expanded Uncertainty, U (%)	+1.3 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Kipp & Zonen
Model:	CMP22	**Serial Number:**	200693
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

200693 Kipp & Zonen CMP22

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

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

where,

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

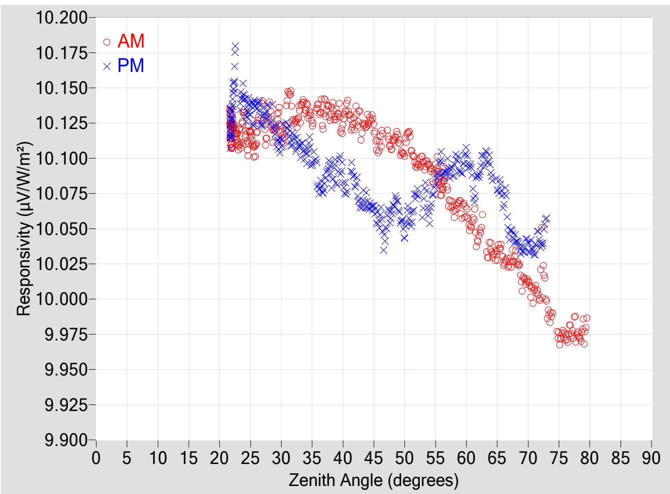


Figure 2. Responsivity vs Local Standard Time

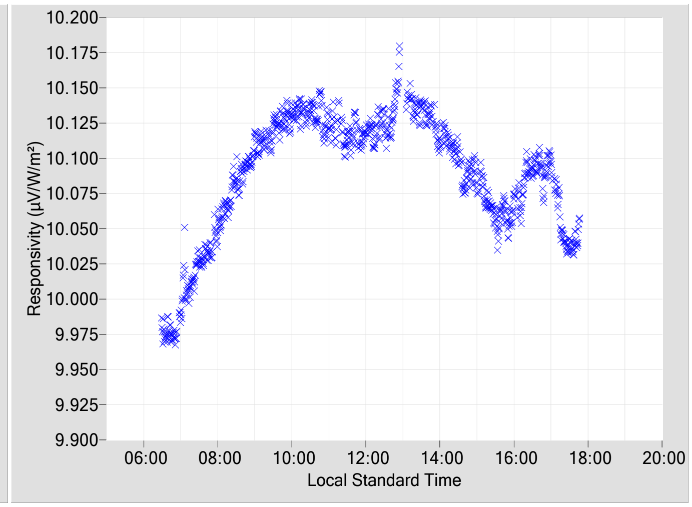


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	10.110	0.42	105.78	10.058	0.41	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.110	0.40	103.76	10.063	0.44	256.35
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.107	0.41	101.86	10.049	0.45	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.095	0.42	99.98	10.075	0.41	260.15
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.094	0.43	98.29	10.062	0.43	261.91
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.080	0.45	94.95	10.095	0.44	263.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.062	0.45	92.10	10.093	0.46	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.061	0.46	90.59	10.102	0.48	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.045	0.48	89.07	10.088	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.036	0.50	87.66	10.089	0.54	269.81
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.027	0.53	86.22	10.070	0.57	271.28
22	10.119	0.36	170.62	10.129	0.36	189.35	68	10.029	0.56	84.76	10.042	N/A	272.74
24	10.124	0.36	151.41	10.140	0.38	208.85	70	10.012	N/A	83.36	10.038	N/A	274.22
26	10.116	0.36	142.23	10.138	0.37	217.77	72	10.018	N/A	81.96	10.039	N/A	275.66
28	10.132	0.34	135.58	10.131	0.34	224.52	74	9.9889	N/A	80.63	N/A	N/A	N/A
30	10.119	0.38	130.11	10.112	0.35	229.93	76	9.9733	N/A	79.10	N/A	N/A	N/A
32	10.126	0.38	125.65	10.114	0.37	234.26	78	9.9736	N/A	77.72	N/A	N/A	N/A
34	10.136	0.36	121.89	10.102	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	10.135	0.41	118.42	10.082	0.37	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	10.133	0.37	115.41	10.091	0.41	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	10.124	0.39	112.75	10.085	0.37	247.37	86	N/A	N/A	N/A	N/A	N/A	N/A
42	10.128	0.39	110.30	10.083	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	10.126	0.38	107.93	10.068	0.40	252.18	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

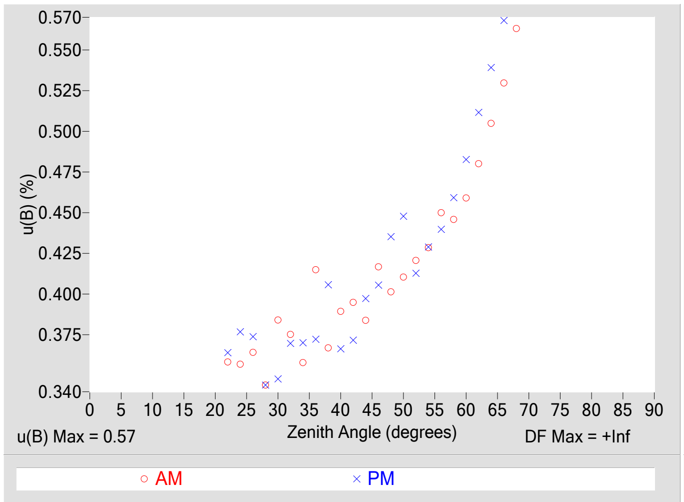


Figure 4. Residuals from Spline Interpolation

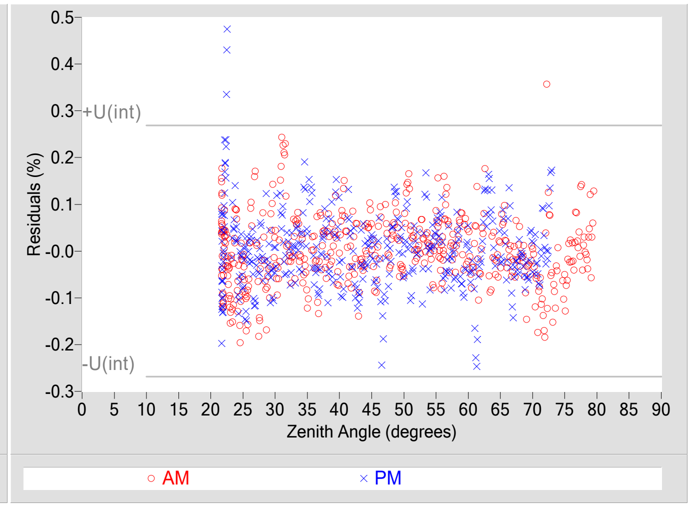


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	284360
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

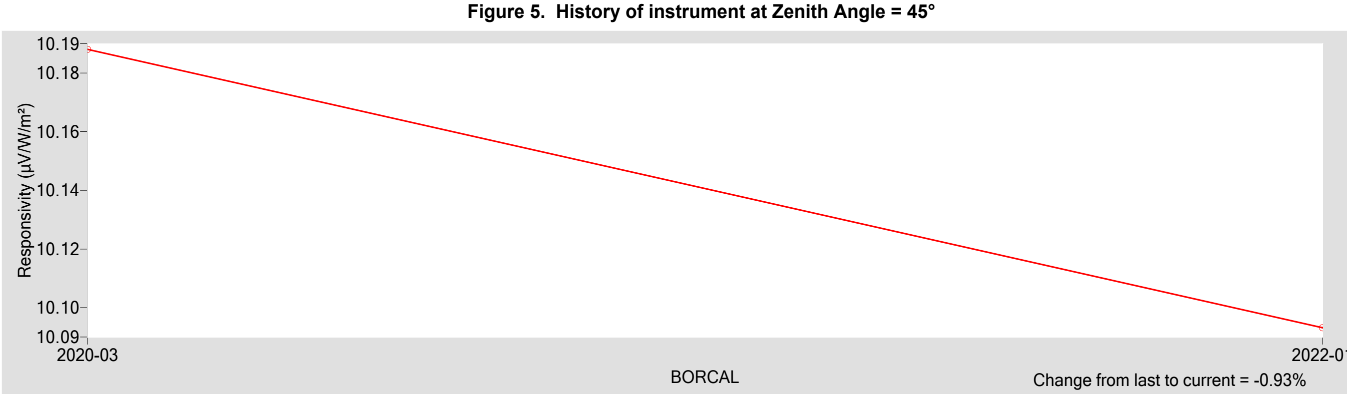
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
10.093	0.087000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+0.42 / -0.44
Expanded Uncertainty, U (%)	+1.4 / -1.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyrheliometer	**Manufacturer:**	Kipp & Zonen
Model:	CHP1	**Serial Number:**	200804
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

200804 Kipp & Zonen CHP1

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

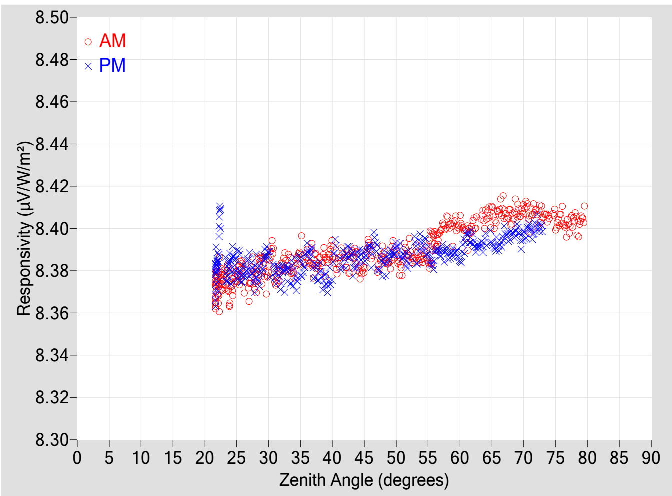


Figure 2. Responsivity vs Local Standard Time

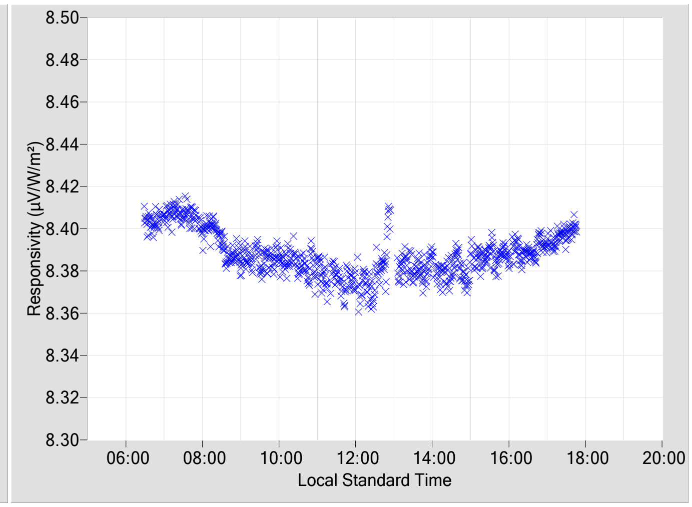


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.3897	0.29	105.80	8.3889	0.31	254.34
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3884	0.30	103.78	8.3838	0.30	256.44
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3874	0.30	101.82	8.3910	0.29	258.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3898	0.29	100.00	8.3852	0.29	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3860	0.29	98.25	8.3931	0.32	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3942	0.30	95.11	8.3853	0.29	263.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4034	0.29	92.07	8.3886	0.29	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4024	0.29	90.61	8.3847	0.29	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4021	0.29	89.09	8.3958	0.32	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4049	0.30	87.63	8.3946	0.30	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4081	0.30	86.19	8.3924	0.32	271.29
22	8.3728	0.30	170.76	8.3840	0.29	189.62	68	8.4058	0.30	84.78	8.3974	N/A	272.75
24	8.3692	0.33	151.62	8.3826	0.30	208.50	70	8.4089	N/A	83.38	8.3966	N/A	274.19
26	8.3787	0.30	142.49	8.3776	0.28	217.77	72	8.4061	N/A	81.93	8.4022	N/A	275.63
28	8.3746	0.29	135.48	8.3797	0.31	224.62	74	8.4046	N/A	80.64	N/A	N/A	N/A
30	8.3818	0.29	130.16	8.3866	0.30	229.85	76	8.4053	N/A	79.12	N/A	N/A	N/A
32	8.3817	0.28	125.75	8.3767	0.31	234.40	78	8.4055	N/A	77.68	N/A	N/A	N/A
34	8.3791	0.30	121.88	8.3784	0.31	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3867	0.30	118.54	8.3892	0.31	241.69	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3837	0.31	115.53	8.3797	0.28	244.77	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3901	0.31	112.70	8.3803	0.30	247.36	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3840	0.30	110.17	8.3862	0.28	249.83	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3838	0.30	107.96	8.3853	0.30	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

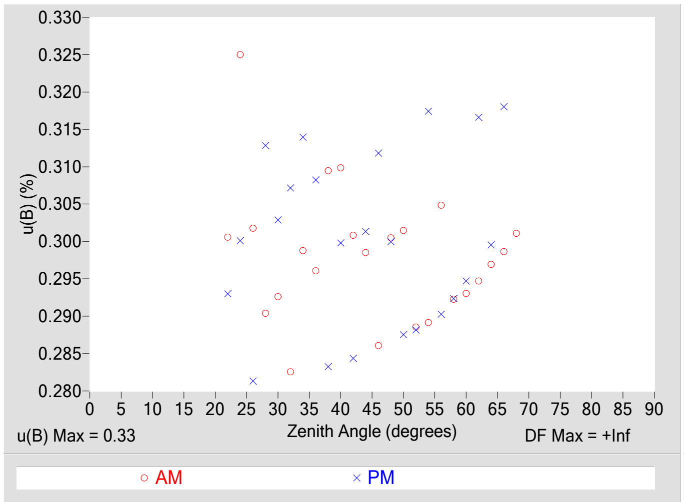


Figure 4. Residuals from Spline Interpolation

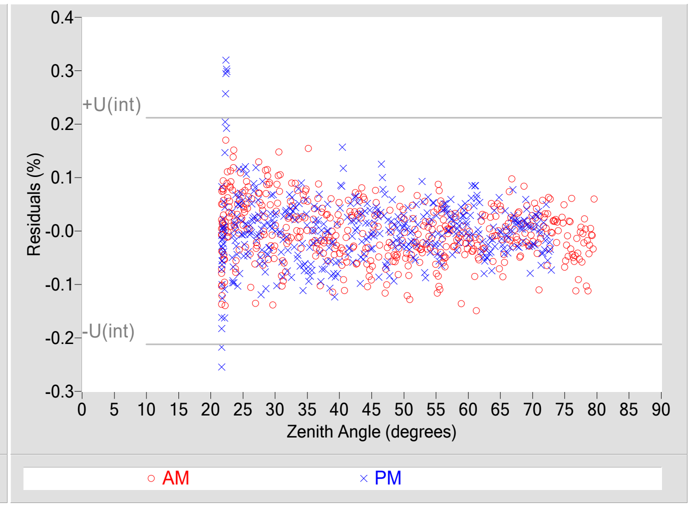


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.11
Combined Standard Uncertainty, u(c) (%)	±0.34
Effective degrees of freedom, DF(c)	87395
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.67
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

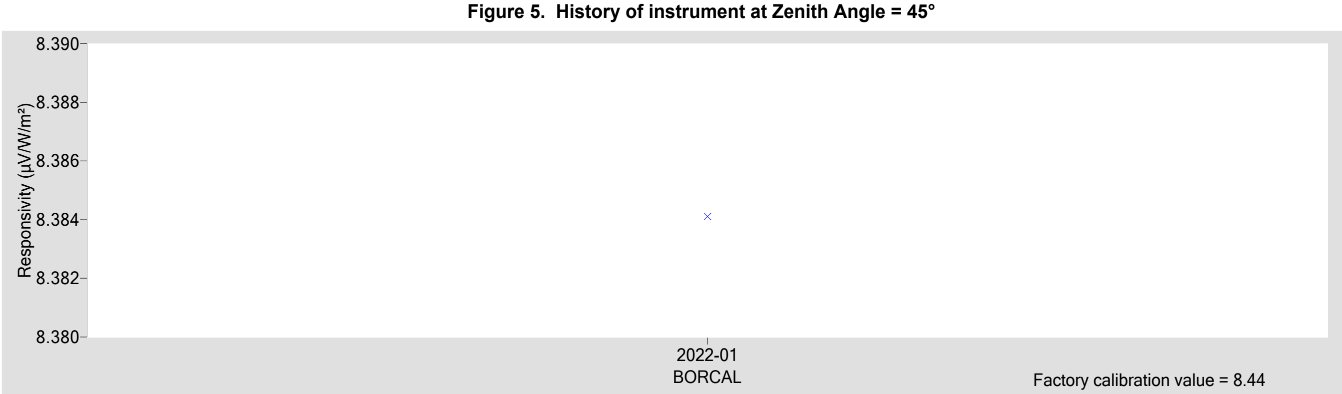
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3841	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.23 / -0.088
Expanded Uncertainty, U (%)	+0.85 / -0.71
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the 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:**	20620F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

20620F3 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

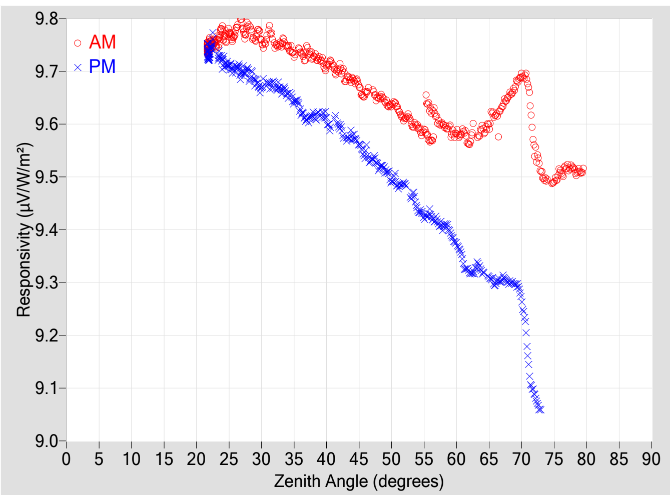


Figure 2. Responsivity vs Local Standard Time

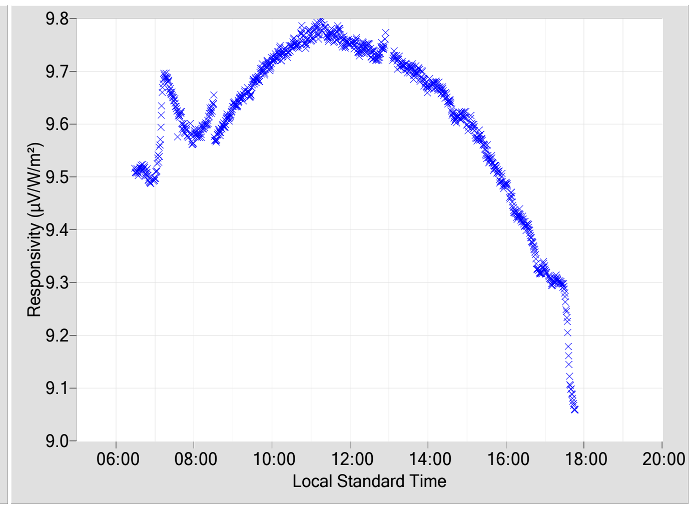


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.6584	0.43	105.78	9.5452	0.41	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.6501	0.44	103.70	9.5198	0.46	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6363	0.45	101.87	9.4913	0.45	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6103	0.44	99.99	9.4864	0.46	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.5953	0.45	98.29	9.4389	0.46	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6020	0.47	94.96	9.4281	0.47	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5984	0.46	92.11	9.4060	0.50	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5817	0.48	90.59	9.3726	0.52	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.5667	0.50	89.08	9.3191	0.56	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.5898	0.53	87.62	9.3191	0.59	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.6161	0.56	86.23	9.2973	0.63	271.28
22	9.7465	0.38	170.79	9.7327	0.36	189.59	68	9.6534	0.59	84.76	9.3004	N/A	272.74
24	9.7724	0.41	151.42	9.7195	0.38	208.63	70	9.6902	N/A	83.36	9.2620	N/A	274.23
26	9.7753	0.36	142.24	9.7058	0.37	218.00	72	9.5567	N/A	81.97	9.0862	N/A	275.66
28	9.7863	0.39	135.70	9.6950	0.40	224.64	74	9.4942	N/A	80.63	N/A	N/A	N/A
30	9.7598	0.42	130.25	9.6704	0.37	229.95	76	9.5093	N/A	79.10	N/A	N/A	N/A
32	9.7492	0.37	125.50	9.6733	0.41	234.40	78	9.5147	N/A	77.67	N/A	N/A	N/A
34	9.7477	0.39	121.90	9.6548	0.39	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.7362	0.37	118.43	9.6250	0.39	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.7275	0.38	115.42	9.6150	0.39	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.7088	0.38	112.76	9.6088	0.40	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.7047	0.41	110.30	9.5956	0.39	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.6834	0.42	107.87	9.5779	0.45	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

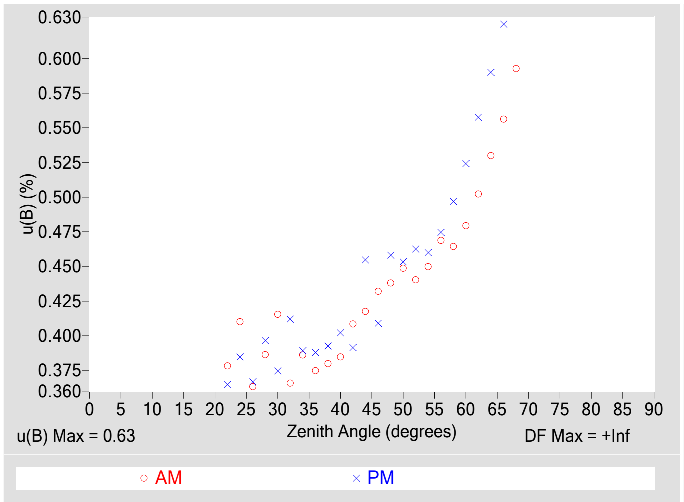


Figure 4. Residuals from Spline Interpolation

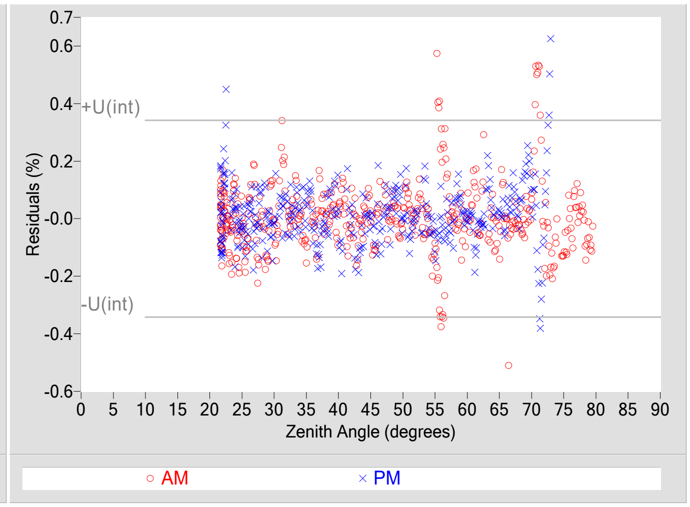


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	164959
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

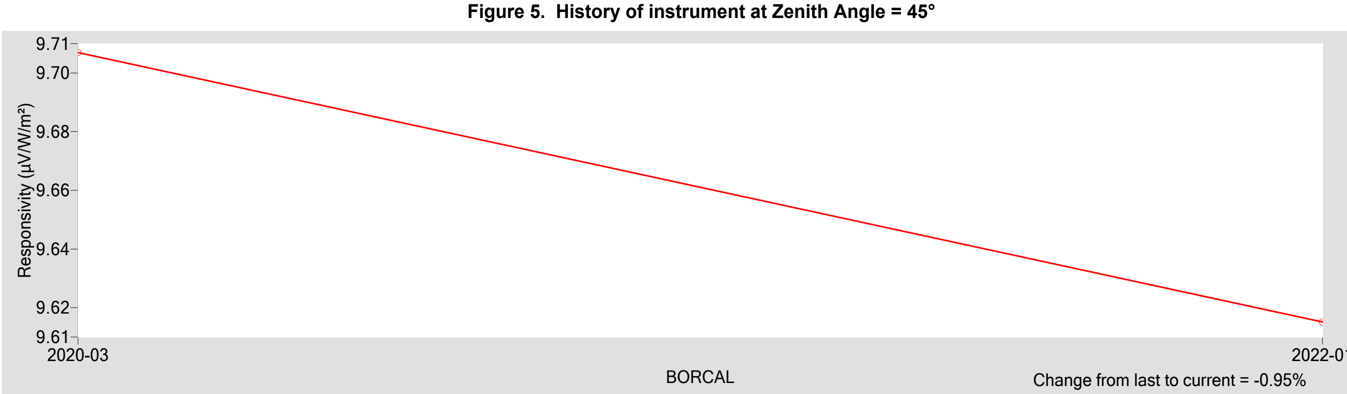
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.6152	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.5 / -2.5
Expanded Uncertainty, U (%)	+2.5 / -3.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29010E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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
29010E6 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

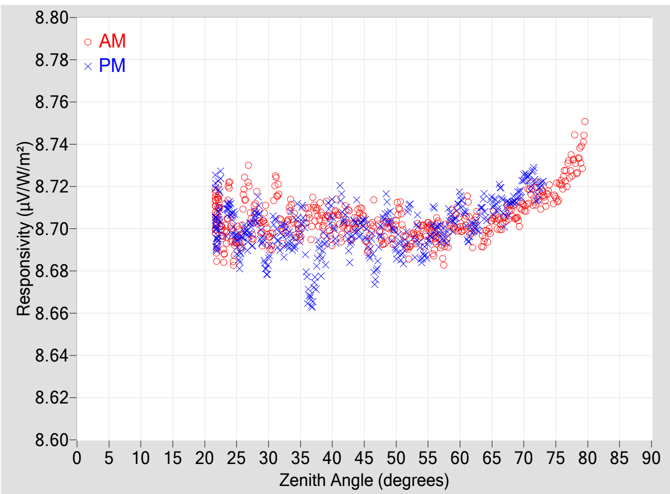


Figure 2. Responsivity vs Local Standard Time

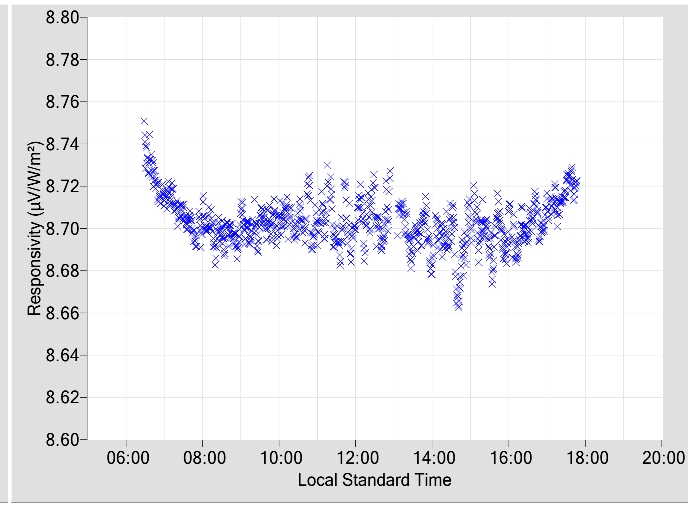


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6985	0.30	105.78	8.6914	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6937	0.30	103.76	8.7045	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7048	0.29	101.80	8.6887	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6901	0.30	100.04	8.7102	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7003	0.29	98.23	8.6869	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6937	0.29	95.28	8.7042	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6960	0.31	92.10	8.6991	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7010	0.29	90.59	8.7143	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6973	0.29	89.07	8.7005	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6970	0.30	87.67	8.7085	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7022	0.30	86.17	8.7140	0.30	271.28
22	8.7060	0.31	170.39	8.7005	0.31	189.82	68	8.7090	0.30	84.76	8.7123	N/A	272.74
24	8.7097	0.30	151.65	8.7088	0.31	208.46	70	8.7107	N/A	83.36	8.7241	N/A	274.18
26	8.7090	0.30	142.23	8.6967	0.30	217.99	72	8.7159	N/A	81.97	8.7176	N/A	275.61
28	8.7112	0.28	135.72	8.7057	0.33	224.55	74	8.7183	N/A	80.63	N/A	N/A	N/A
30	8.6953	0.31	130.12	8.6853	0.31	229.94	76	8.7215	N/A	79.15	N/A	N/A	N/A
32	8.7003	0.31	125.60	8.6975	0.31	234.51	78	8.7335	N/A	77.67	N/A	N/A	N/A
34	8.7015	0.30	121.84	8.6940	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7069	0.28	118.56	8.6761	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7063	0.30	115.50	8.6885	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6991	0.32	112.68	8.7060	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7045	0.30	110.22	8.7043	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7055	0.30	107.93	8.6976	0.30	252.33	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

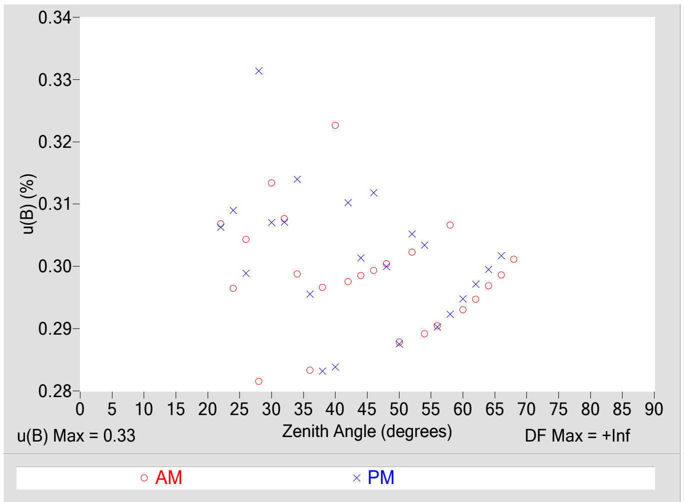


Figure 4. Residuals from Spline Interpolation

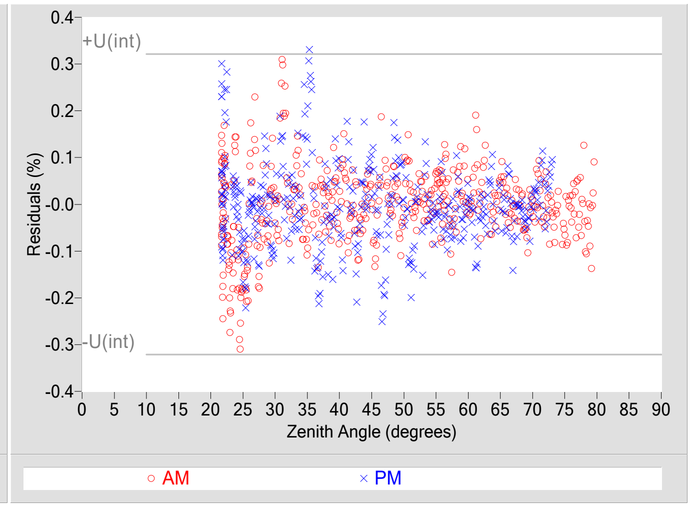


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	22234
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.72
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

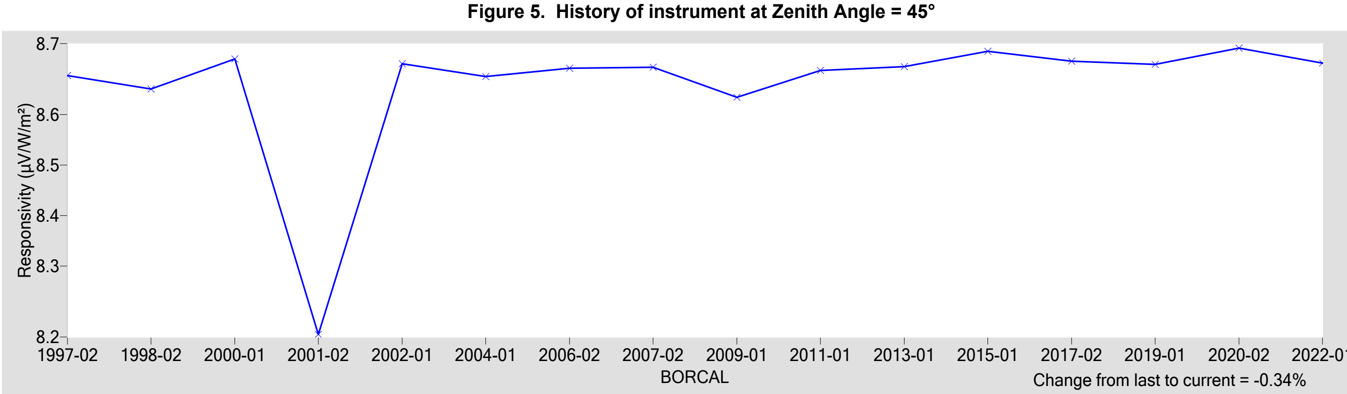
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.7016	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.15 / -0.29
Expanded Uncertainty, U (%)	+0.78 / -0.93
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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:**	29011E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

29011E6 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

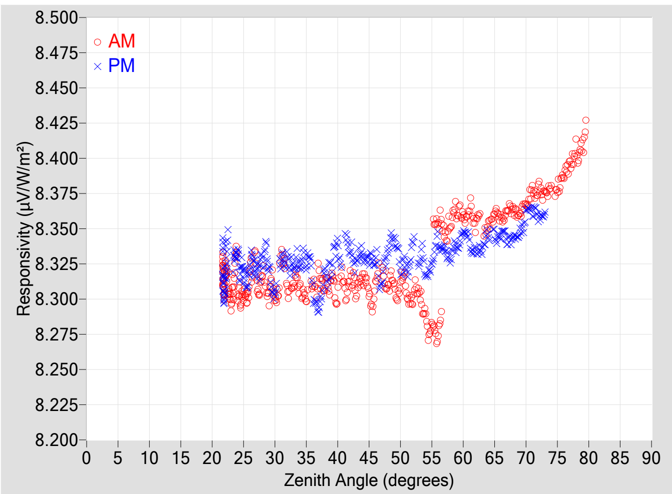


Figure 2. Responsivity vs Local Standard Time

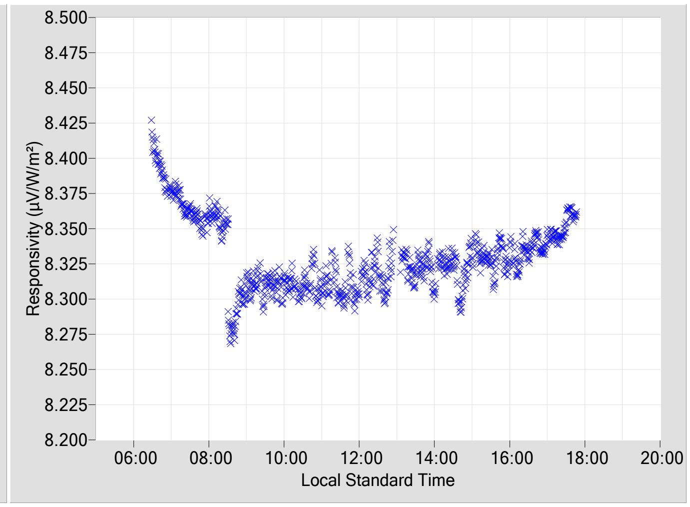


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3092	0.30	105.78	8.3274	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3082	0.30	103.76	8.3346	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3113	0.29	101.80	8.3209	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3007	0.30	100.04	8.3404	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2875	0.29	98.23	8.3191	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3100	0.29	95.28	8.3411	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3538	0.31	92.10	8.3293	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3588	0.29	90.59	8.3472	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3540	0.29	89.07	8.3342	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3528	0.30	87.67	8.3453	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3570	0.30	86.17	8.3455	0.30	271.28
22	8.3158	0.31	170.39	8.3123	0.31	189.82	68	8.3634	0.30	84.76	8.3437	N/A	272.74
24	8.3181	0.30	151.65	8.3309	0.31	208.46	70	8.3673	N/A	83.36	8.3600	N/A	274.18
26	8.3154	0.30	142.23	8.3240	0.30	217.99	72	8.3777	N/A	81.97	8.3581	N/A	275.61
28	8.3171	0.28	135.72	8.3275	0.33	224.55	74	8.3791	N/A	80.63	N/A	N/A	N/A
30	8.3014	0.31	130.12	8.3053	0.31	229.94	76	8.3876	N/A	79.15	N/A	N/A	N/A
32	8.3064	0.31	125.60	8.3274	0.31	234.51	78	8.4038	N/A	77.67	N/A	N/A	N/A
34	8.3063	0.30	121.84	8.3242	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3108	0.28	118.56	8.3088	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3099	0.30	115.50	8.3171	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3041	0.32	112.75	8.3358	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3132	0.30	110.22	8.3342	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3147	0.30	107.93	8.3304	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

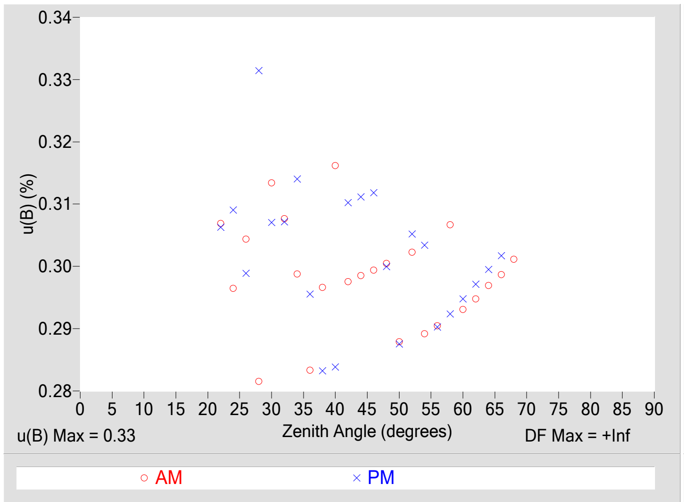


Figure 4. Residuals from Spline Interpolation

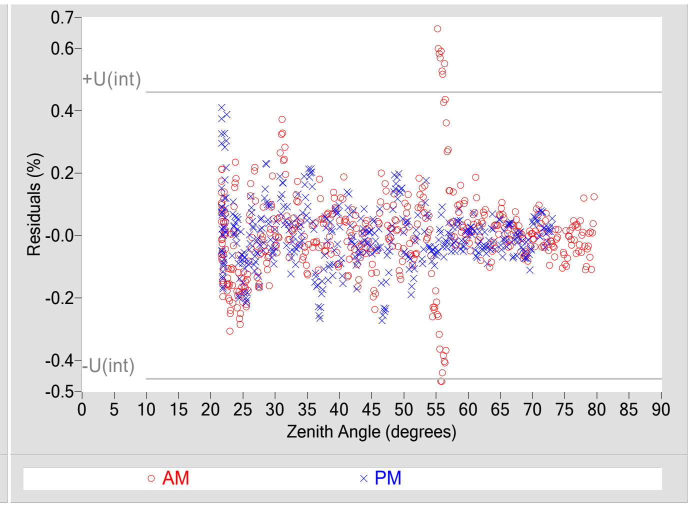


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	7616
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.79
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

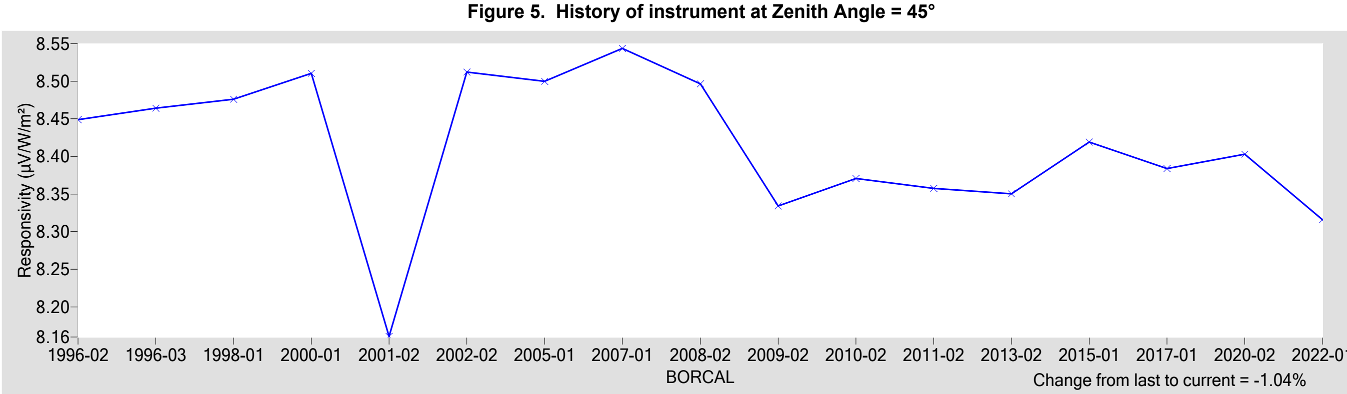
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3160	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.52 / -0.34
Expanded Uncertainty, U (%)	+1.1 / -0.96
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the 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:**	29278F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

29278F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

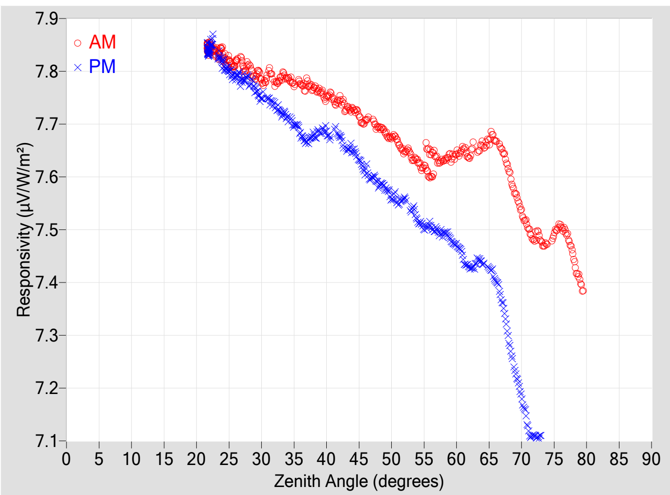


Figure 2. Responsivity vs Local Standard Time

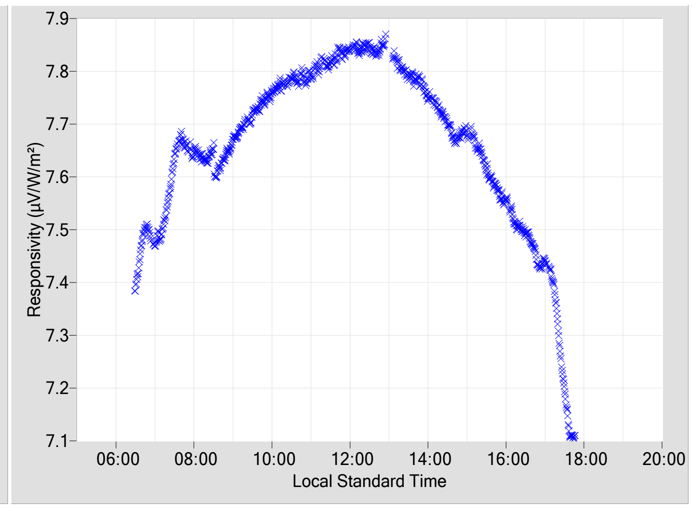


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.7059	0.42	105.78	7.6124	0.39	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6935	0.43	103.70	7.5858	0.44	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6747	0.44	101.87	7.5583	0.44	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6473	0.43	99.99	7.5580	0.44	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6307	0.44	98.29	7.5168	0.44	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6263	0.46	94.96	7.5070	0.45	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6312	0.45	92.11	7.4923	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6427	0.47	90.59	7.4701	0.50	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6402	0.49	89.08	7.4281	0.53	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.6600	0.51	87.62	7.4362	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.6685	0.54	86.23	7.4033	0.59	271.28
22	7.8435	0.37	170.79	7.8402	0.36	189.59	68	7.6145	0.57	84.76	7.2933	N/A	272.74
24	7.8332	0.40	151.42	7.8160	0.38	208.63	70	7.5333	N/A	83.36	7.1786	N/A	274.23
26	7.8156	0.36	142.24	7.7908	0.36	218.00	72	7.4840	N/A	81.97	7.1092	N/A	275.66
28	7.8124	0.38	135.70	7.7819	0.39	224.64	74	7.4724	N/A	80.63	N/A	N/A	N/A
30	7.7850	0.41	130.25	7.7498	0.37	229.95	76	7.5065	N/A	79.10	N/A	N/A	N/A
32	7.7769	0.36	125.50	7.7364	0.40	234.40	78	7.4455	N/A	77.67	N/A	N/A	N/A
34	7.7868	0.38	121.90	7.7104	0.38	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7761	0.37	118.43	7.6813	0.38	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7677	0.37	115.42	7.6774	0.38	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7496	0.38	112.76	7.6848	0.39	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7457	0.40	110.30	7.6772	0.38	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7275	0.41	107.87	7.6520	0.44	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

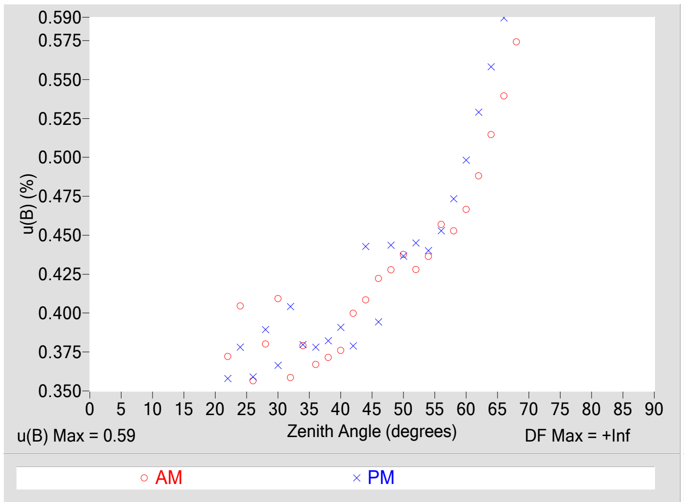


Figure 4. Residuals from Spline Interpolation

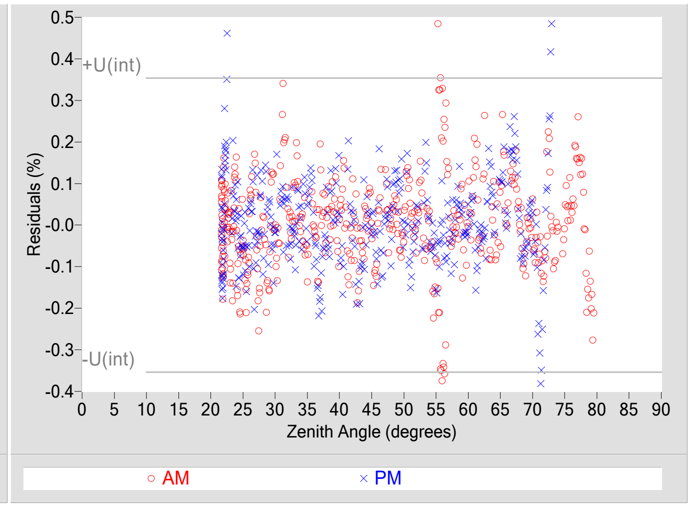


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	117336
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

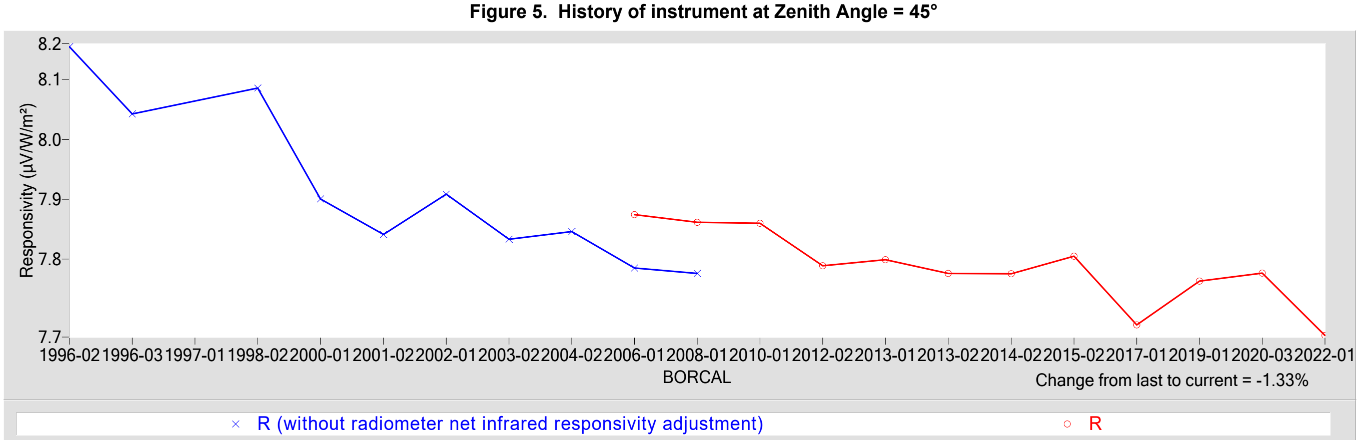
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6729	0.56800

† Rnet determination date: 04/05/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.5 / -2.6
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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29541E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

29541E6 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

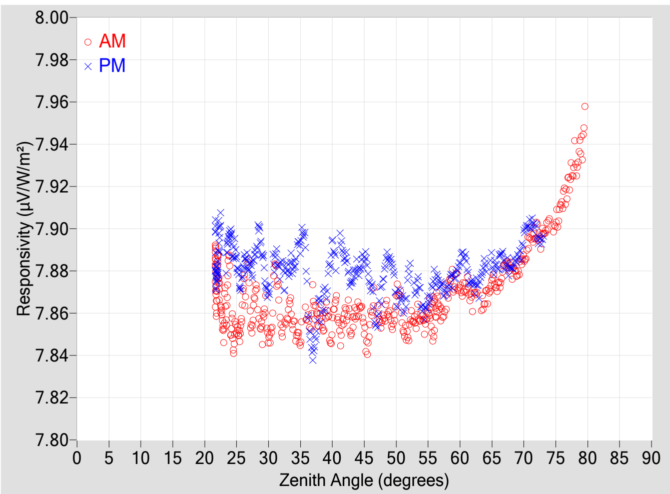


Figure 2. Responsivity vs Local Standard Time

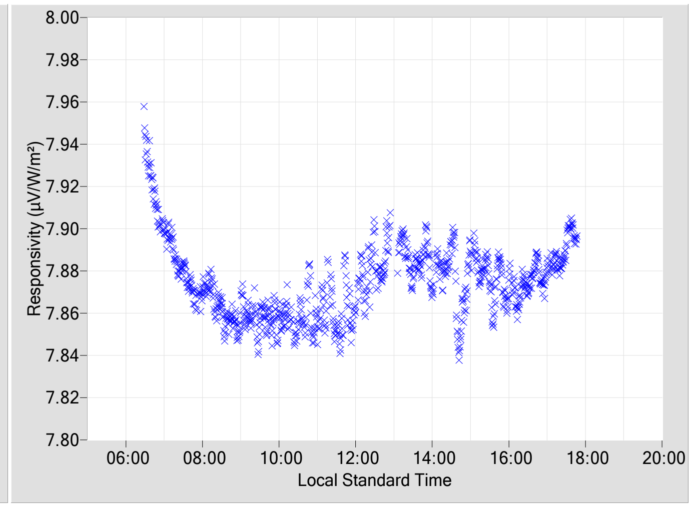


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8567	0.30	105.78	7.8734	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8569	0.30	103.76	7.8777	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8660	0.29	101.80	7.8664	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8517	0.30	100.04	7.8797	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8576	0.29	98.23	7.8646	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8584	0.29	95.28	7.8763	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8689	0.31	92.10	7.8712	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8717	0.29	90.59	7.8853	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8676	0.29	89.07	7.8736	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8675	0.30	87.67	7.8828	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8729	0.30	86.17	7.8840	0.30	271.28
22	7.8760	0.31	170.39	7.8828	0.31	189.82	68	7.8805	0.30	84.76	7.8814	N/A	272.74
24	7.8689	0.30	151.65	7.8970	0.31	208.46	70	7.8858	N/A	83.36	7.8966	N/A	274.18
26	7.8672	0.30	142.23	7.8815	0.30	217.99	72	7.8980	N/A	81.97	7.8974	N/A	275.61
28	7.8700	0.28	135.72	7.8896	0.33	224.55	74	7.9027	N/A	80.63	N/A	N/A	N/A
30	7.8489	0.31	130.12	7.8700	0.31	229.94	76	7.9125	N/A	79.15	N/A	N/A	N/A
32	7.8531	0.31	125.60	7.8816	0.31	234.51	78	7.9315	N/A	77.67	N/A	N/A	N/A
34	7.8529	0.30	121.84	7.8822	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8589	0.28	118.56	7.8725	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8579	0.30	115.50	7.8641	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8554	0.32	112.68	7.8909	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8591	0.30	110.22	7.8859	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8614	0.30	107.93	7.8813	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

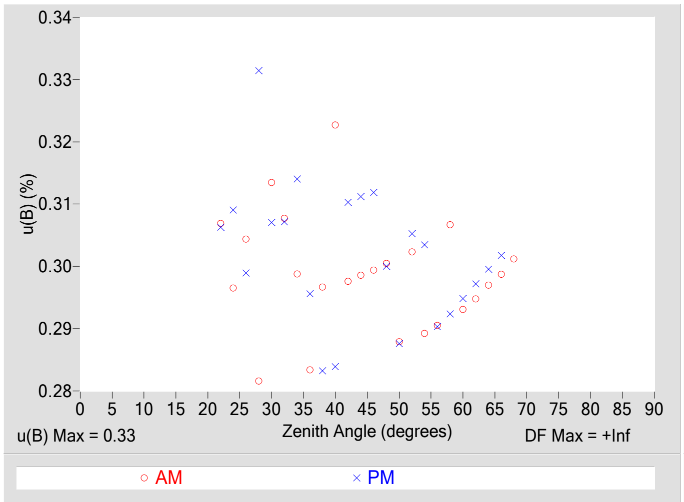


Figure 4. Residuals from Spline Interpolation

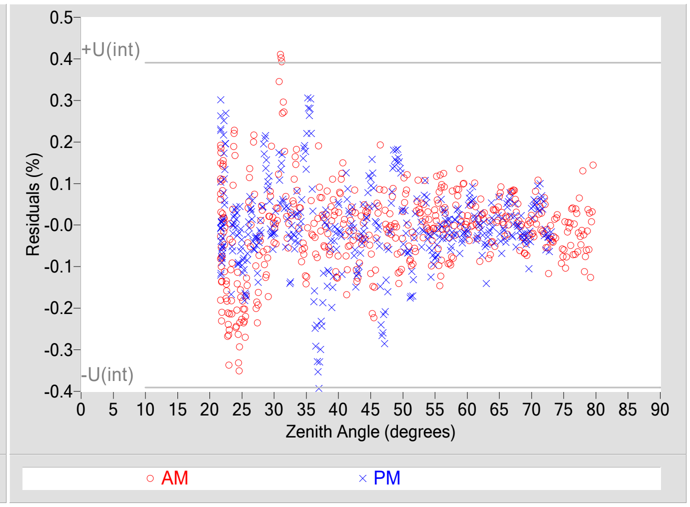


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	12092
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

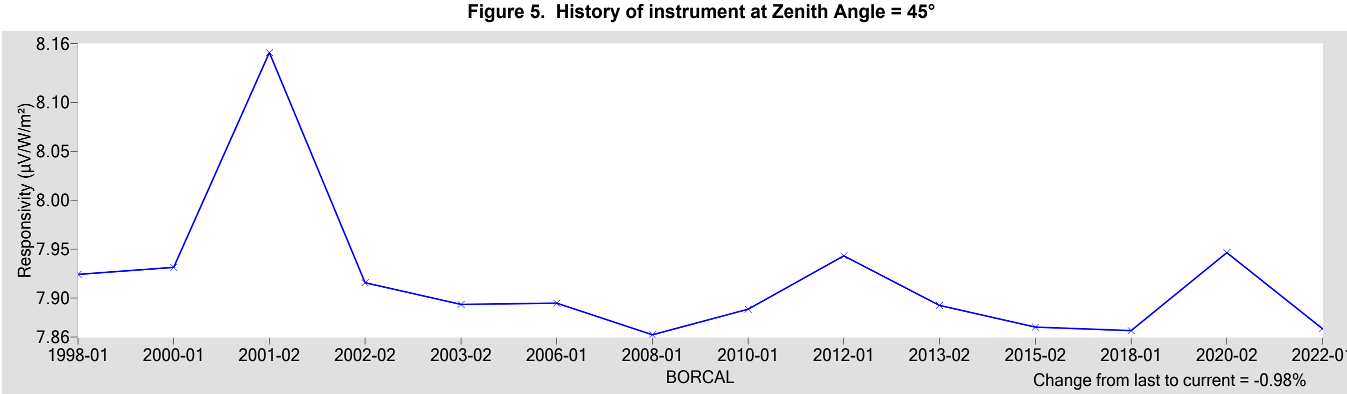
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8685	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.28 / -0.25
Expanded Uncertainty, U (%)	+0.92 / -0.88
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

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

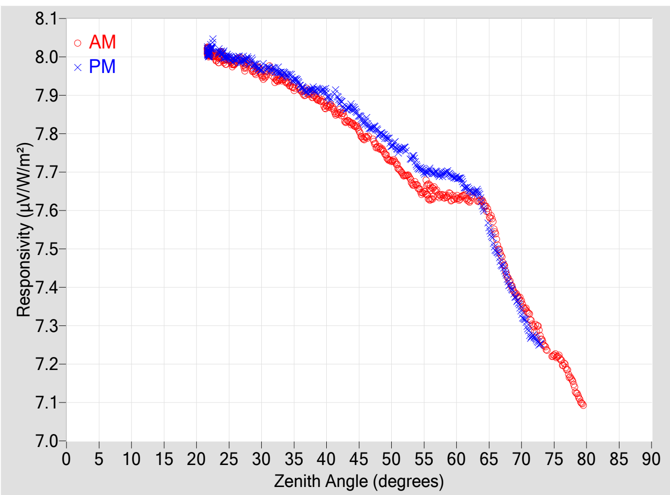


Figure 2. Responsivity vs Local Standard Time

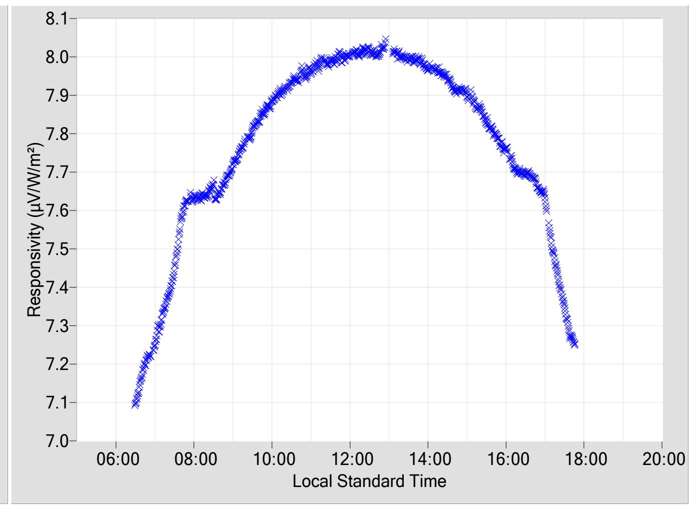


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.7897	0.42	105.78	7.8300	0.39	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.7634	0.43	103.70	7.8026	0.44	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.7295	0.44	101.87	7.7691	0.44	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6913	0.43	99.99	7.7613	0.44	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6628	0.44	98.29	7.7128	0.44	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6466	0.46	94.96	7.7026	0.45	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6368	0.45	92.11	7.6950	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6330	0.47	90.59	7.6848	0.50	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.6273	0.49	89.08	7.6526	0.53	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.6215	0.51	87.62	7.6091	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5402	0.54	86.23	7.4970	0.59	271.28
22	8.0113	0.37	170.79	8.0118	0.36	189.59	68	7.4207	0.58	84.76	7.4113	N/A	272.74
24	7.9999	0.40	151.42	8.0071	0.38	208.63	70	7.3613	N/A	83.36	7.3303	N/A	274.23
26	7.9863	0.36	142.24	7.9950	0.36	218.00	72	7.2959	N/A	81.97	7.2690	N/A	275.66
28	7.9834	0.38	135.70	7.9900	0.39	224.64	74	7.2366	N/A	80.63	N/A	N/A	N/A
30	7.9556	0.41	130.25	7.9691	0.37	229.95	76	7.2110	N/A	79.10	N/A	N/A	N/A
32	7.9398	0.36	125.50	7.9659	0.40	234.40	78	7.1456	N/A	77.67	N/A	N/A	N/A
34	7.9333	0.38	121.90	7.9505	0.38	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9137	0.37	118.43	7.9238	0.38	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8971	0.37	115.42	7.9148	0.38	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8701	0.38	112.76	7.9052	0.39	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8553	0.40	110.30	7.8866	0.38	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8240	0.41	107.87	7.8680	0.44	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

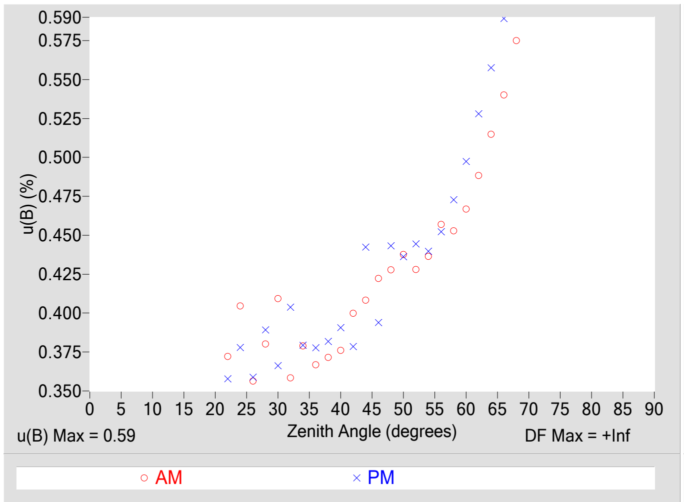


Figure 4. Residuals from Spline Interpolation

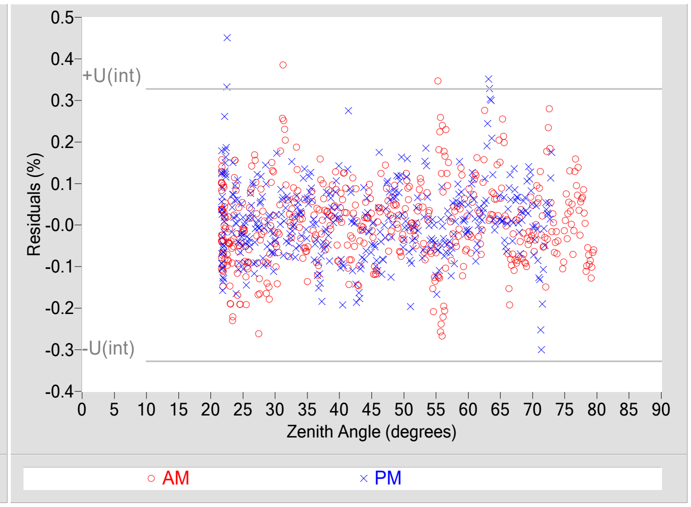


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	155606
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

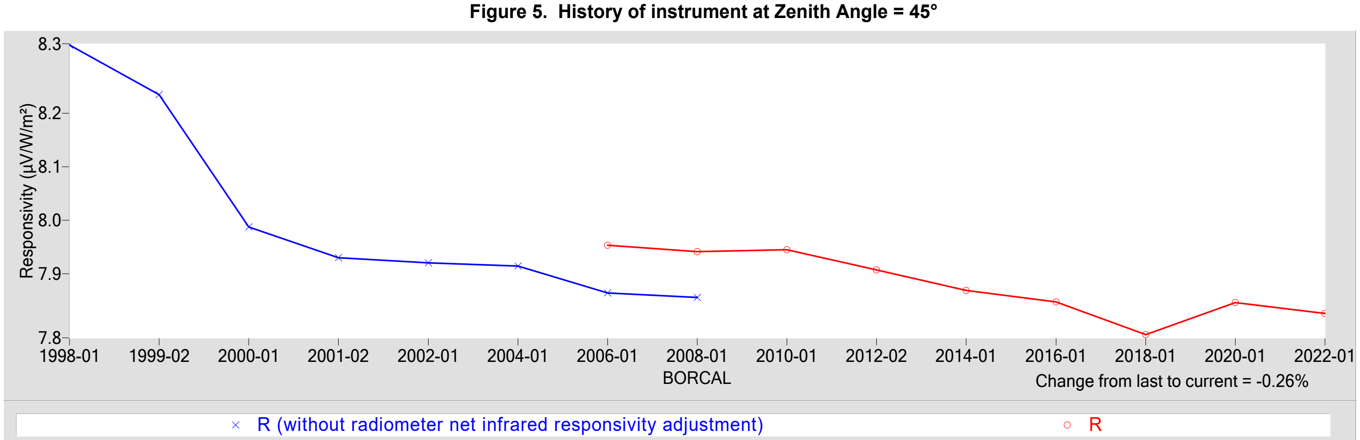
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8252	0.57100

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.8 / -2.5
Expanded Uncertainty, U (%)	+2.8 / -3.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	29609F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

29609F3 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

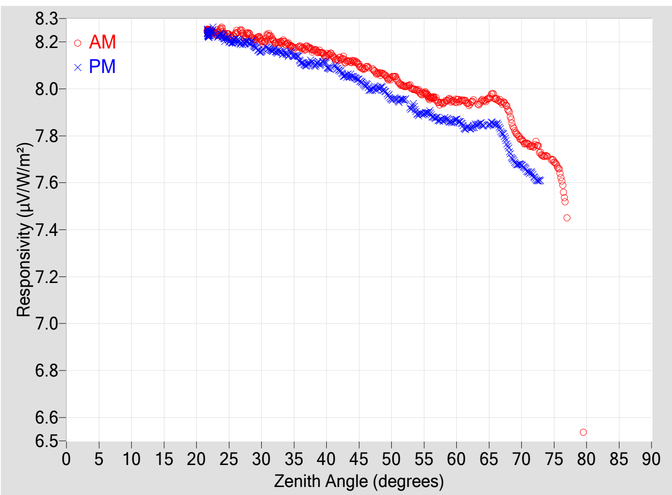


Figure 2. Responsivity vs Local Standard Time

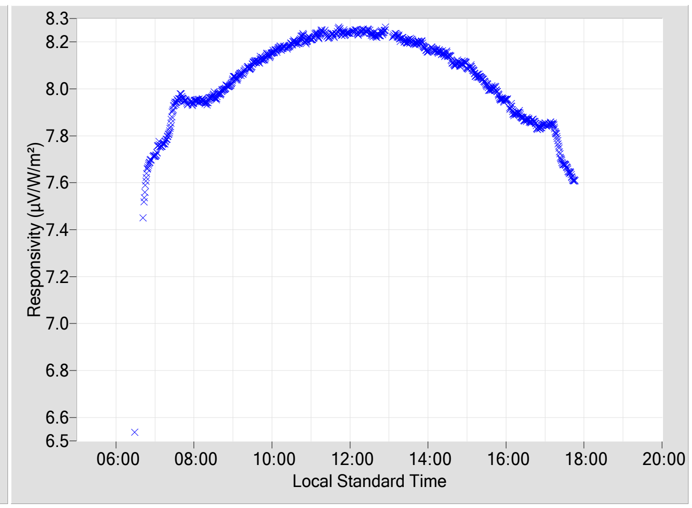


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0891	0.42	105.81	8.0164	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0661	0.41	103.79	8.0037	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0479	0.44	101.83	7.9563	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0111	0.43	100.01	7.9546	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9938	0.44	98.26	7.8934	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9615	0.47	95.11	7.8942	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9402	0.46	92.08	7.8681	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9503	0.47	90.56	7.8684	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9363	0.49	89.10	7.8344	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9498	0.52	87.64	7.8466	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9582	0.54	86.19	7.8492	0.59	271.30
22	8.2439	0.36	170.80	8.2319	0.37	189.45	68	7.9064	0.61	84.78	7.7448	N/A	272.76
24	8.2457	0.38	151.44	8.2242	0.37	208.66	70	7.7840	N/A	83.38	7.6750	N/A	274.20
26	8.2338	0.37	142.41	8.2060	0.36	217.79	72	7.7612	N/A	81.94	7.6221	N/A	275.64
28	8.2355	0.39	135.64	8.1967	0.36	224.64	74	7.7149	N/A	80.65	N/A	N/A	N/A
30	8.2058	0.38	130.17	8.1612	0.38	229.87	76	7.6320	N/A	79.12	N/A	N/A	N/A
32	8.2007	0.40	125.77	8.1624	0.39	234.42	78	N/A	N/A	N/A	N/A	N/A	N/A
34	8.1915	0.41	121.83	8.1458	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1775	0.40	118.46	8.1144	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1644	0.39	115.54	8.1049	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1416	0.39	112.71	8.1032	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1284	0.38	110.26	8.0797	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1157	0.39	107.97	8.0540	0.44	252.15	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

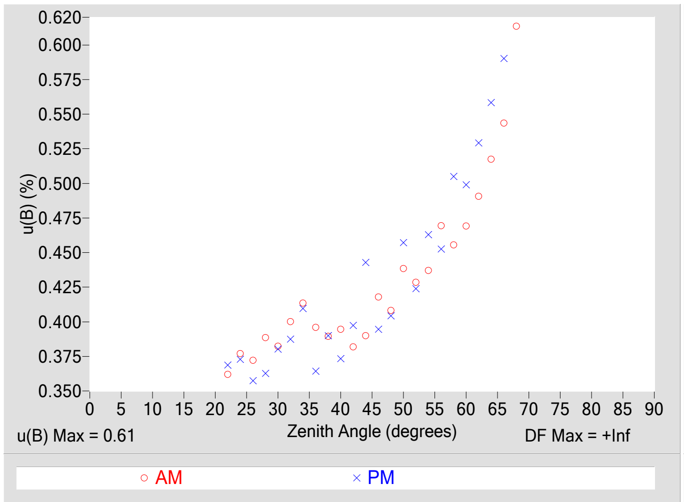


Figure 4. Residuals from Spline Interpolation

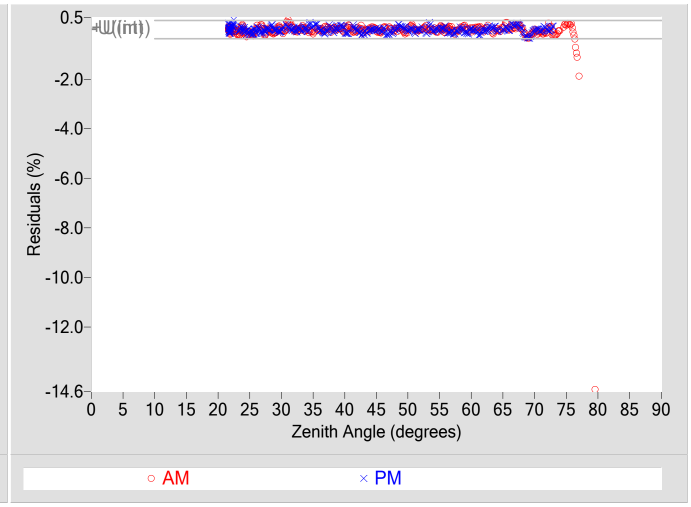


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	119117
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

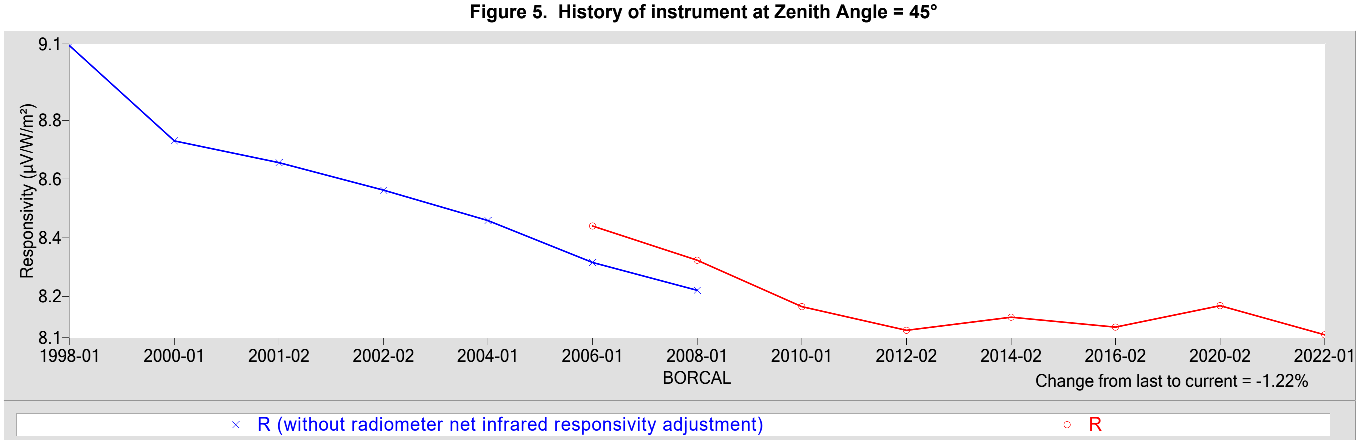
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0696	0.63600

† Rnet determination date: 04/20/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.7 / -2.5
Expanded Uncertainty, U (%)	+2.7 / -3.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

[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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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 - 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

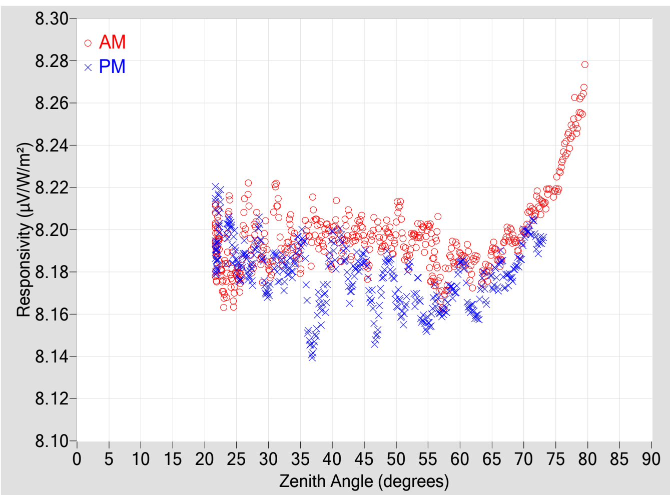


Figure 2. Responsivity vs Local Standard Time

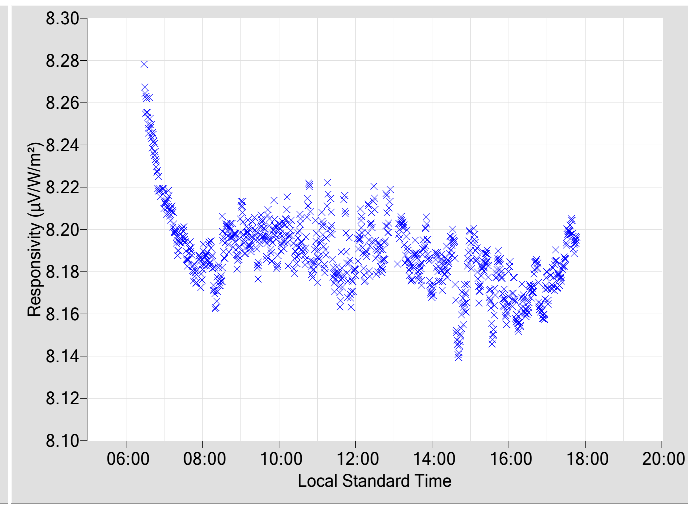


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1928	0.30	105.78	8.1685	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1928	0.30	103.76	8.1800	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2032	0.29	101.80	8.1659	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1865	0.30	100.04	8.1824	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2003	0.29	98.23	8.1594	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1836	0.29	95.28	8.1679	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1759	0.31	92.10	8.1658	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1877	0.29	90.59	8.1840	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1806	0.29	89.07	8.1620	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1803	0.30	87.67	8.1707	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1848	0.30	86.17	8.1780	0.30	271.28
22	8.1931	0.31	170.39	8.1919	0.31	189.82	68	8.1977	0.30	84.76	8.1772	N/A	272.74
24	8.1945	0.30	151.65	8.2020	0.31	208.46	70	8.1992	N/A	83.36	8.1961	N/A	274.18
26	8.1957	0.30	142.23	8.1876	0.30	217.99	72	8.2118	N/A	81.97	8.1934	N/A	275.61
28	8.2027	0.28	135.72	8.1921	0.33	224.55	74	8.2185	N/A	80.63	N/A	N/A	N/A
30	8.1829	0.31	130.12	8.1708	0.31	229.94	76	8.2317	N/A	79.15	N/A	N/A	N/A
32	8.1889	0.31	125.60	8.1831	0.31	234.51	78	8.2526	N/A	77.67	N/A	N/A	N/A
34	8.1915	0.30	121.84	8.1834	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2008	0.28	118.56	8.1660	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1972	0.30	115.50	8.1641	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1916	0.32	112.68	8.1953	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1975	0.30	110.22	8.1855	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2003	0.30	107.93	8.1838	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

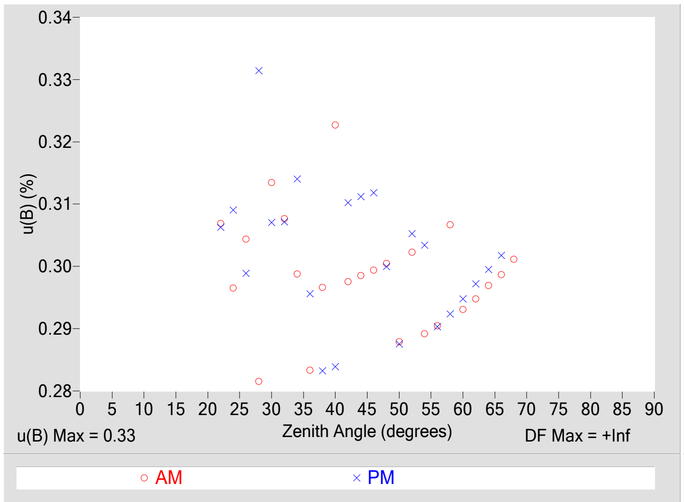


Figure 4. Residuals from Spline Interpolation

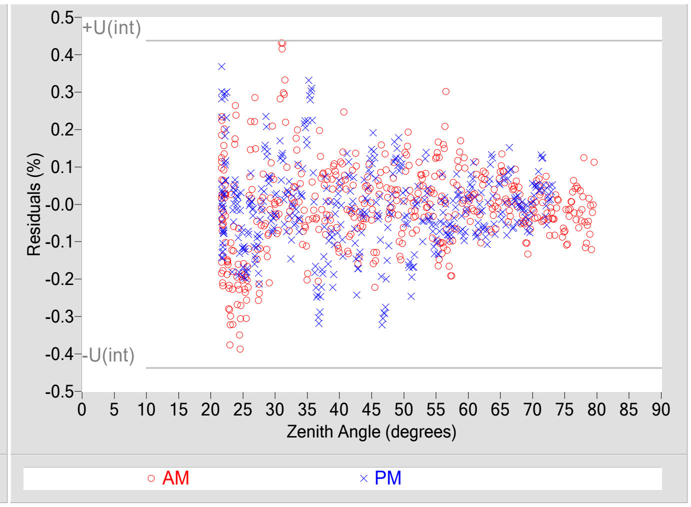


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	8717
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

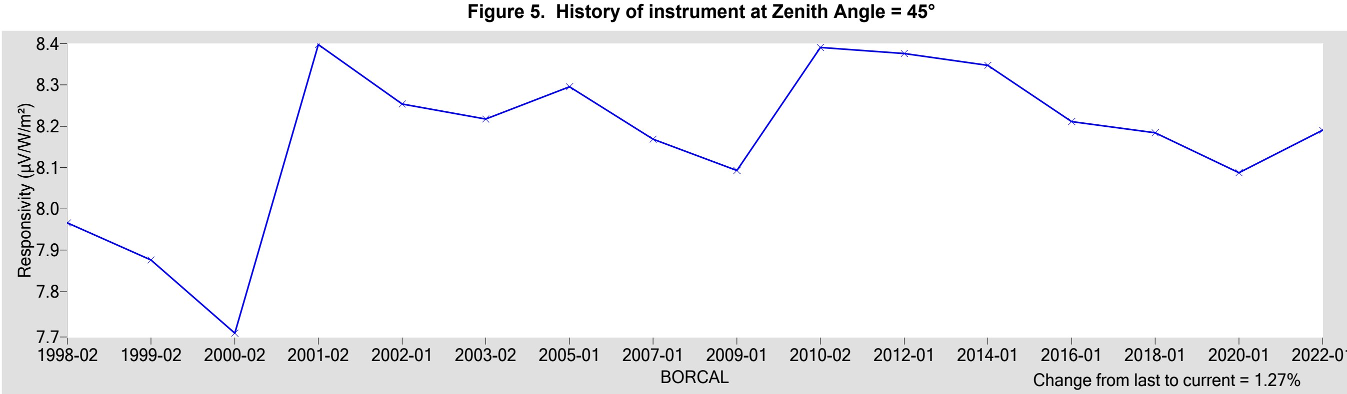
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.1904	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.16 / -0.38
Expanded Uncertainty, U (%)	+0.79 / -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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29848E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

where,

- V = radiometer output voltage (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

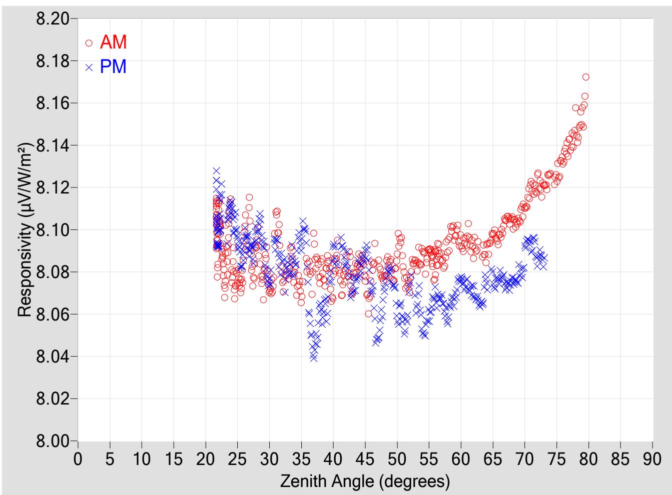


Figure 2. Responsivity vs Local Standard Time

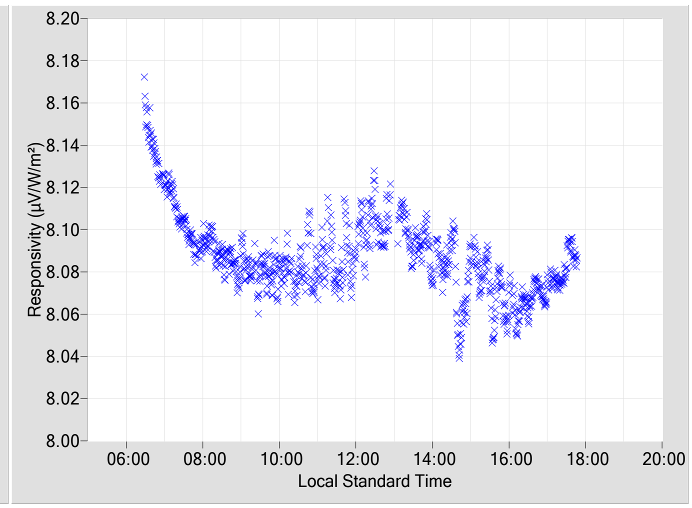


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0786	0.30	105.78	8.0721	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0776	0.30	103.76	8.0723	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0891	0.29	101.80	8.0590	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0756	0.30	100.04	8.0743	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0885	0.29	98.23	8.0529	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0836	0.29	95.28	8.0671	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0931	0.31	92.10	8.0587	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0933	0.29	90.59	8.0764	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0915	0.29	89.07	8.0701	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0897	0.30	87.67	8.0754	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0962	0.30	86.17	8.0769	0.30	271.28
22	8.1001	0.31	170.39	8.0991	0.31	189.82	68	8.1042	0.30	84.76	8.0757	N/A	272.74
24	8.0951	0.30	151.65	8.1101	0.31	208.46	70	8.1109	N/A	83.36	8.0884	N/A	274.18
26	8.0918	0.30	142.23	8.0926	0.30	217.99	72	8.1216	N/A	81.97	8.0860	N/A	275.61
28	8.0942	0.28	135.72	8.0988	0.33	224.55	74	8.1261	N/A	80.63	N/A	N/A	N/A
30	8.0730	0.31	130.12	8.0760	0.31	229.94	76	8.1334	N/A	79.15	N/A	N/A	N/A
32	8.0767	0.31	125.60	8.0836	0.31	234.51	78	8.1477	N/A	77.67	N/A	N/A	N/A
34	8.0766	0.30	121.84	8.0832	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0838	0.28	118.56	8.0745	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0802	0.30	115.50	8.0616	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0761	0.32	112.68	8.0897	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0807	0.30	110.22	8.0844	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0841	0.30	107.93	8.0811	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

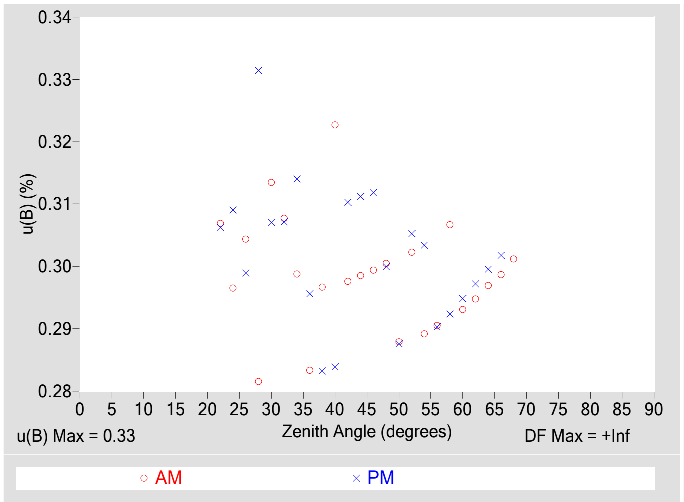


Figure 4. Residuals from Spline Interpolation

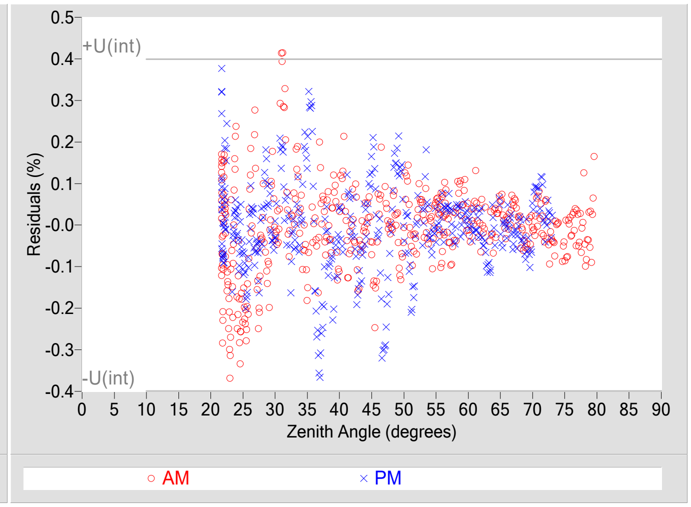


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	11393
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.76
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

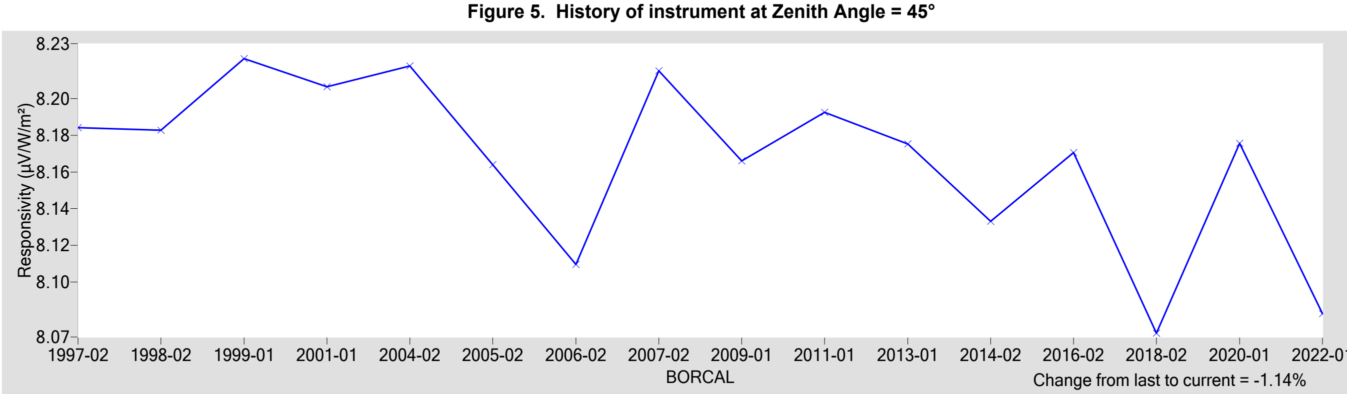
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0827	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.13 / -0.37
Expanded Uncertainty, U (%)	+0.76 / -1.0
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	29911F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

29911F3 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

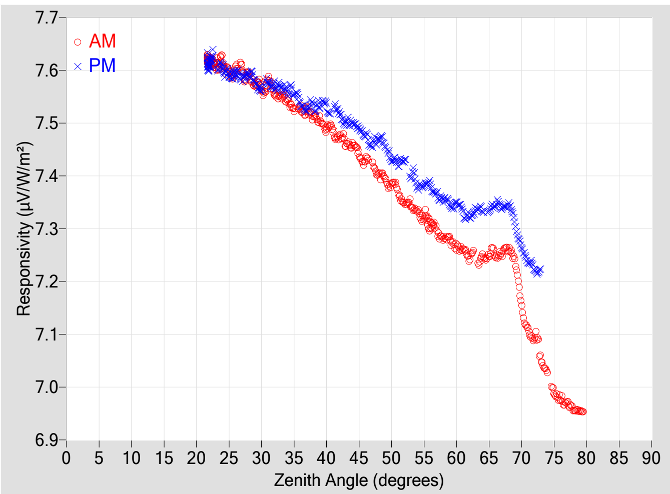


Figure 2. Responsivity vs Local Standard Time

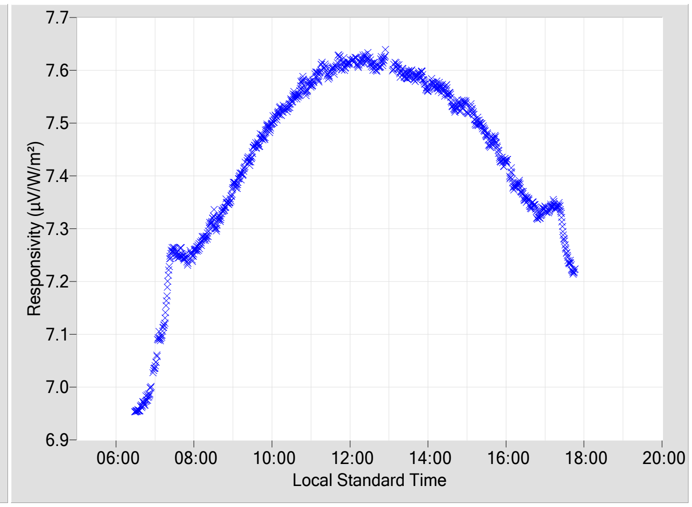


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.4286	0.42	105.81	7.4771	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4036	0.41	103.79	7.4686	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3844	0.44	101.83	7.4295	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3478	0.43	100.01	7.4291	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3330	0.44	98.26	7.3792	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3063	0.47	95.11	7.3822	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2815	0.46	92.08	7.3551	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.2658	0.47	90.56	7.3490	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2449	0.49	89.10	7.3233	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2465	0.52	87.64	7.3344	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.2478	0.54	86.19	7.3454	0.59	271.30
22	7.6178	0.36	170.80	7.6097	0.37	189.45	68	7.2601	0.61	84.78	7.3438	N/A	272.76
24	7.6171	0.38	151.44	7.6048	0.37	208.66	70	7.1581	N/A	83.38	7.2648	N/A	274.20
26	7.6005	0.37	142.41	7.5943	0.36	217.79	72	7.0945	N/A	81.94	7.2227	N/A	275.64
28	7.5945	0.39	135.64	7.5903	0.36	224.64	74	7.0314	N/A	80.65	N/A	N/A	N/A
30	7.5639	0.38	130.17	7.5648	0.38	229.87	76	6.9797	N/A	79.12	N/A	N/A	N/A
32	7.5566	0.40	125.77	7.5716	0.39	234.42	78	6.9577	N/A	77.69	N/A	N/A	N/A
34	7.5420	0.41	121.83	7.5593	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5266	0.40	118.46	7.5348	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5129	0.39	115.54	7.5301	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4885	0.39	112.71	7.5317	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4740	0.38	110.26	7.5197	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4569	0.39	107.97	7.5009	0.44	252.15	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

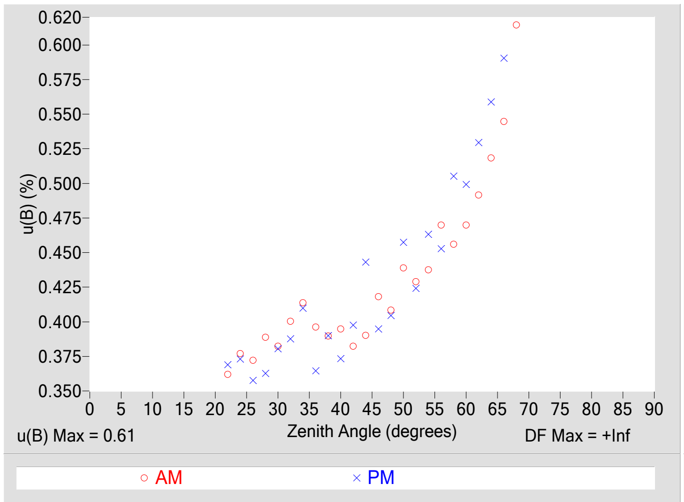


Figure 4. Residuals from Spline Interpolation

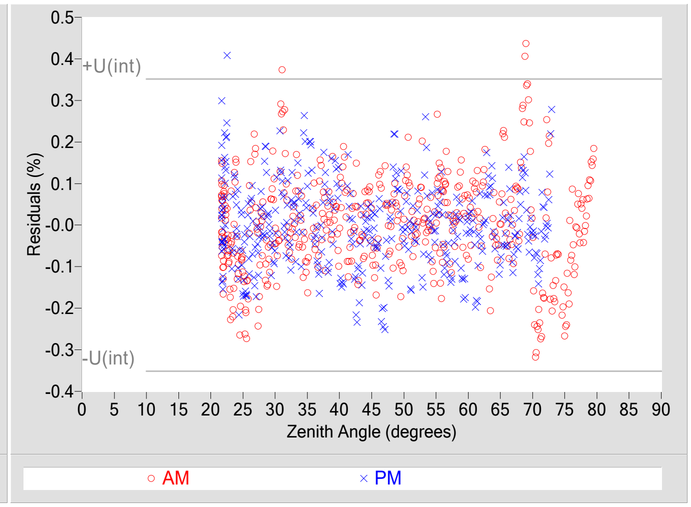


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	140072
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

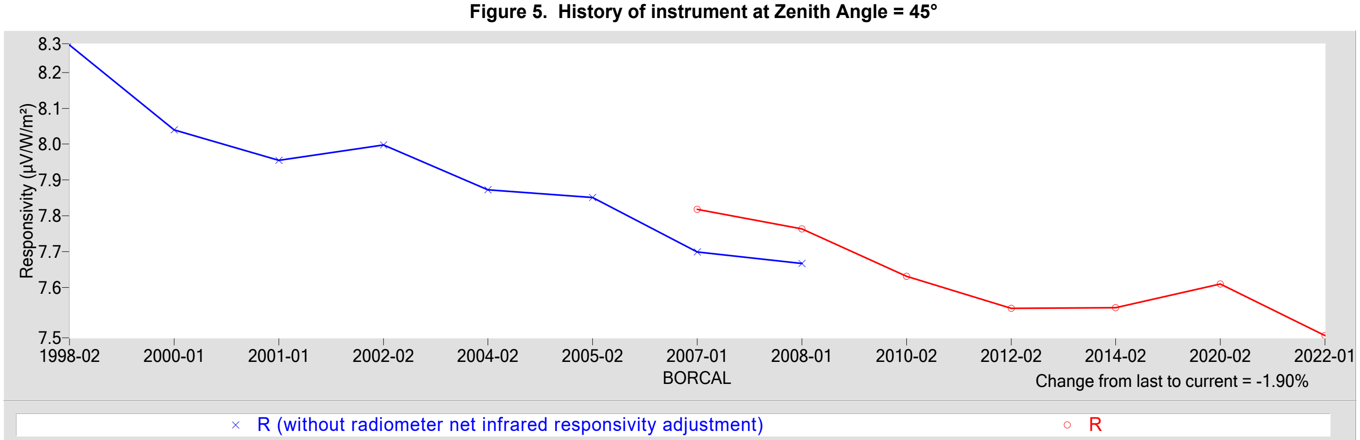
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.4660	0.59755

† Rnet determination date: 04/24/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.4 / -2.7
Expanded Uncertainty, U (%)	+2.4 / -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:**	29917F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

29917F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

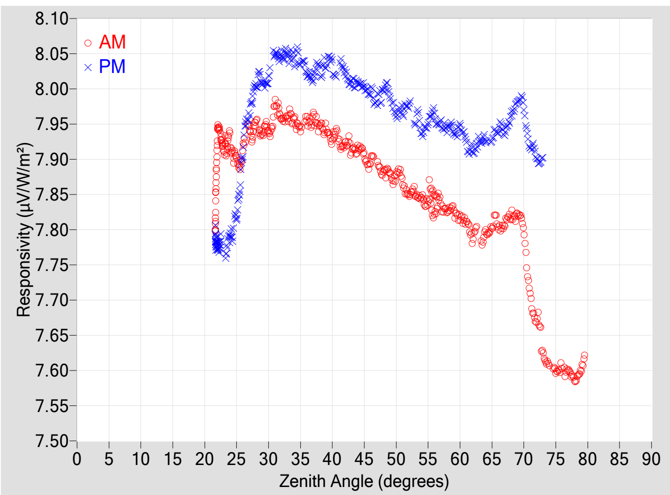


Figure 2. Responsivity vs Local Standard Time

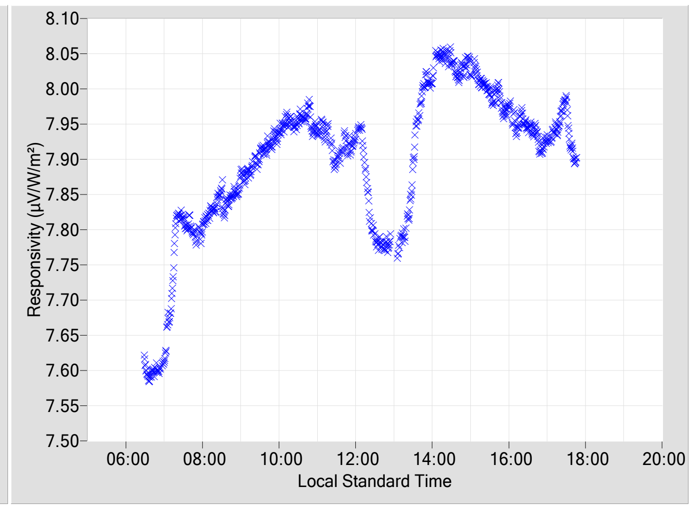


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.8963	0.42	105.81	7.9957	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8815	0.41	103.79	7.9986	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8775	0.44	101.83	7.9630	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8496	0.43	100.01	7.9778	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8454	0.44	98.26	7.9377	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8358	0.47	95.11	7.9629	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8266	0.45	92.08	7.9443	0.50	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8173	0.47	90.56	7.9465	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7894	0.49	89.10	7.9127	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7945	0.52	87.64	7.9278	0.55	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8048	0.54	86.19	7.9421	0.59	271.30
22	7.8986	0.36	170.80	7.7786	0.37	189.45	68	7.8187	0.61	84.78	7.9623	N/A	272.76
24	7.9230	0.38	151.44	7.7913	0.37	208.66	70	7.7962	N/A	83.38	7.9695	N/A	274.20
26	7.9132	0.37	142.41	7.9143	0.36	217.79	72	7.6737	N/A	81.94	7.9019	N/A	275.64
28	7.9520	0.39	135.64	8.0038	0.36	224.64	74	7.6100	N/A	80.65	N/A	N/A	N/A
30	7.9389	0.38	130.17	8.0149	0.38	229.87	76	7.6068	N/A	79.21	N/A	N/A	N/A
32	7.9592	0.40	125.77	8.0482	0.39	234.42	78	7.5862	N/A	77.69	N/A	N/A	N/A
34	7.9553	0.41	121.83	8.0408	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9551	0.40	118.46	8.0208	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9473	0.39	115.54	8.0255	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9288	0.39	112.71	8.0331	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9210	0.38	110.26	8.0248	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9128	0.39	107.97	8.0092	0.44	252.15	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

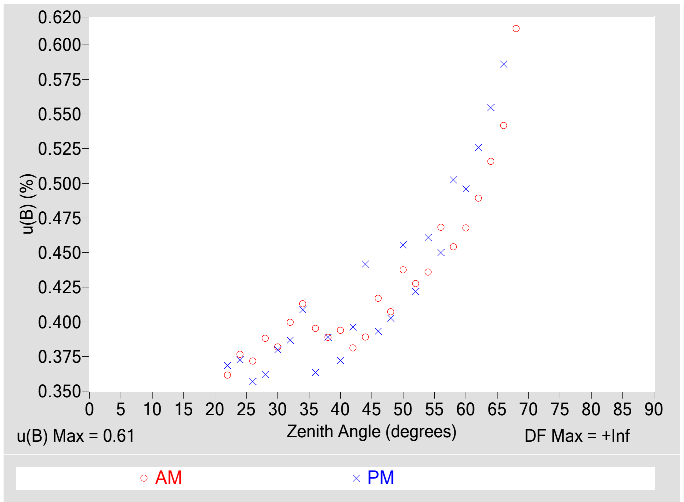


Figure 4. Residuals from Spline Interpolation

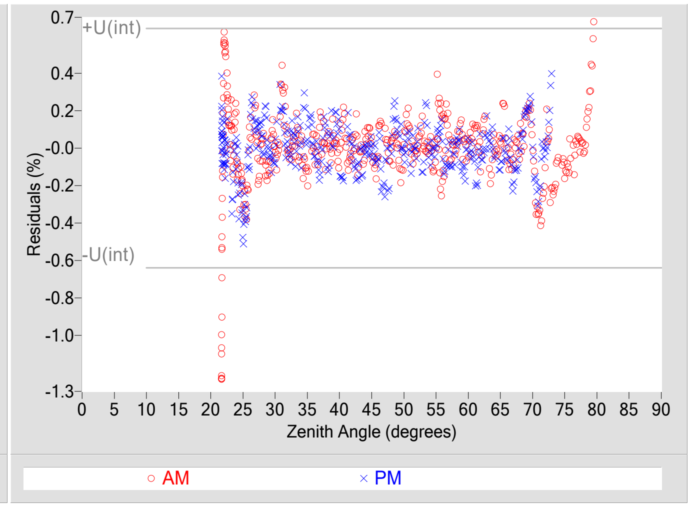


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.32
Combined Standard Uncertainty, u(c) (%)	±0.69
Effective degrees of freedom, DF(c)	17291
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.4
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

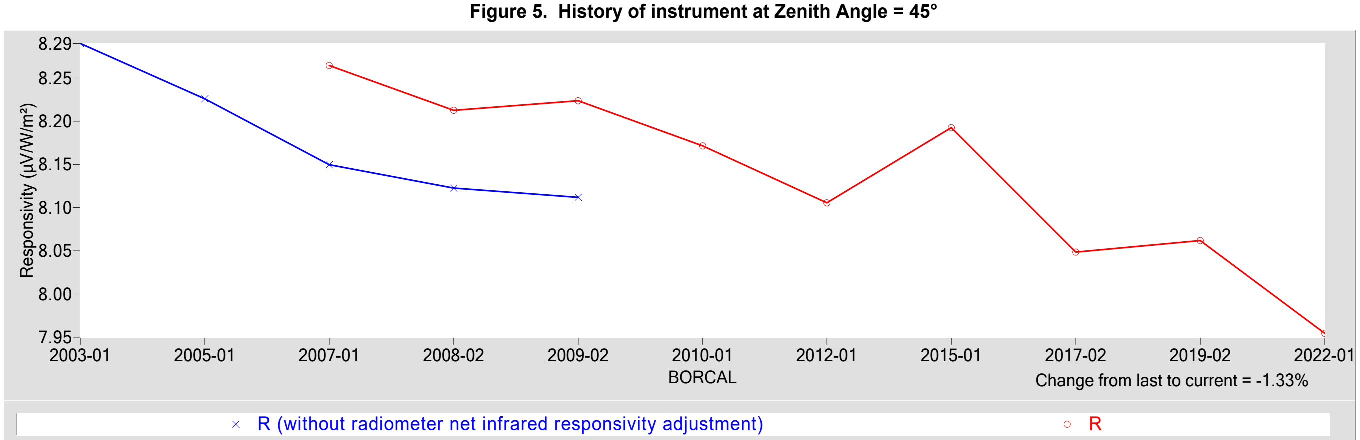
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9544	0.58000

† Rnet determination date: 06/28/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.2 / -1.7
Expanded Uncertainty, U (%)	+2.2 / -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:**	29935E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

29935E6 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

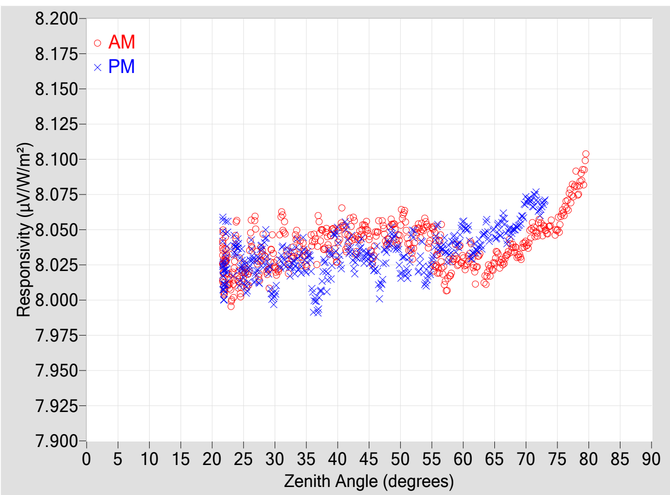


Figure 2. Responsivity vs Local Standard Time

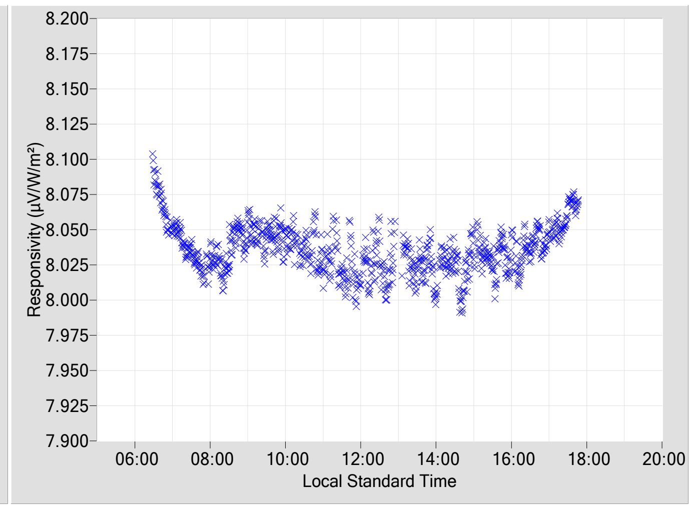


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0424	0.30	105.78	8.0267	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0411	0.30	103.76	8.0384	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0528	0.29	101.80	8.0196	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0353	0.30	100.04	8.0475	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0542	0.29	98.23	8.0135	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0299	0.29	95.28	8.0448	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0219	0.31	92.10	8.0338	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0281	0.29	90.59	8.0536	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0196	0.29	89.07	8.0360	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0209	0.30	87.67	8.0480	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0257	0.30	86.17	8.0510	0.30	271.28
22	8.0247	0.31	170.39	8.0178	0.31	189.82	68	8.0371	0.30	84.76	8.0495	N/A	272.74
24	8.0324	0.30	151.65	8.0362	0.31	208.46	70	8.0400	N/A	83.36	8.0701	N/A	274.18
26	8.0337	0.30	142.23	8.0291	0.30	217.99	72	8.0512	N/A	81.97	8.0655	N/A	275.61
28	8.0360	0.28	135.72	8.0326	0.33	224.55	74	8.0539	N/A	80.63	N/A	N/A	N/A
30	8.0239	0.31	130.12	8.0041	0.31	229.94	76	8.0629	N/A	79.15	N/A	N/A	N/A
32	8.0274	0.31	125.60	8.0300	0.31	234.51	78	8.0821	N/A	77.67	N/A	N/A	N/A
34	8.0337	0.30	121.84	8.0255	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0433	0.28	118.56	8.0050	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0417	0.30	115.50	8.0218	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0375	0.32	112.68	8.0401	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0479	0.30	110.22	8.0367	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0497	0.30	107.93	8.0327	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

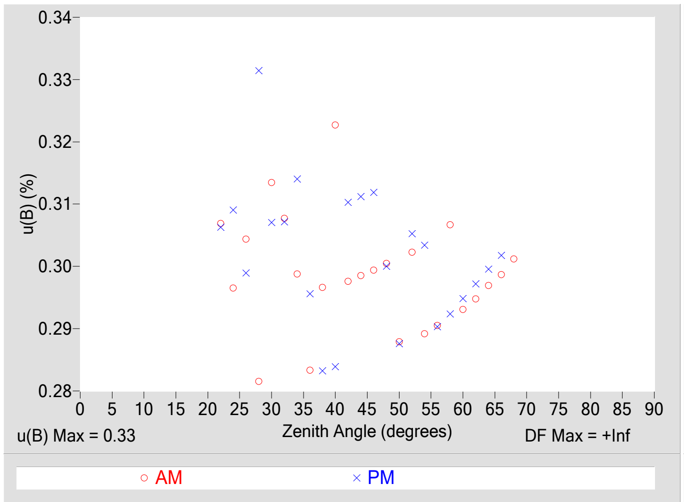


Figure 4. Residuals from Spline Interpolation

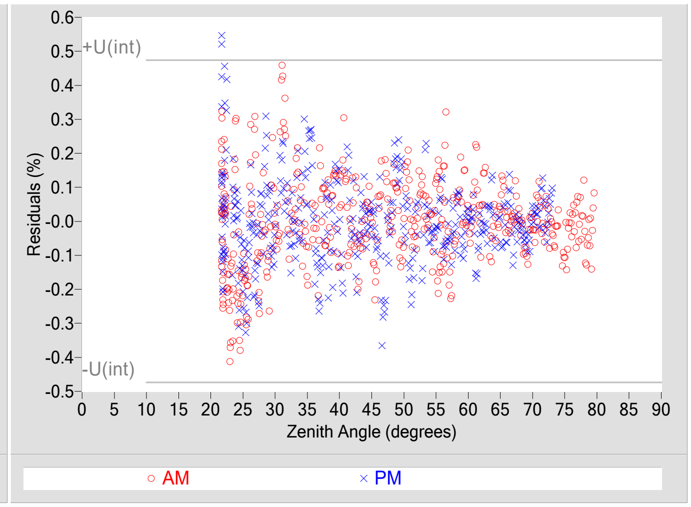


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.41
Effective degrees of freedom, DF(c)	7033
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.80
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

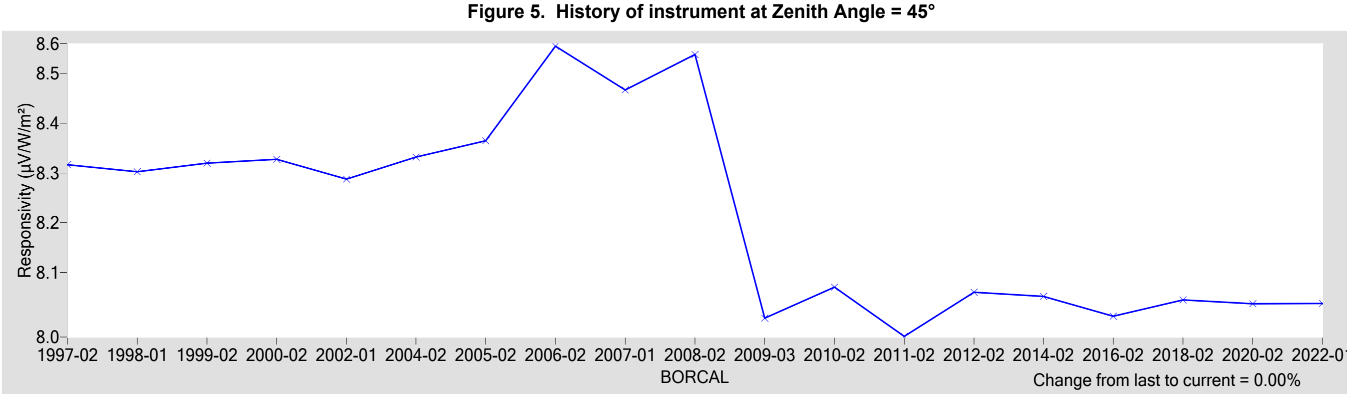
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0372	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.21 / -0.41
Expanded Uncertainty, U (%)	+0.84 / -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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	29937E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

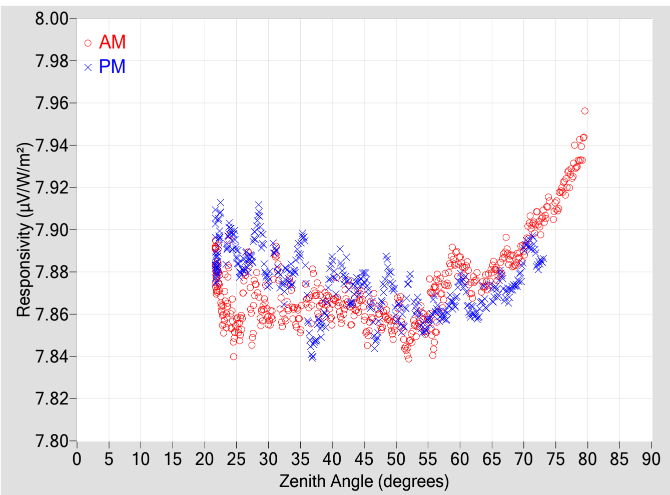


Figure 2. Responsivity vs Local Standard Time

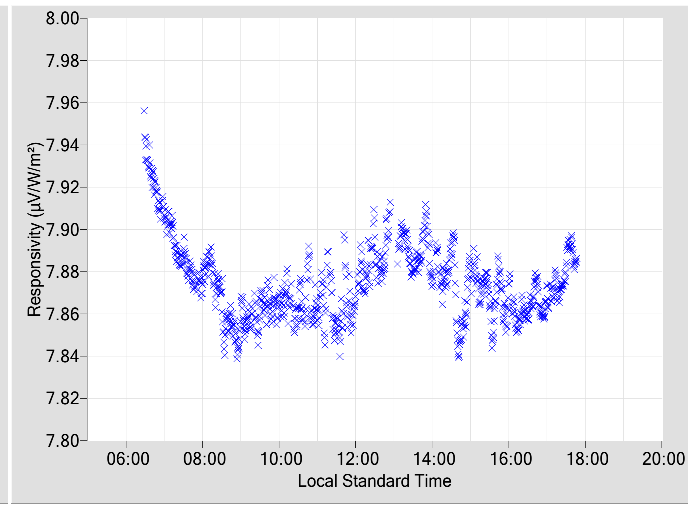


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	7.8581	0.30	105.78	7.8651	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8582	0.30	103.76	7.8721	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8596	0.29	101.80	7.8591	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8437	0.30	100.04	7.8760	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8597	0.29	98.23	7.8551	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8580	0.29	95.28	7.8645	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8761	0.31	92.10	7.8598	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8855	0.29	90.59	7.8767	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8725	0.29	89.07	7.8614	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8749	0.30	87.67	7.8666	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8784	0.30	86.17	7.8732	0.30	271.28
22	7.8790	0.31	170.39	7.8864	0.31	189.82	68	7.8863	0.30	84.76	7.8712	N/A	272.74
24	7.8732	0.30	151.65	7.8992	0.31	208.46	70	7.8906	N/A	83.36	7.8884	N/A	274.18
26	7.8681	0.30	142.23	7.8822	0.30	217.99	72	7.9040	N/A	81.97	7.8853	N/A	275.61
28	7.8746	0.28	135.72	7.8999	0.33	224.55	74	7.9133	N/A	80.63	N/A	N/A	N/A
30	7.8579	0.31	130.12	7.8760	0.31	229.94	76	7.9192	N/A	79.15	N/A	N/A	N/A
32	7.8601	0.31	125.60	7.8749	0.31	234.51	78	7.9326	N/A	77.67	N/A	N/A	N/A
34	7.8596	0.30	121.84	7.8799	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8684	0.28	118.56	7.8679	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8647	0.30	115.50	7.8547	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8623	0.32	112.68	7.8828	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8650	0.30	110.22	7.8783	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8651	0.30	107.93	7.8733	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

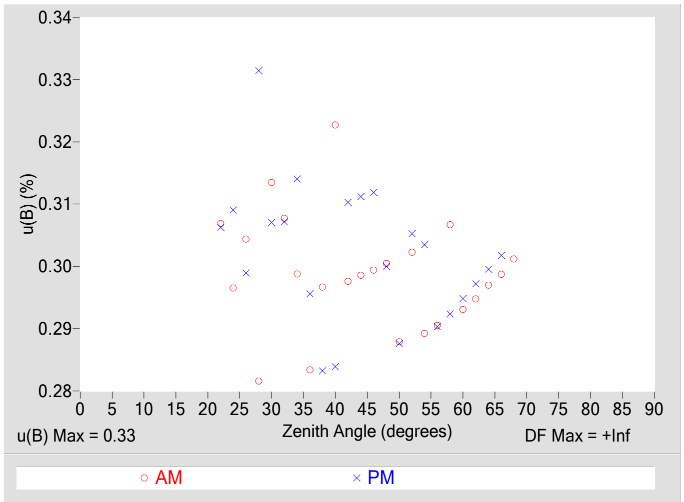


Figure 4. Residuals from Spline Interpolation

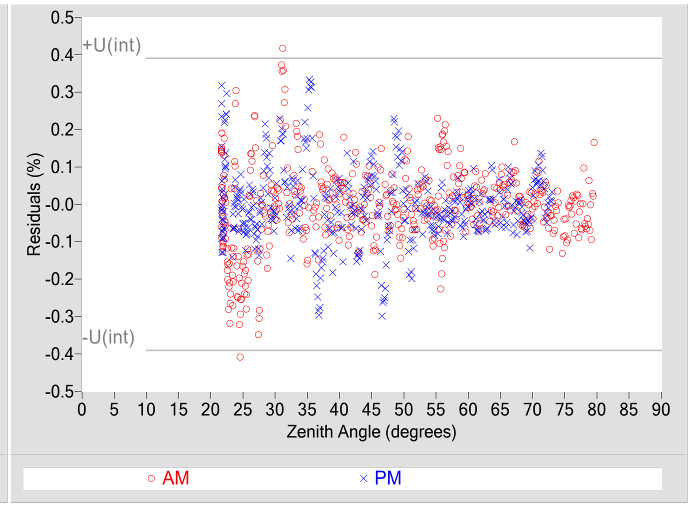


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	12120
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

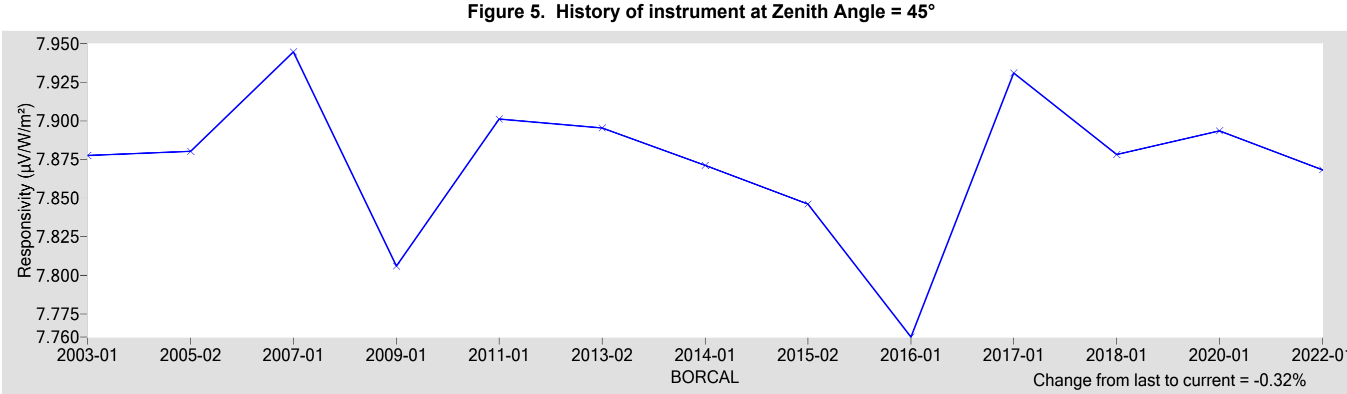
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8683	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.22 / -0.31
Expanded Uncertainty, U (%)	+0.85 / -0.94
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	30584E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

30584E6 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

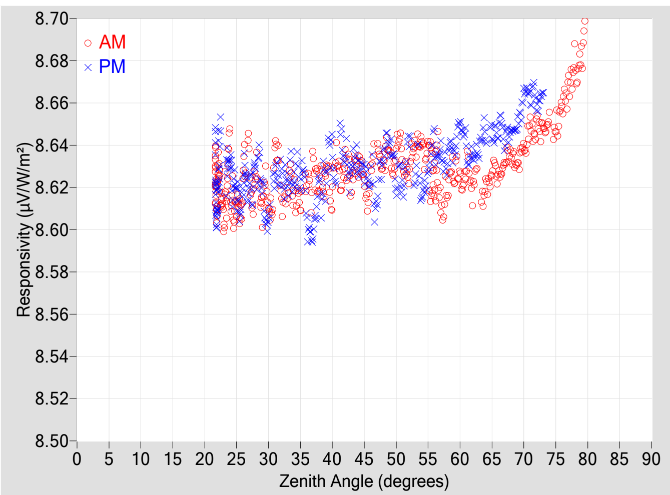


Figure 2. Responsivity vs Local Standard Time

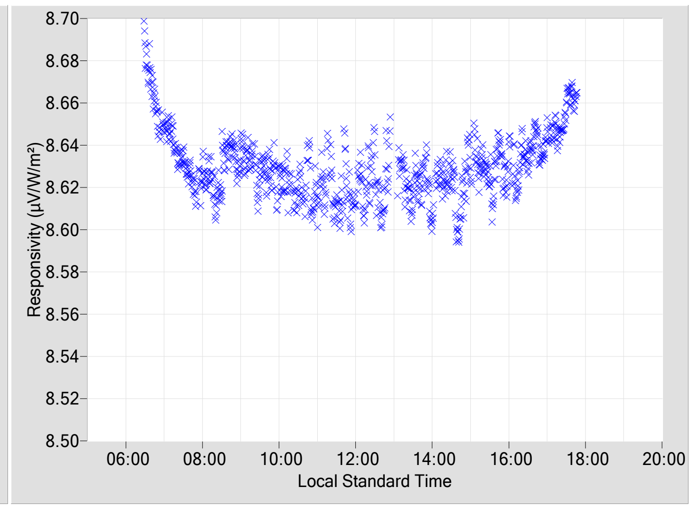


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6256	0.30	105.78	8.6257	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6302	0.30	103.76	8.6348	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6369	0.29	101.80	8.6198	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6272	0.30	100.04	8.6423	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6411	0.29	98.23	8.6170	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6257	0.29	95.28	8.6399	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6193	0.31	92.10	8.6313	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6244	0.29	90.59	8.6492	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6187	0.29	89.07	8.6353	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6203	0.30	87.67	8.6458	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6251	0.30	86.17	8.6475	0.30	271.28
22	8.6213	0.31	170.39	8.6167	0.31	189.82	68	8.6347	0.30	84.76	8.6462	N/A	272.74
24	8.6277	0.30	151.65	8.6303	0.31	208.46	70	8.6387	N/A	83.36	8.6634	N/A	274.18
26	8.6228	0.30	142.23	8.6239	0.30	217.99	72	8.6484	N/A	81.97	8.6596	N/A	275.61
28	8.6269	0.28	135.72	8.6265	0.33	224.55	74	8.6522	N/A	80.63	N/A	N/A	N/A
30	8.6107	0.31	130.12	8.6055	0.31	229.94	76	8.6586	N/A	79.15	N/A	N/A	N/A
32	8.6147	0.31	125.60	8.6261	0.31	234.51	78	8.6773	N/A	77.67	N/A	N/A	N/A
34	8.6154	0.30	121.84	8.6235	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6229	0.28	118.56	8.6053	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6226	0.30	115.50	8.6189	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6171	0.32	112.75	8.6352	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6298	0.30	110.22	8.6345	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6315	0.30	107.93	8.6306	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

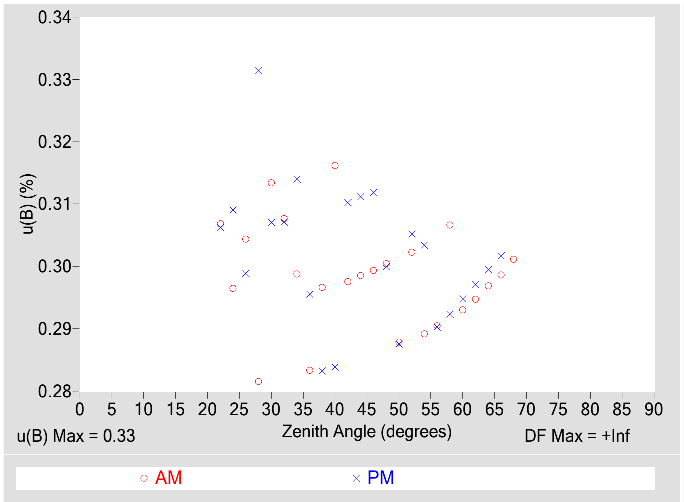


Figure 4. Residuals from Spline Interpolation

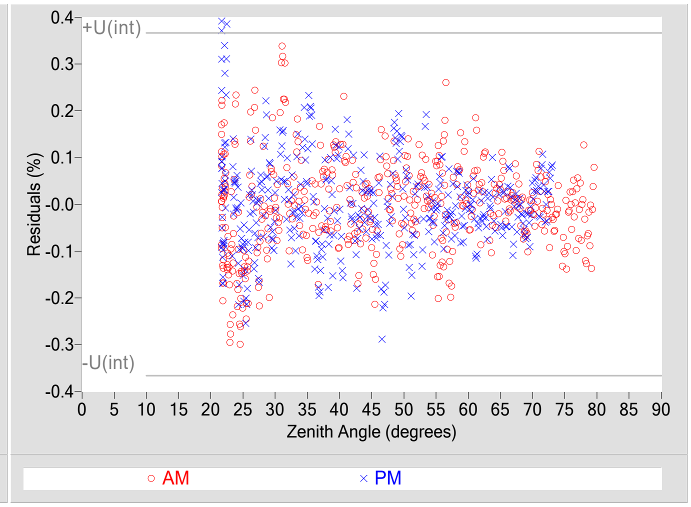


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	14639
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.74
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

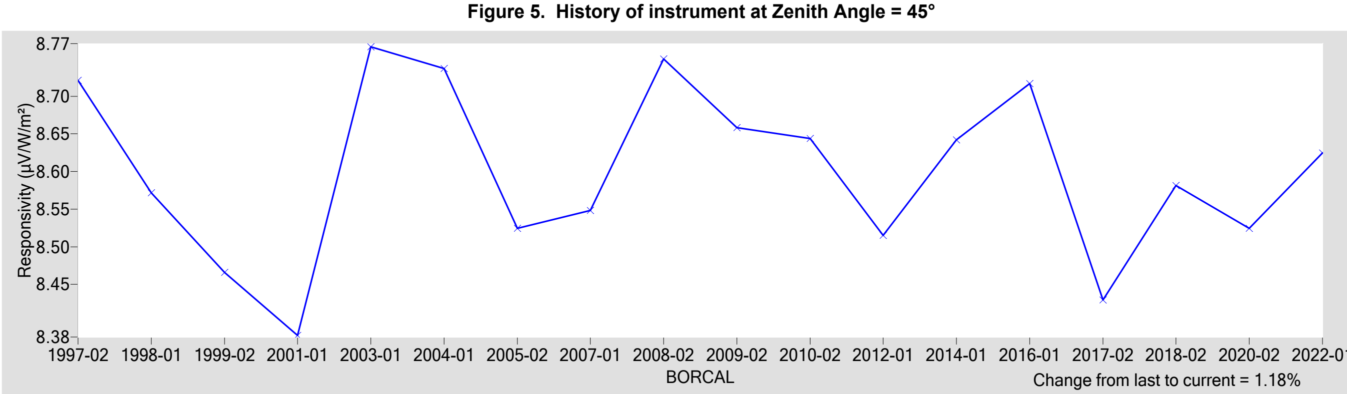
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6247	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.28 / -0.23
Expanded Uncertainty, U (%)	+0.90 / -0.84
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the 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:**	30615F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

30615F3 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

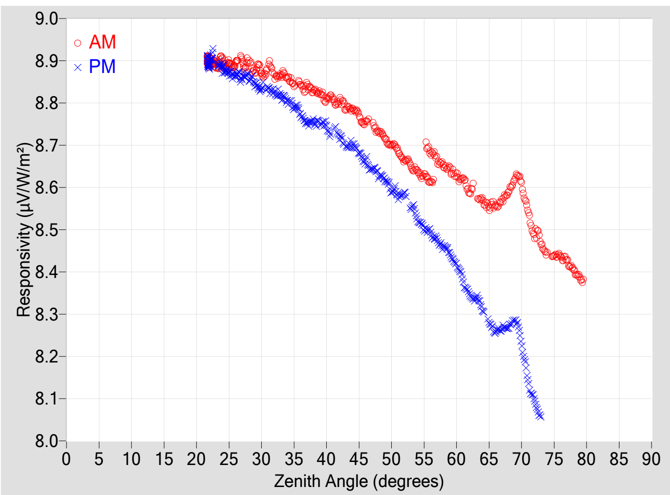


Figure 2. Responsivity vs Local Standard Time

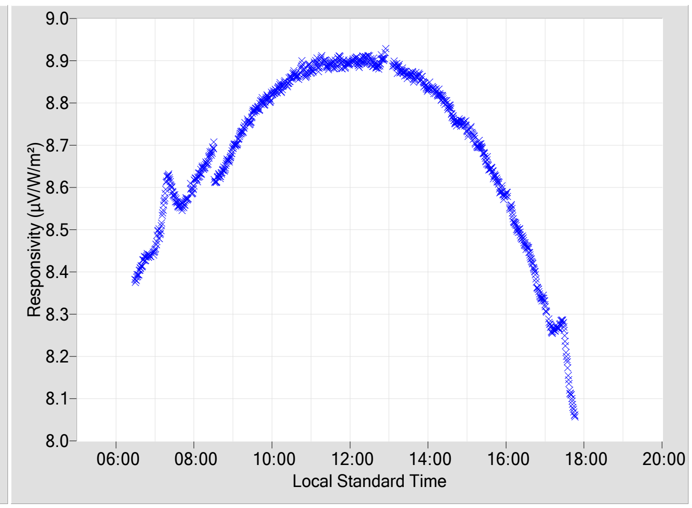


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7548	0.42	105.78	8.6617	0.40	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7312	0.43	103.70	8.6302	0.44	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7008	0.44	101.87	8.5905	0.44	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6639	0.43	99.99	8.5848	0.45	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6386	0.44	98.29	8.5238	0.44	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6529	0.46	94.96	8.4929	0.45	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6520	0.45	92.11	8.4594	0.48	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6288	0.47	90.59	8.4161	0.50	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5907	0.49	89.08	8.3462	0.53	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5686	0.52	87.62	8.3092	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5557	0.54	86.23	8.2579	0.59	271.28
22	8.8994	0.37	170.79	8.8937	0.36	189.59	68	8.5905	0.58	84.76	8.2691	N/A	272.74
24	8.8982	0.41	151.42	8.8834	0.38	208.63	70	8.6070	N/A	83.36	8.2239	N/A	274.23
26	8.8933	0.36	142.24	8.8662	0.36	218.00	72	8.4902	N/A	81.97	8.0936	N/A	275.66
28	8.8982	0.38	135.70	8.8604	0.39	224.64	74	8.4435	N/A	80.63	N/A	N/A	N/A
30	8.8731	0.41	130.25	8.8350	0.37	229.95	76	8.4365	N/A	79.10	N/A	N/A	N/A
32	8.8629	0.36	125.50	8.8244	0.40	234.40	78	8.4041	N/A	77.67	N/A	N/A	N/A
34	8.8604	0.38	121.90	8.8023	0.38	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8434	0.37	118.43	8.7727	0.38	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8285	0.37	115.42	8.7548	0.38	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8079	0.38	112.76	8.7443	0.39	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8045	0.40	110.30	8.7216	0.38	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7843	0.41	107.87	8.7012	0.44	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

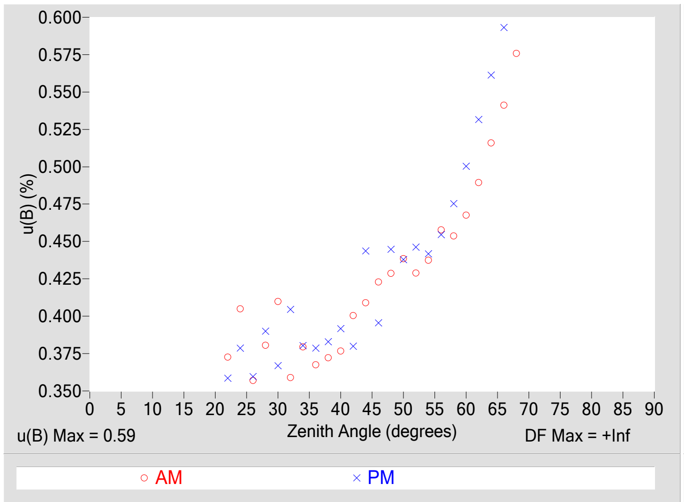


Figure 4. Residuals from Spline Interpolation

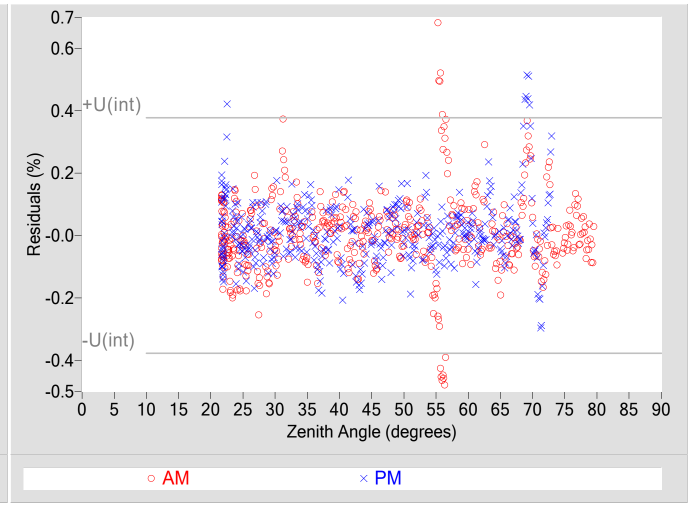


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	94277
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

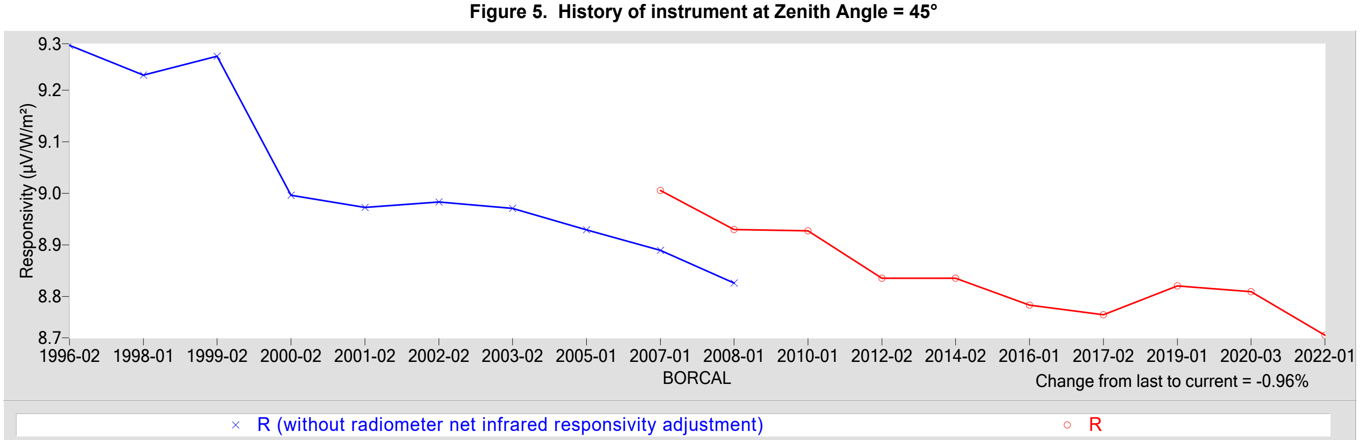
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7248	0.68534

† Rnet determination date: 04/25/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.7 / -3.5
Expanded Uncertainty, U (%)	+2.7 / -4.5
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:** 30666F3

Calibration Date: 5/7/2022 **Due Date:** 5/7/2023

Customer: SGP **Environmental Conditions:** see page 4

Test Dates: 4/30, 5/7

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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* [1]

where,

V = radiometer output voltage (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

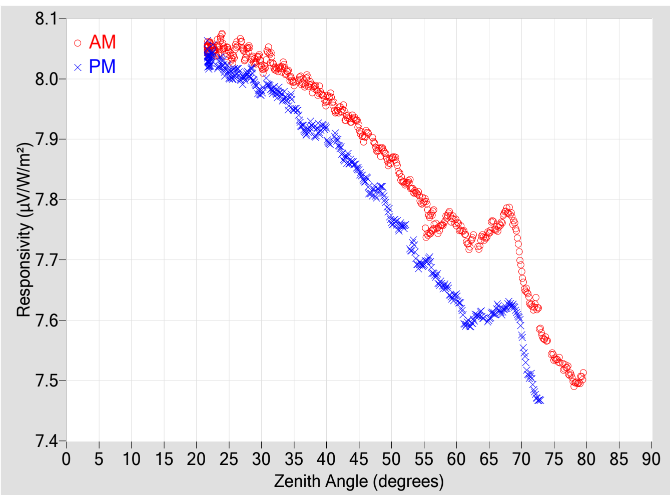


Figure 2. Responsivity vs Local Standard Time

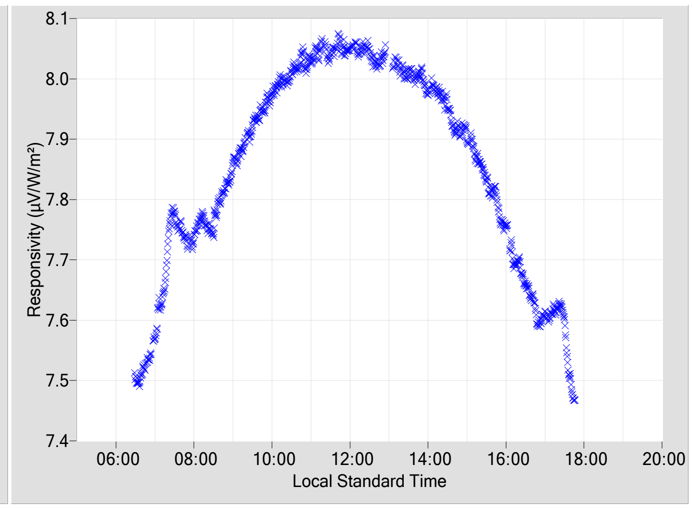


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9058	0.42	105.81	7.8324	0.40	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8825	0.41	103.79	7.8155	0.41	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8668	0.44	101.83	7.7633	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8274	0.43	100.01	7.7561	0.43	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8099	0.44	98.26	7.6928	0.47	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7597	0.47	95.11	7.6938	0.46	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7603	0.46	92.08	7.6564	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7615	0.47	90.56	7.6392	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7242	0.49	89.10	7.5925	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7365	0.52	87.64	7.6068	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7515	0.55	86.19	7.6155	0.60	271.30
22	8.0503	0.36	170.80	8.0287	0.37	189.45	68	7.7805	0.62	84.78	7.6261	N/A	272.76
24	8.0612	0.38	151.44	8.0243	0.37	208.66	70	7.6851	N/A	83.38	7.5786	N/A	274.20
26	8.0488	0.37	142.41	8.0115	0.36	217.79	72	7.6256	N/A	81.94	7.4814	N/A	275.64
28	8.0507	0.39	135.64	8.0066	0.36	224.64	74	7.5680	N/A	80.65	N/A	N/A	N/A
30	8.0213	0.38	130.17	7.9775	0.38	229.87	76	7.5338	N/A	79.21	N/A	N/A	N/A
32	8.0196	0.40	125.77	7.9810	0.39	234.42	78	7.4972	N/A	77.69	N/A	N/A	N/A
34	8.0101	0.41	121.83	7.9602	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9977	0.40	118.46	7.9249	0.37	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9856	0.39	115.54	7.9128	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9627	0.40	112.71	7.9102	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9488	0.38	110.26	7.8898	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9326	0.39	107.97	7.8622	0.44	252.15	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

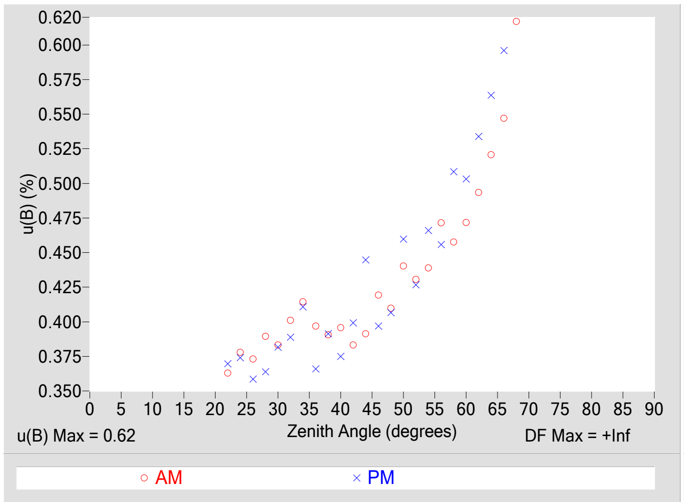


Figure 4. Residuals from Spline Interpolation

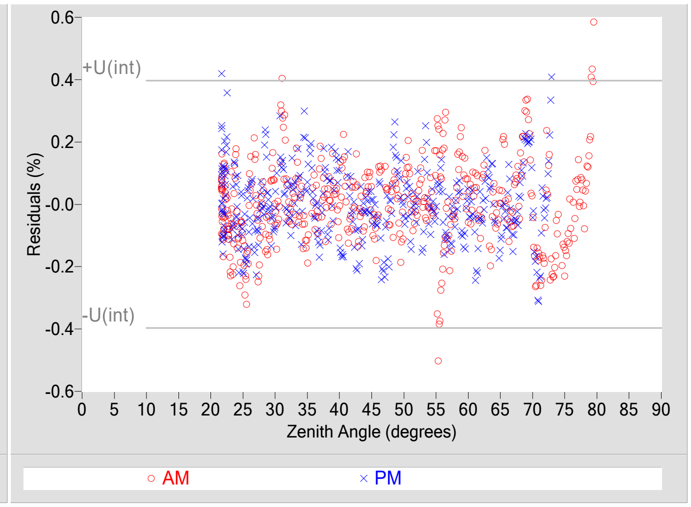


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	91356
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

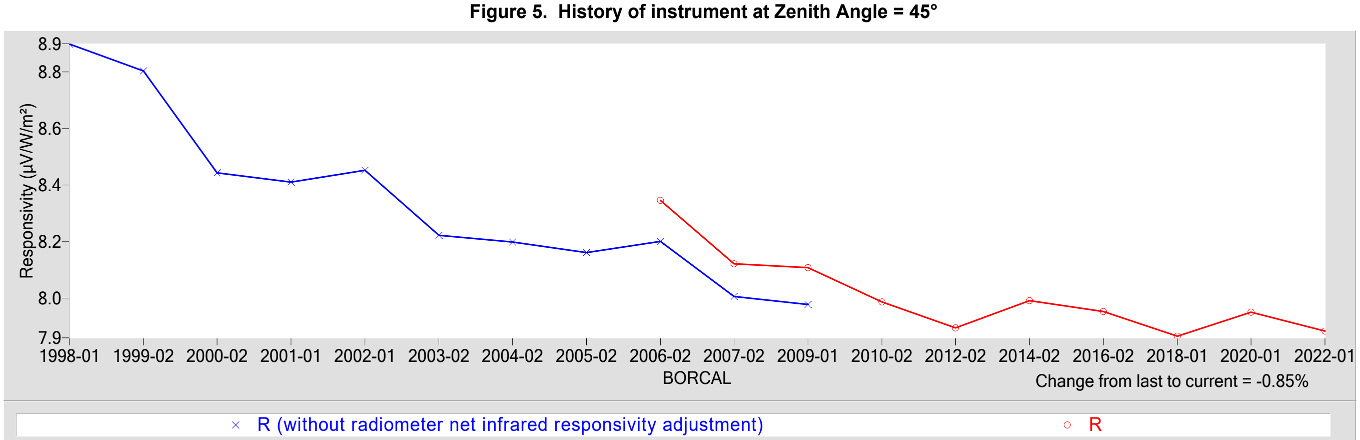
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.8835	0.69195

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+1.7 / -3.1
Expanded Uncertainty, U (%)	+2.7 / -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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

where,

V = radiometer output voltage (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

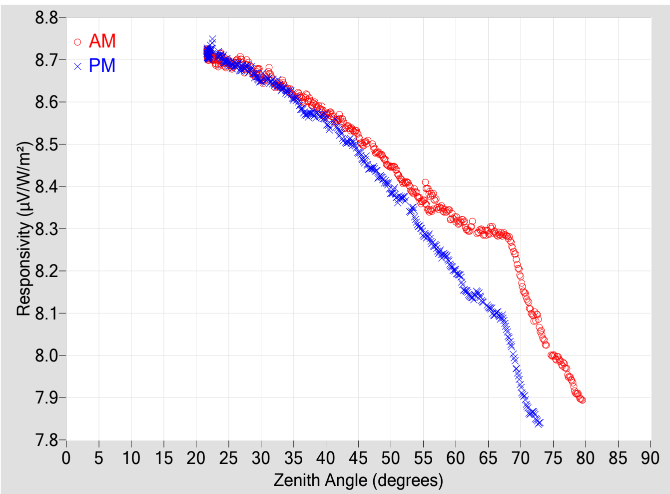


Figure 2. Responsivity vs Local Standard Time

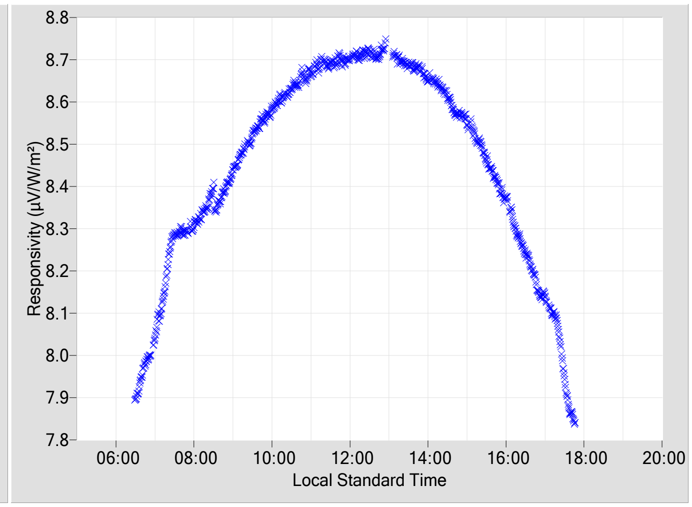


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5028	0.42	105.78	8.4606	0.39	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4793	0.43	103.70	8.4277	0.44	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4470	0.44	101.87	8.3852	0.44	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4090	0.43	99.99	8.3724	0.44	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3821	0.44	98.29	8.3127	0.44	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3661	0.46	94.96	8.2760	0.45	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3461	0.45	92.11	8.2372	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3230	0.47	90.59	8.1985	0.50	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2972	0.49	89.08	8.1433	0.53	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2935	0.51	87.62	8.1299	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2907	0.54	86.23	8.0970	0.59	271.28
22	8.7103	0.37	170.79	8.7127	0.36	189.59	68	8.2807	0.57	84.76	8.0504	N/A	272.74
24	8.7009	0.40	151.42	8.7033	0.38	208.63	70	8.1830	N/A	83.36	7.9233	N/A	274.23
26	8.6912	0.36	142.24	8.6883	0.36	218.00	72	8.0935	N/A	81.97	7.8613	N/A	275.66
28	8.6912	0.38	135.70	8.6792	0.39	224.64	74	8.0246	N/A	80.63	N/A	N/A	N/A
30	8.6603	0.41	130.25	8.6527	0.37	229.95	76	7.9880	N/A	79.10	N/A	N/A	N/A
32	8.6408	0.36	125.50	8.6455	0.40	234.40	78	7.9319	N/A	77.67	N/A	N/A	N/A
34	8.6313	0.38	121.90	8.6223	0.38	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6139	0.37	118.43	8.5888	0.38	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5956	0.37	115.42	8.5720	0.38	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5695	0.38	112.76	8.5565	0.39	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5606	0.40	110.30	8.5310	0.38	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5338	0.41	107.87	8.5050	0.44	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

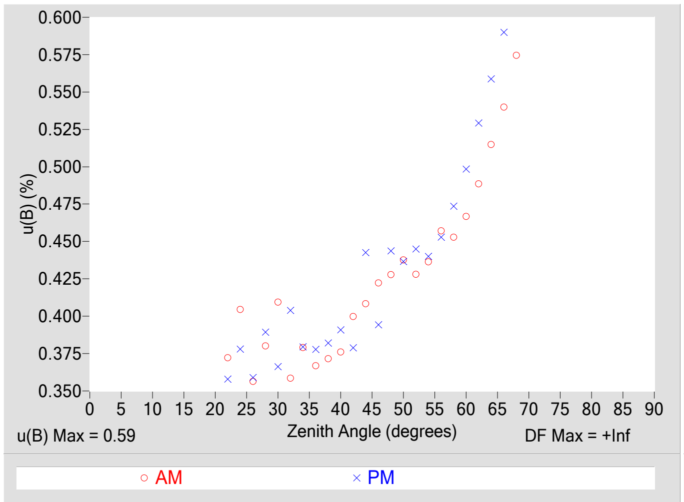


Figure 4. Residuals from Spline Interpolation

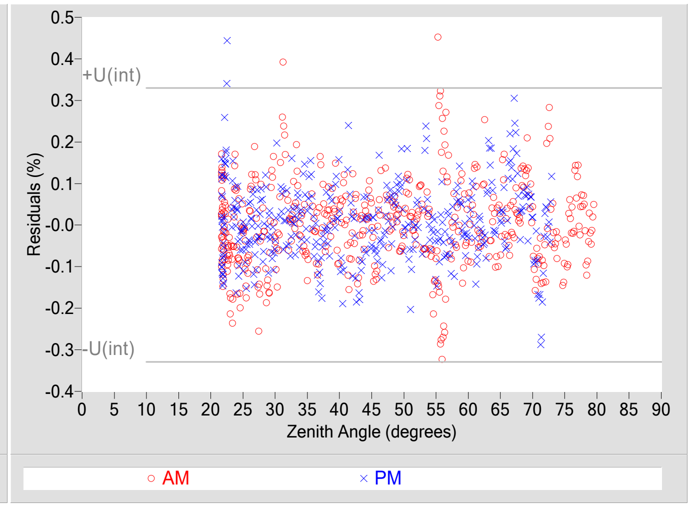


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	152846
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

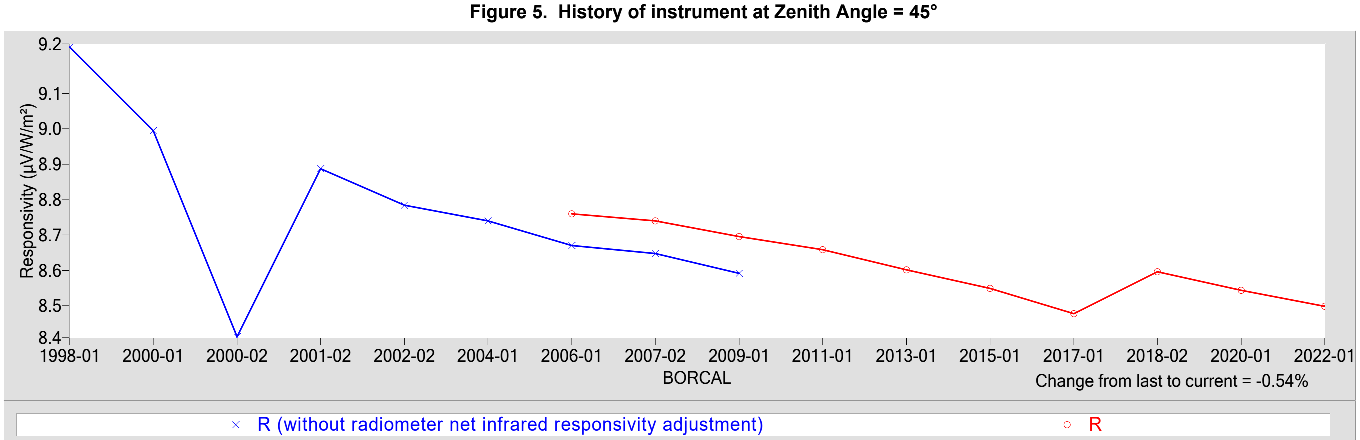
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4982	0.62861

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.9 / -3.5
Expanded Uncertainty, U (%)	+2.9 / -4.5
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: 30674F3
Calibration Date: 5/7/2022
Due Date: 5/7/2023
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 4/30, 5/7

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

where,

- V = radiometer output voltage (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

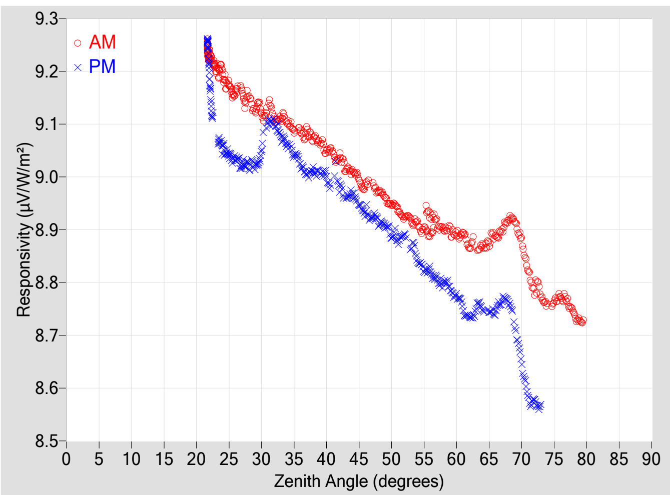


Figure 2. Responsivity vs Local Standard Time

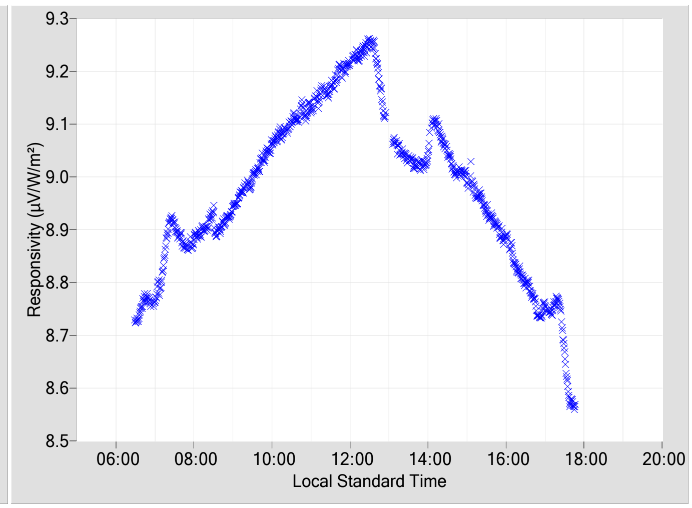


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.9847	0.42	105.78	8.9335	0.39	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9720	0.43	103.70	8.9144	0.44	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9476	0.44	101.87	8.8864	0.44	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9233	0.43	99.99	8.8886	0.44	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9115	0.44	98.29	8.8415	0.44	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9113	0.46	94.96	8.8199	0.45	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9011	0.45	92.11	8.7982	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8920	0.47	90.59	8.7735	0.50	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8684	0.49	89.08	8.7348	0.53	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8688	0.51	87.62	8.7482	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8865	0.54	86.23	8.7441	0.59	271.28
22	9.2314	0.37	170.79	9.2033	0.36	189.59	68	8.9190	0.57	84.76	8.7621	N/A	272.74
24	9.1954	0.40	151.42	9.0567	0.38	208.63	70	8.8788	N/A	83.36	8.6436	N/A	274.23
26	9.1595	0.36	142.24	9.0341	0.36	218.00	72	8.7897	N/A	81.97	8.5753	N/A	275.66
28	9.1539	0.38	135.70	9.0226	0.39	224.64	74	8.7578	N/A	80.63	N/A	N/A	N/A
30	9.1236	0.41	130.25	9.0530	0.37	229.95	76	8.7720	N/A	79.10	N/A	N/A	N/A
32	9.1092	0.36	125.50	9.1013	0.40	234.40	78	8.7423	N/A	77.67	N/A	N/A	N/A
34	9.1033	0.38	121.90	9.0584	0.38	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0860	0.37	118.43	9.0227	0.38	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0731	0.37	115.42	9.0107	0.38	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0488	0.38	112.76	8.9996	0.39	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0365	0.40	110.30	8.9828	0.38	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0088	0.41	107.87	8.9669	0.44	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

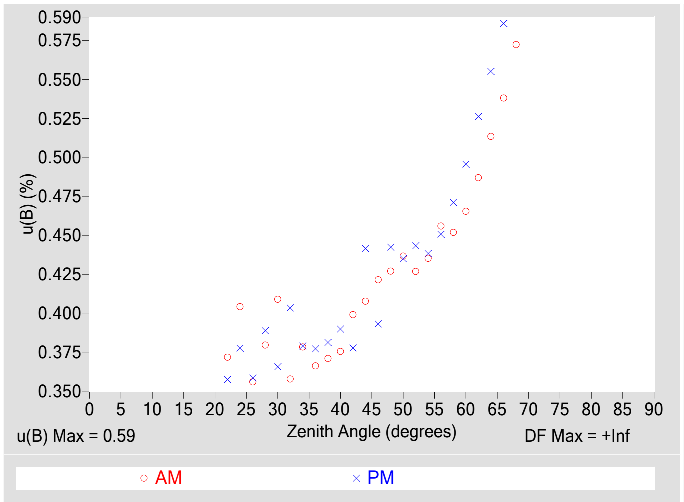


Figure 4. Residuals from Spline Interpolation

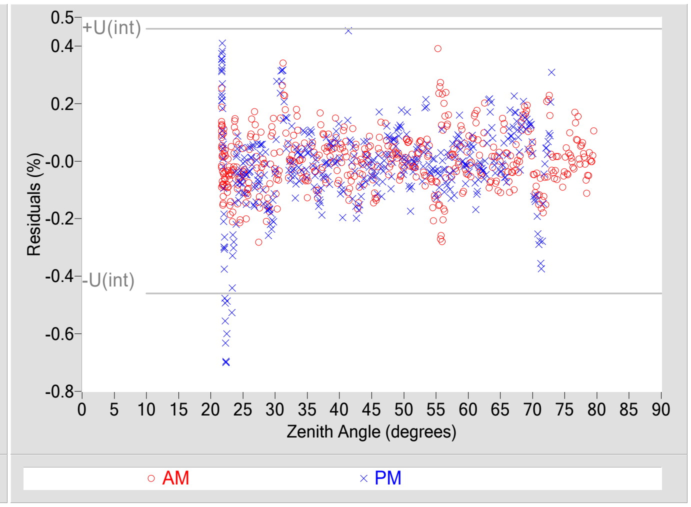


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.63
Effective degrees of freedom, DF(c)	45070
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

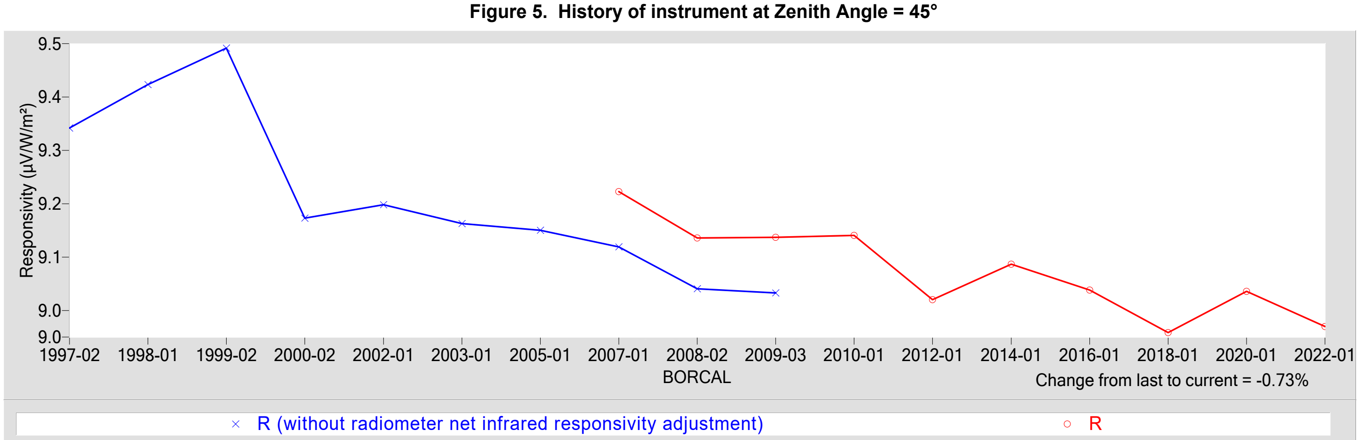
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.9695	0.61487

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.7 / -2.2
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:**	30720E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

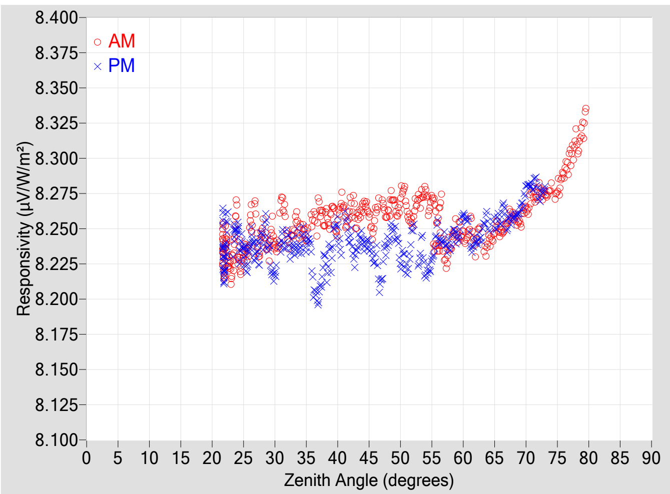


Figure 2. Responsivity vs Local Standard Time

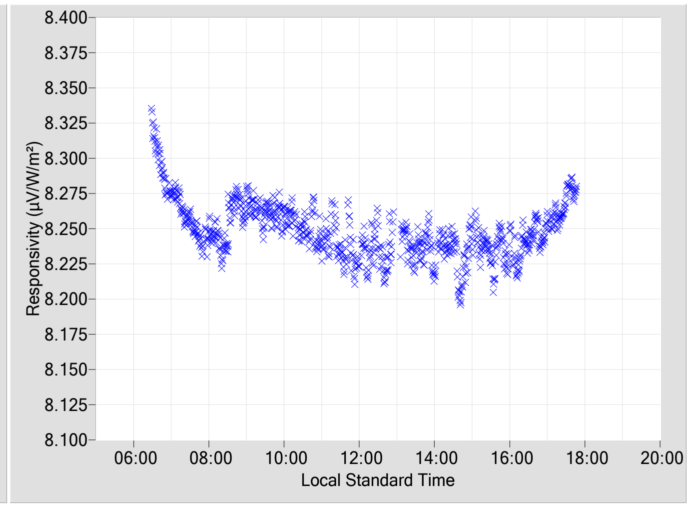


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.2591	0.30	105.78	8.2295	0.31	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2602	0.30	103.76	8.2406	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2710	0.29	101.80	8.2251	0.29	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2566	0.30	100.04	8.2506	0.31	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2756	0.29	98.23	8.2191	0.30	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2490	0.29	95.28	8.2477	0.29	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2391	0.31	92.10	8.2388	0.29	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2454	0.29	90.59	8.2591	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2384	0.29	89.07	8.2407	0.30	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2410	0.30	87.67	8.2539	0.30	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2469	0.30	86.17	8.2583	0.30	271.28
22	8.2339	0.31	170.39	8.2280	0.31	189.82	68	8.2591	0.30	84.76	8.2574	N/A	272.74
24	8.2467	0.30	151.65	8.2481	0.31	208.46	70	8.2640	N/A	83.36	8.2780	N/A	274.18
26	8.2482	0.30	142.23	8.2397	0.30	217.99	72	8.2762	N/A	81.97	8.2745	N/A	275.61
28	8.2491	0.28	135.72	8.2427	0.33	224.55	74	8.2788	N/A	80.63	N/A	N/A	N/A
30	8.2385	0.31	130.12	8.2179	0.31	229.94	76	8.2888	N/A	79.15	N/A	N/A	N/A
32	8.2428	0.31	125.60	8.2428	0.31	234.51	78	8.3115	N/A	77.67	N/A	N/A	N/A
34	8.2471	0.30	121.84	8.2370	0.31	238.27	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2575	0.28	118.56	8.2154	0.30	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2565	0.30	115.50	8.2260	0.28	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2545	0.32	112.68	8.2490	0.28	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2636	0.30	110.22	8.2427	0.31	249.96	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2654	0.30	107.93	8.2403	0.31	252.26	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

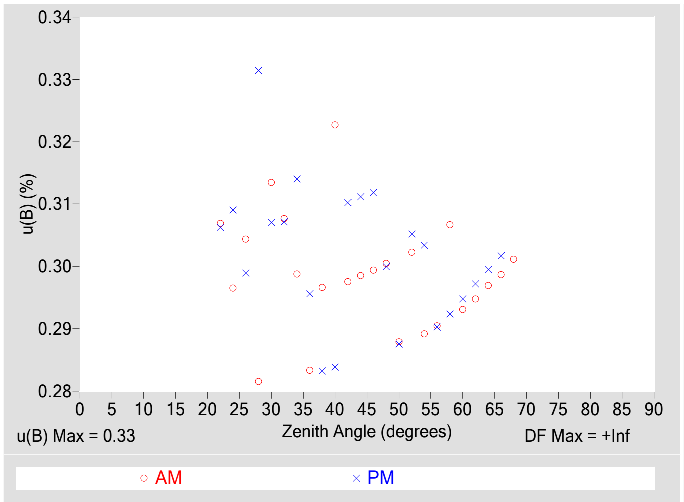


Figure 4. Residuals from Spline Interpolation

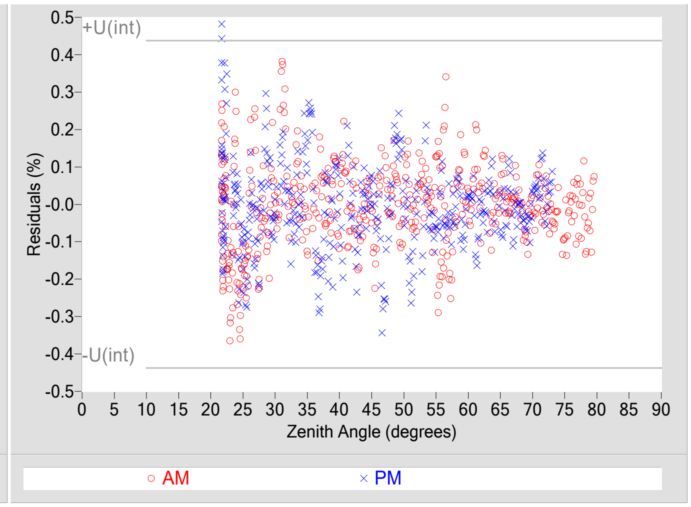


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.33
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	8732
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

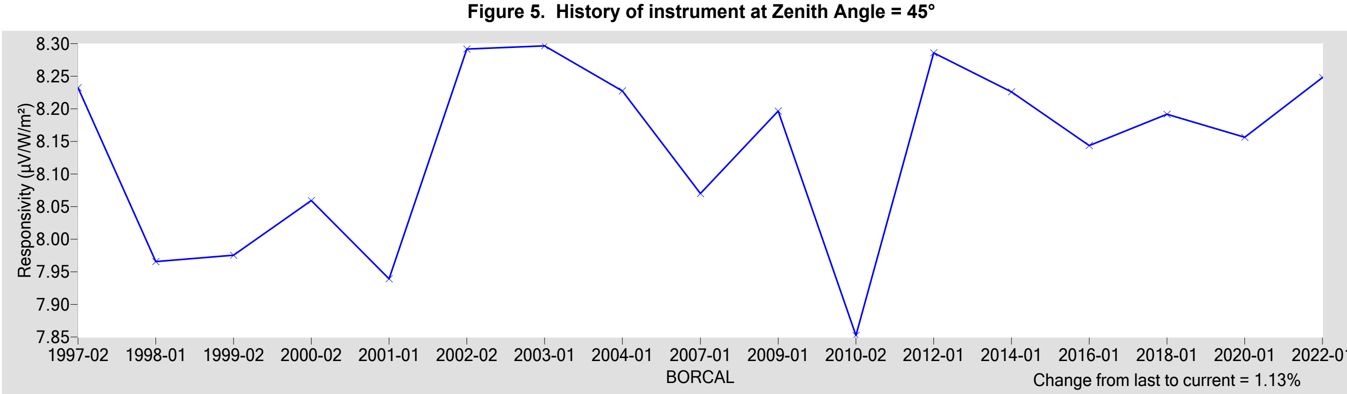
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.2482	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.63
Offset Uncertainty, U(off) (%)	+0.33 / -0.40
Expanded Uncertainty, U (%)	+0.96 / -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:**	30797F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

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

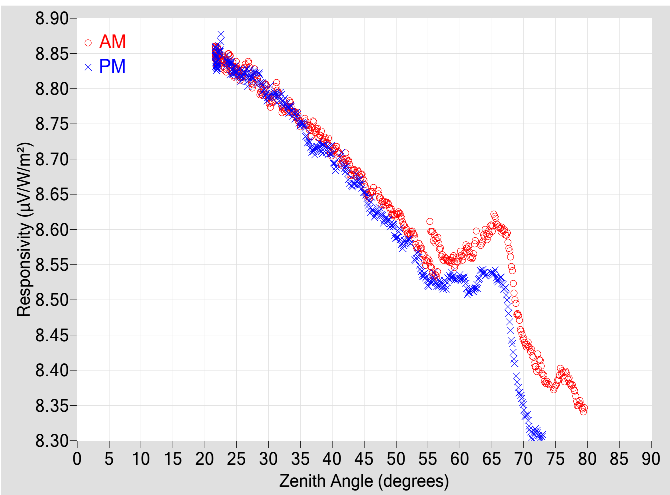


Figure 2. Responsivity vs Local Standard Time

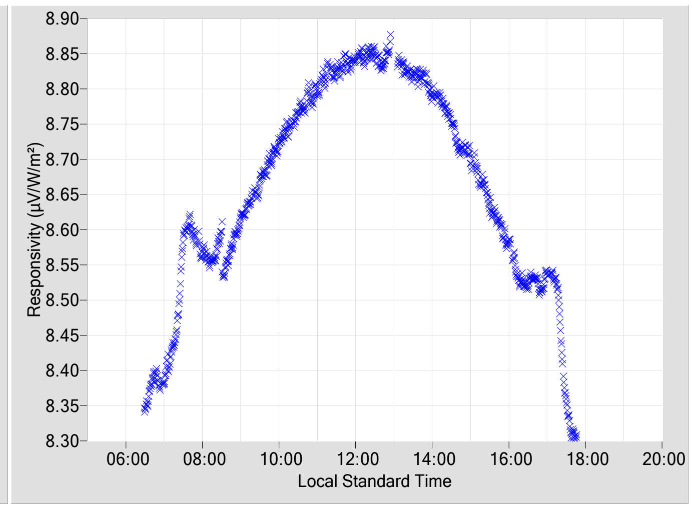


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6508	0.42	105.78	8.6331	0.39	254.39
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6379	0.43	103.70	8.6150	0.44	256.36
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6210	0.44	101.87	8.5889	0.43	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5929	0.43	99.99	8.5844	0.44	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5708	0.44	98.29	8.5380	0.44	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5644	0.46	94.96	8.5282	0.45	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5567	0.45	92.11	8.5244	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5612	0.47	90.59	8.5318	0.50	266.74
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5653	0.49	89.08	8.5136	0.53	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5923	0.51	87.62	8.5360	0.55	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6054	0.54	86.23	8.5283	0.59	271.28
22	8.8470	0.37	170.79	8.8402	0.36	189.59	68	8.5548	0.57	84.76	8.4513	N/A	272.74
24	8.8374	0.40	151.42	8.8322	0.38	208.63	70	8.4431	N/A	83.36	8.3436	N/A	274.23
26	8.8234	0.36	142.24	8.8207	0.36	218.00	72	8.4079	N/A	81.97	8.3121	N/A	275.66
28	8.8193	0.38	135.70	8.8175	0.40	224.48	74	8.3803	N/A	80.63	N/A	N/A	N/A
30	8.7885	0.41	130.25	8.7904	0.37	229.95	76	8.3965	N/A	79.10	N/A	N/A	N/A
32	8.7714	0.36	125.50	8.7857	0.40	234.40	78	8.3671	N/A	77.67	N/A	N/A	N/A
34	8.7663	0.38	121.90	8.7620	0.38	238.17	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7487	0.37	118.43	8.7303	0.38	241.66	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7335	0.37	115.42	8.7162	0.38	244.66	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7106	0.38	112.76	8.7046	0.39	247.38	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7008	0.40	110.30	8.6872	0.38	249.89	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6787	0.41	107.87	8.6689	0.44	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

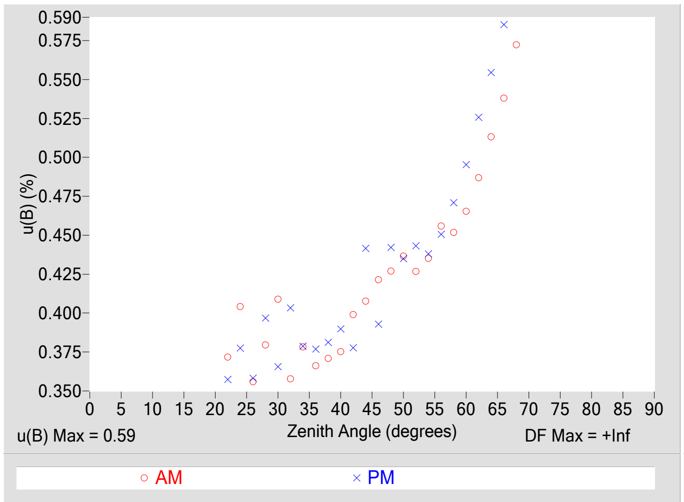


Figure 4. Residuals from Spline Interpolation

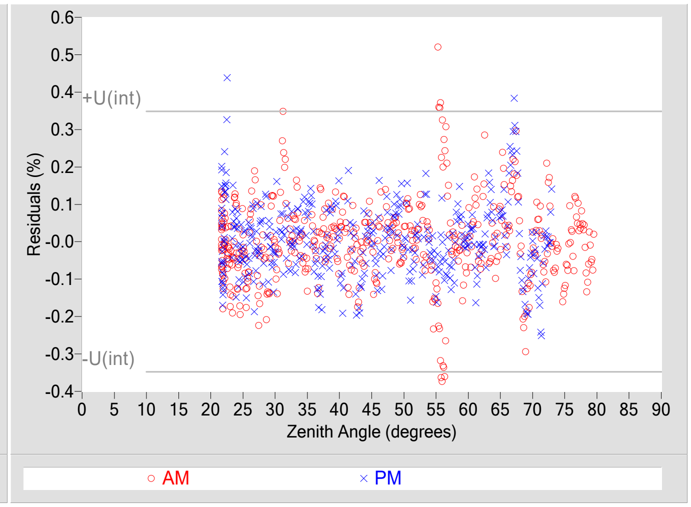


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	121068
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

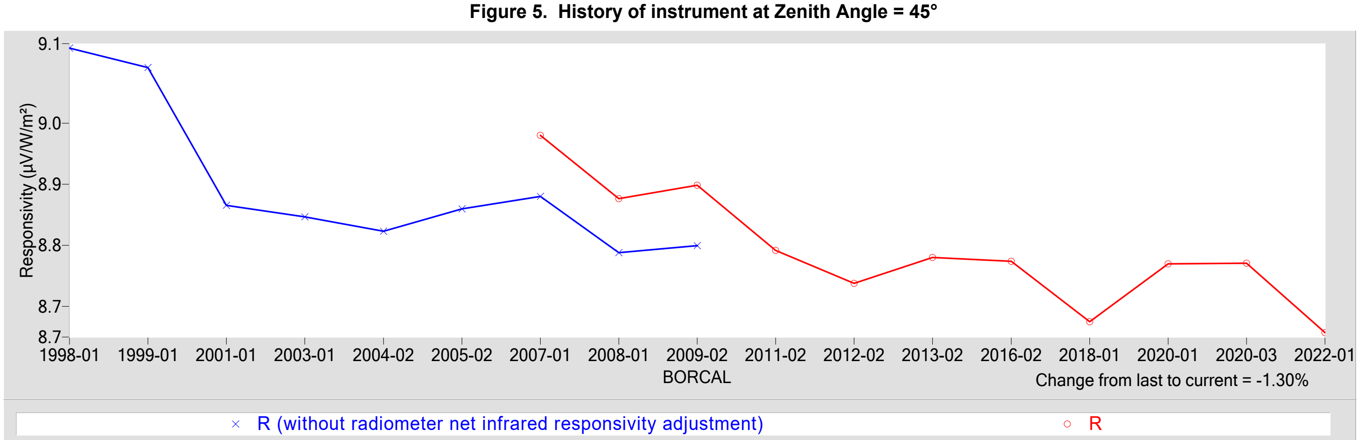
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6572	0.58912

† Rnet determination date: 04/25/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.5 / -1.5
Expanded Uncertainty, U (%)	+2.5 / -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:**	30811F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

where,

- V = radiometer output voltage (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

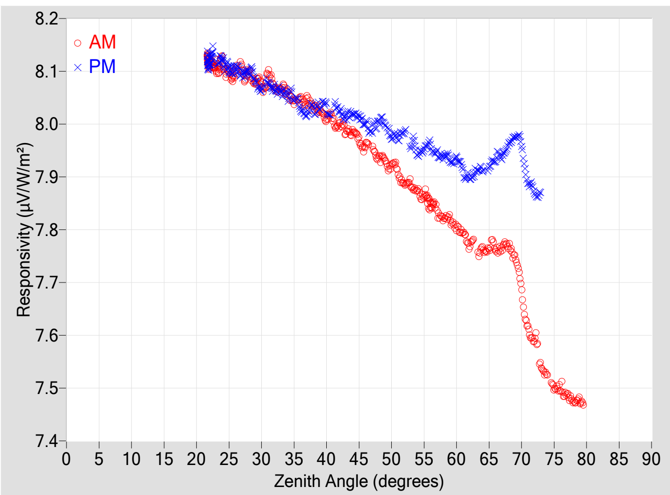


Figure 2. Responsivity vs Local Standard Time

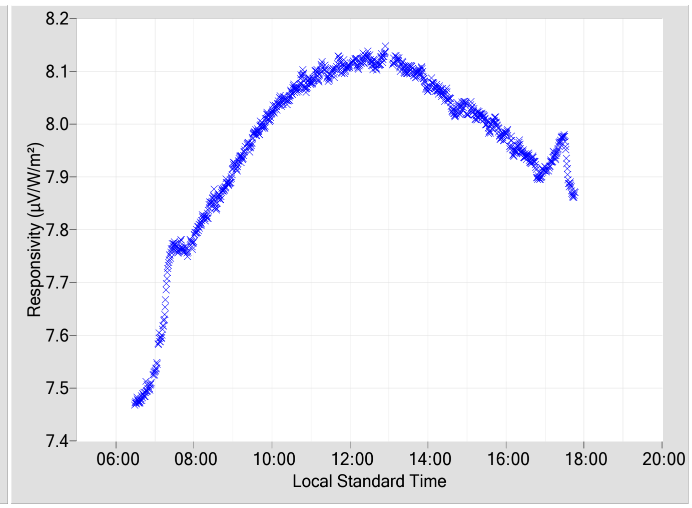


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9579	0.42	105.81	8.0018	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9367	0.41	103.79	8.0048	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9221	0.44	101.83	7.9743	0.45	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8866	0.43	100.01	7.9856	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8741	0.44	98.26	7.9435	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8470	0.47	95.11	7.9594	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8213	0.45	92.08	7.9383	0.50	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8048	0.47	90.56	7.9356	0.49	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7703	0.49	89.10	7.8995	0.52	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7630	0.52	87.64	7.9133	0.55	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7628	0.54	86.19	7.9346	0.58	271.30
22	8.1181	0.36	170.80	8.1157	0.37	189.45	68	7.7685	0.61	84.78	7.9615	N/A	272.76
24	8.1157	0.38	151.44	8.1200	0.37	208.66	70	7.6897	N/A	83.38	7.9575	N/A	274.20
26	8.0996	0.37	142.41	8.1057	0.36	217.79	72	7.5938	N/A	81.94	7.8702	N/A	275.64
28	8.0998	0.39	135.64	8.0980	0.36	224.64	74	7.5270	N/A	80.65	N/A	N/A	N/A
30	8.0728	0.38	130.17	8.0666	0.38	229.87	76	7.5021	N/A	79.12	N/A	N/A	N/A
32	8.0698	0.40	125.77	8.0677	0.39	234.42	78	7.4740	N/A	77.69	N/A	N/A	N/A
34	8.0596	0.41	121.83	8.0525	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0458	0.39	118.46	8.0272	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0336	0.39	115.54	8.0266	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0098	0.39	112.71	8.0310	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9980	0.38	110.26	8.0264	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9832	0.39	107.97	8.0197	0.44	252.15	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

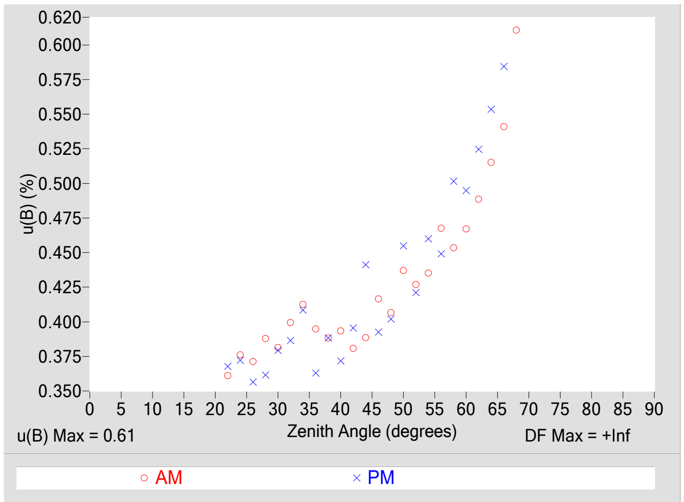


Figure 4. Residuals from Spline Interpolation

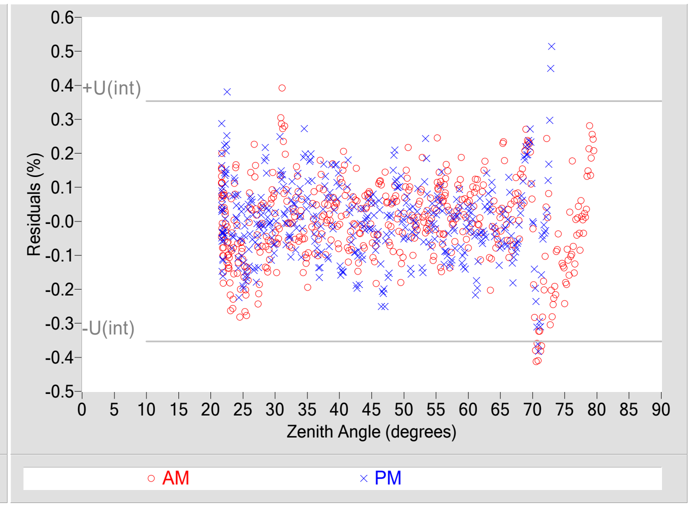


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	134583
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

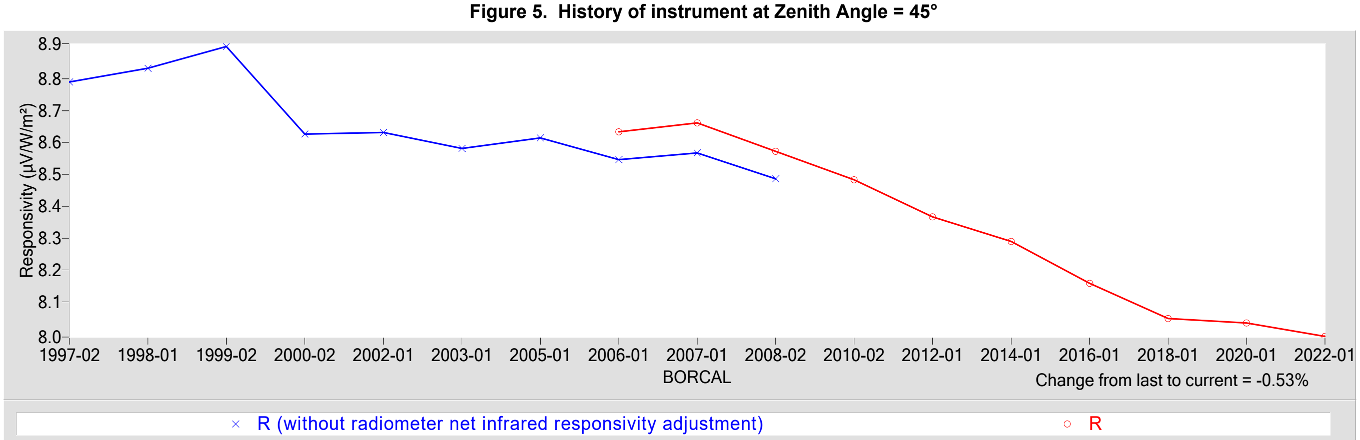
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9920	0.55500

† Rnet determination date: 04/05/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.0 / -2.3
Expanded Uncertainty, U (%)	+2.0 / -3.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30887F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

30887F3 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

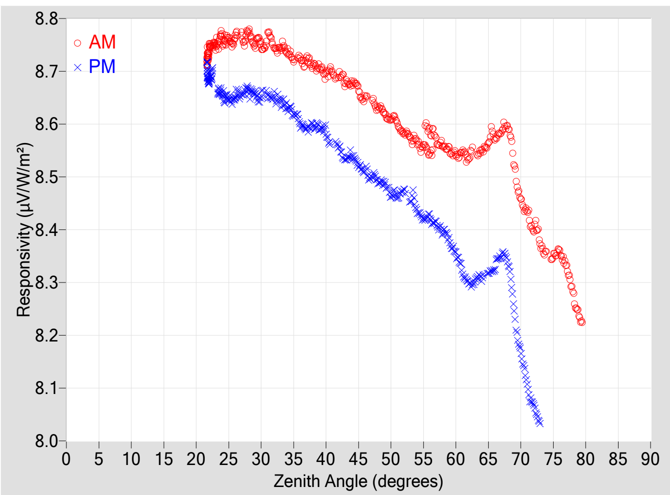


Figure 2. Responsivity vs Local Standard Time

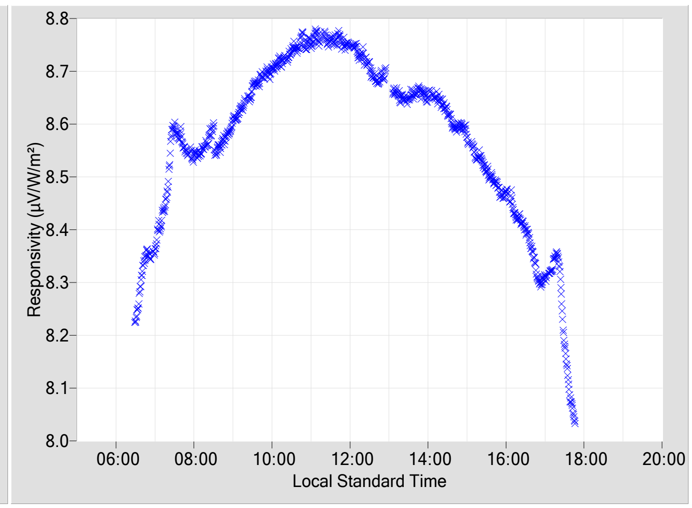


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6504	0.40	105.72	8.5127	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6297	0.43	103.71	8.4906	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6096	0.44	101.87	8.4645	0.42	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5828	0.43	100.00	8.4733	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5683	0.44	98.30	8.4355	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5673	0.46	94.97	8.4217	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5605	0.45	92.12	8.3970	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.5433	0.47	90.55	8.3535	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5378	0.49	89.08	8.3002	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5487	0.51	87.62	8.3093	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5740	0.54	86.18	8.3285	0.59	271.29
22	8.7372	0.37	170.27	8.6874	0.36	189.67	68	8.5933	0.57	84.77	8.3365	N/A	272.75
24	8.7631	0.38	151.57	8.6576	0.38	208.53	70	8.4595	N/A	83.37	8.1687	N/A	274.18
26	8.7646	0.38	142.27	8.6516	0.37	217.71	72	8.4014	N/A	81.97	8.0650	N/A	275.67
28	8.7745	0.37	135.61	8.6659	0.38	224.47	74	8.3588	N/A	80.64	N/A	N/A	N/A
30	8.7515	0.37	130.27	8.6543	0.37	229.99	76	8.3577	N/A	79.11	N/A	N/A	N/A
32	8.7452	0.38	125.56	8.6500	0.40	234.41	78	8.2813	N/A	77.68	N/A	N/A	N/A
34	8.7365	0.38	121.91	8.6306	0.38	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7245	0.37	118.44	8.6004	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7114	0.37	115.43	8.5981	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6949	0.38	112.77	8.5838	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6921	0.38	110.16	8.5554	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6773	0.39	107.88	8.5399	0.41	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

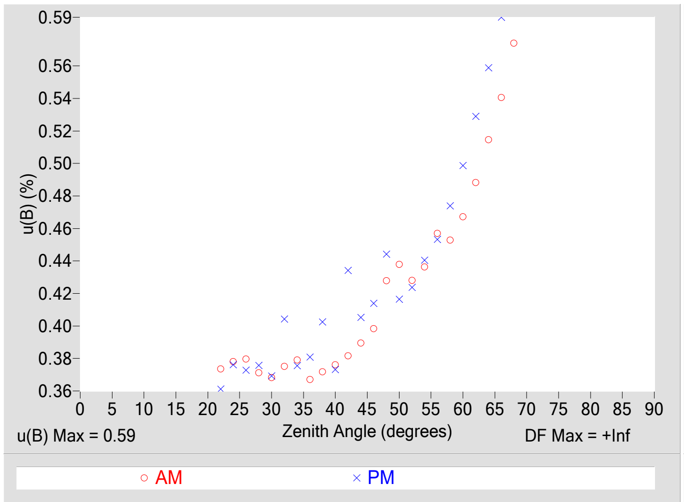


Figure 4. Residuals from Spline Interpolation

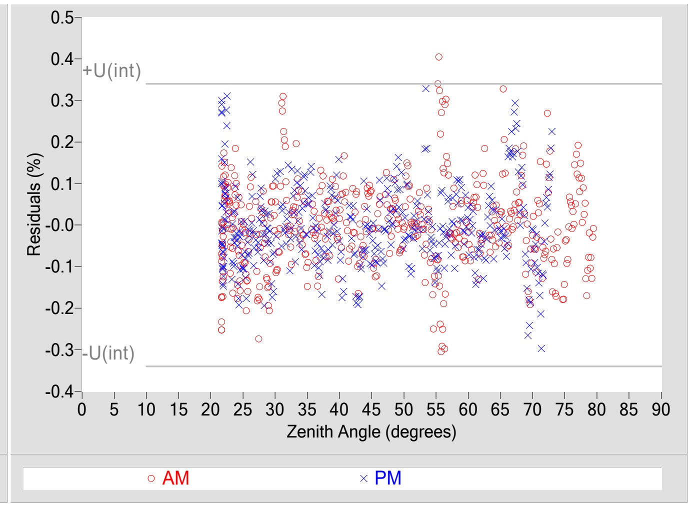


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	136488
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

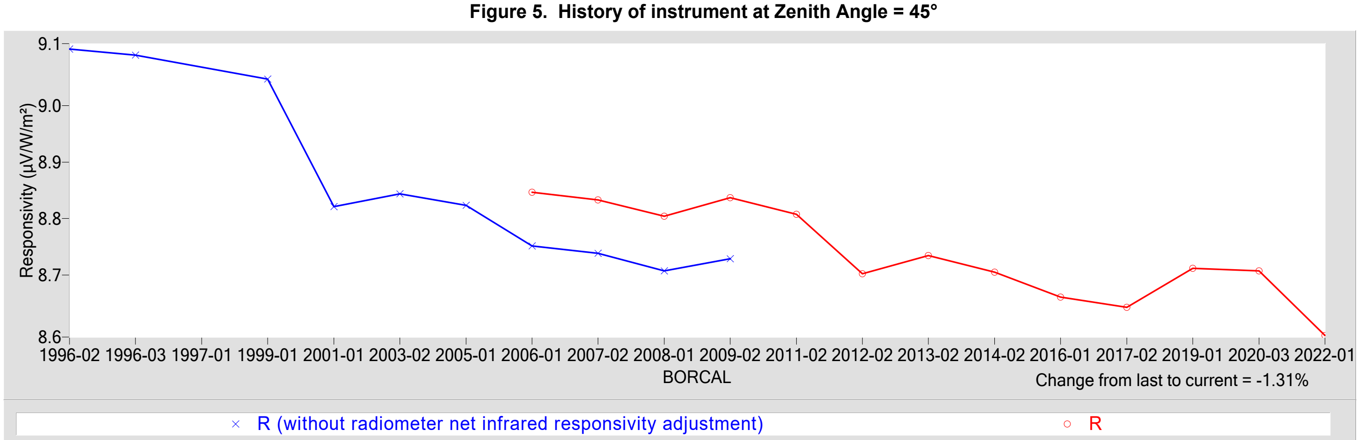
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5931	0.64358

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.8 / -2.8
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

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Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30890F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

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

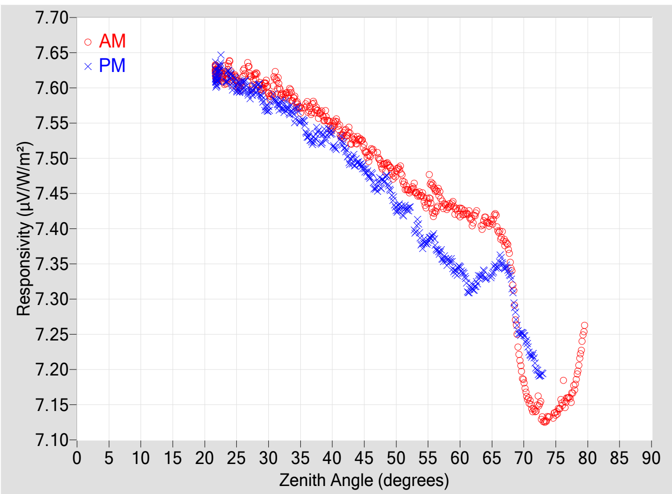


Figure 2. Responsivity vs Local Standard Time

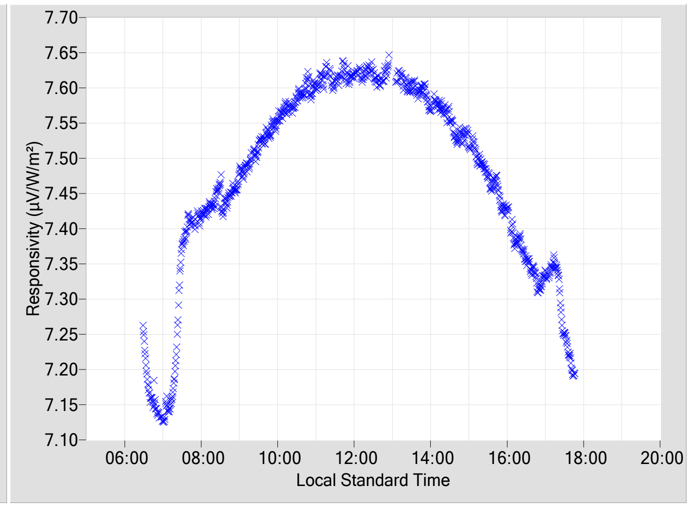


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5054	0.42	105.81	7.4750	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4895	0.41	103.79	7.4683	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4814	0.44	101.83	7.4277	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4538	0.43	100.01	7.4290	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4472	0.44	98.26	7.3785	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4397	0.47	95.11	7.3831	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4305	0.46	92.08	7.3538	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4244	0.47	90.56	7.3446	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4114	0.49	89.10	7.3157	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4123	0.52	87.64	7.3321	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3977	0.54	86.19	7.3502	0.59	271.30
22	7.6209	0.36	170.80	7.6129	0.37	189.45	68	7.3443	0.61	84.78	7.3238	N/A	272.76
24	7.6258	0.38	151.44	7.6155	0.37	208.66	70	7.1818	N/A	83.38	7.2475	N/A	274.20
26	7.6158	0.37	142.41	7.6041	0.36	217.79	72	7.1481	N/A	81.94	7.2003	N/A	275.64
28	7.6183	0.39	135.64	7.5975	0.36	224.64	74	7.1327	N/A	80.65	N/A	N/A	N/A
30	7.5934	0.38	130.17	7.5707	0.38	229.87	76	7.1609	N/A	79.12	N/A	N/A	N/A
32	7.5927	0.40	125.77	7.5758	0.39	234.42	78	7.1783	N/A	77.69	N/A	N/A	N/A
34	7.5843	0.41	121.83	7.5605	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5728	0.40	118.46	7.5327	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5636	0.39	115.54	7.5288	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5448	0.39	112.71	7.5287	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5354	0.38	110.26	7.5144	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5250	0.39	107.97	7.4944	0.44	252.15	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

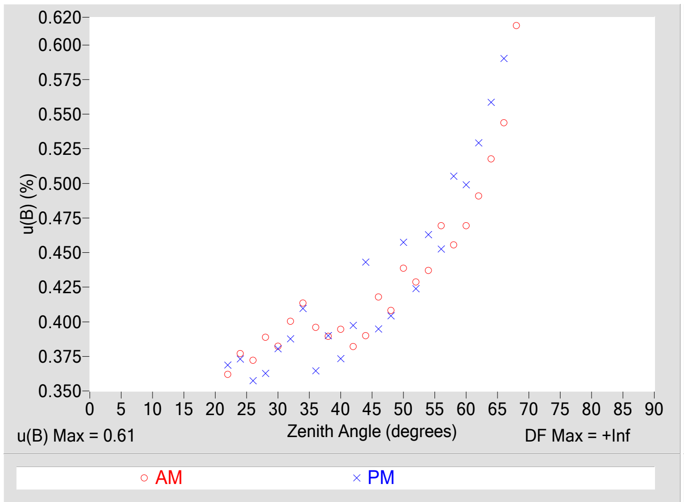


Figure 4. Residuals from Spline Interpolation

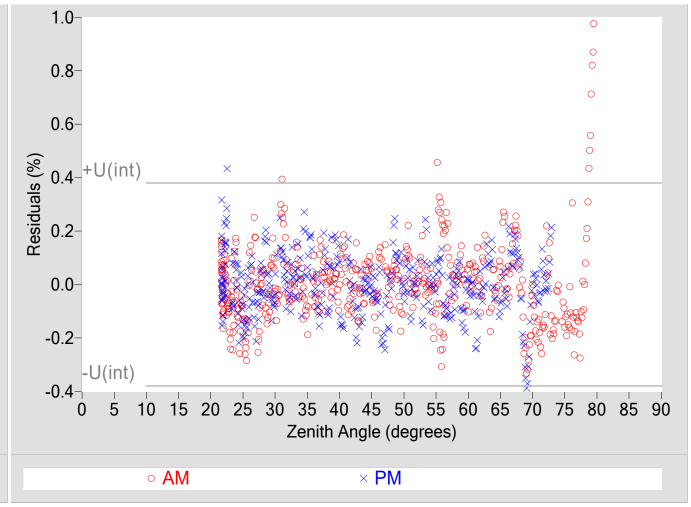


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	105133
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

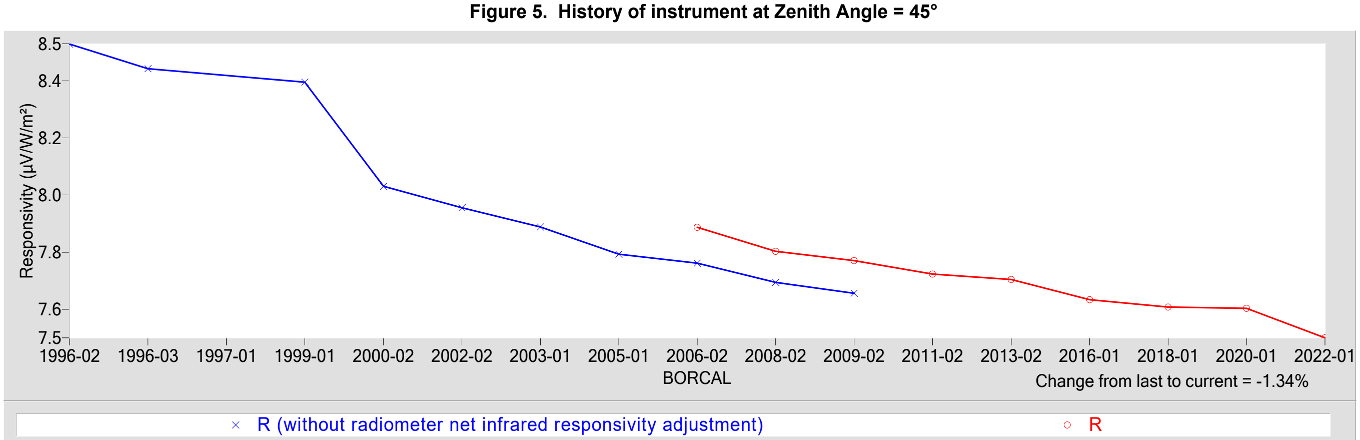
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5005	0.59445

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.2 / -2.1
Expanded Uncertainty, U (%)	+2.2 / -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:**	30894F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

30894F3 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

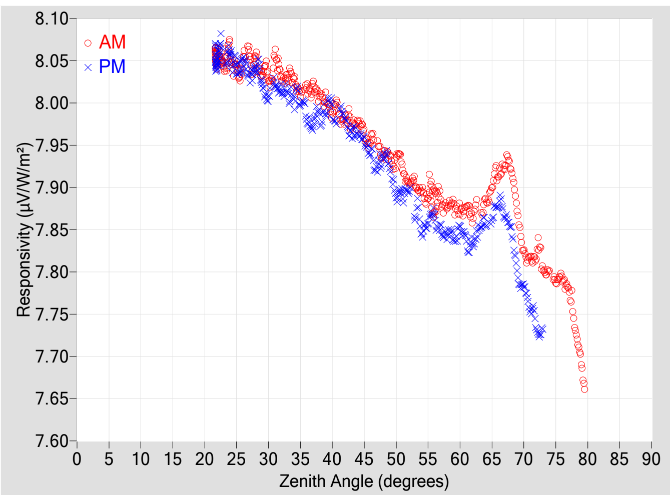


Figure 2. Responsivity vs Local Standard Time

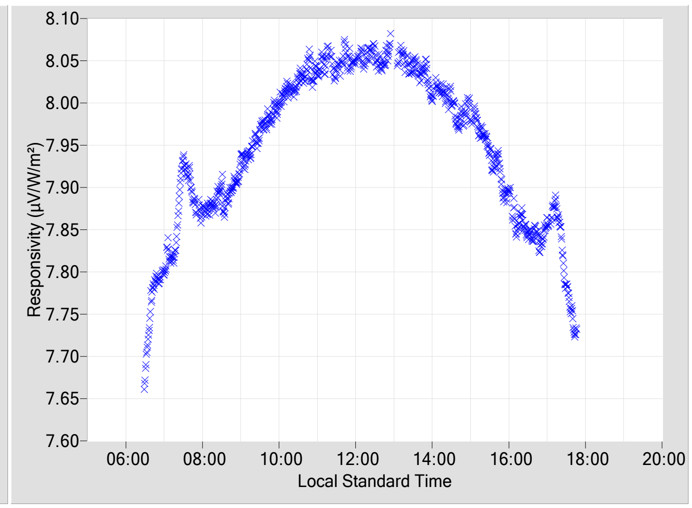


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM			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	7.9556	0.42	105.81	7.9419	0.40	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9391	0.41	103.79	7.9355	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9337	0.44	101.83	7.8895	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9054	0.43	100.01	7.8963	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8957	0.44	98.26	7.8468	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8826	0.47	95.11	7.8643	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8768	0.46	92.08	7.8441	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8736	0.47	90.56	7.8528	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8656	0.49	89.10	7.8346	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8834	0.52	87.64	7.8575	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9141	0.54	86.19	7.8811	0.59	271.30
22	8.0548	0.36	170.80	8.0493	0.37	189.45	68	7.9206	0.61	84.78	7.8482	N/A	272.76
24	8.0584	0.38	151.44	8.0571	0.37	208.66	70	7.8246	N/A	83.38	7.7821	N/A	274.20
26	8.0486	0.37	142.41	8.0474	0.36	217.79	72	7.8239	N/A	81.94	7.7330	N/A	275.64
28	8.0545	0.39	135.64	8.0396	0.36	224.64	74	7.8016	N/A	80.65	N/A	N/A	N/A
30	8.0284	0.38	130.17	8.0071	0.38	229.87	76	7.7929	N/A	79.12	N/A	N/A	N/A
32	8.0322	0.40	125.77	8.0150	0.39	234.42	78	7.7339	N/A	77.69	N/A	N/A	N/A
34	8.0268	0.41	121.83	8.0026	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0171	0.40	118.46	7.9786	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0085	0.39	115.54	7.9813	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9896	0.39	112.71	7.9919	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9807	0.38	110.26	7.9818	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9741	0.39	107.97	7.9640	0.44	252.15	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

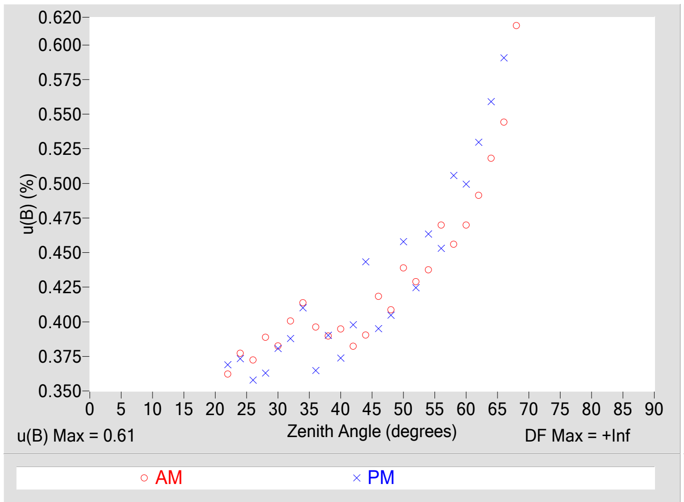


Figure 4. Residuals from Spline Interpolation

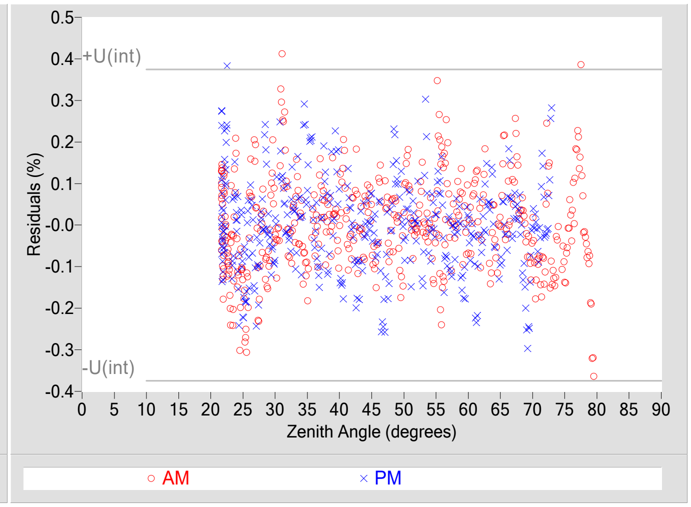


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	110326
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

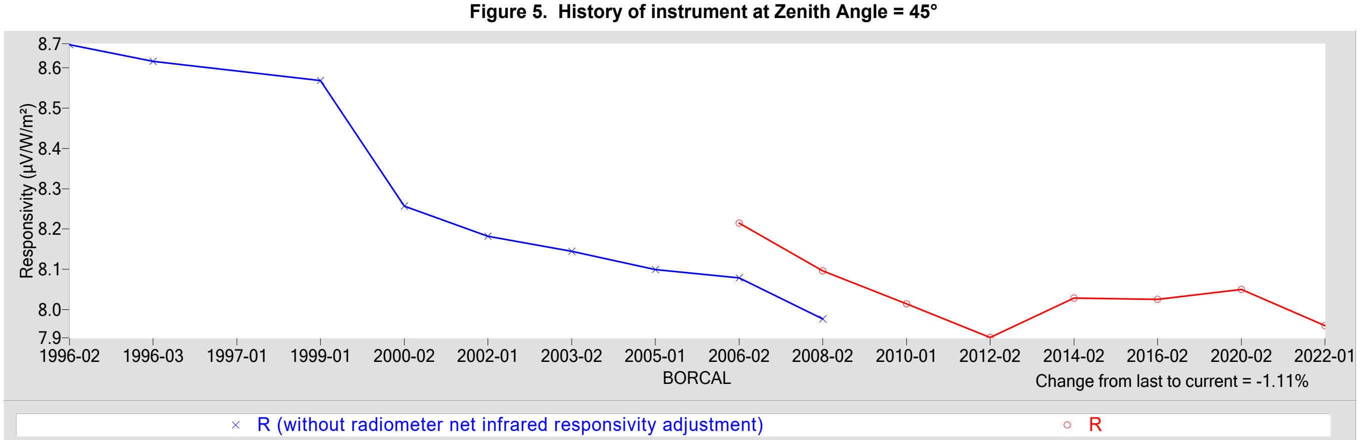
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9602	0.64666

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+0.90 / -1.5
Expanded Uncertainty, U (%)	+1.9 / -2.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30895F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

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

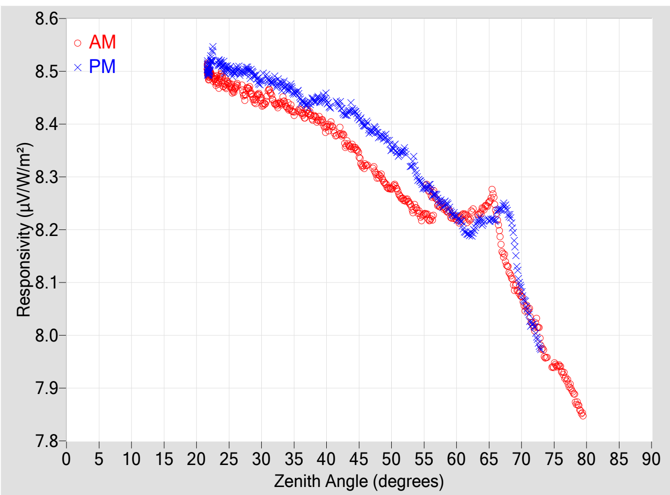


Figure 2. Responsivity vs Local Standard Time

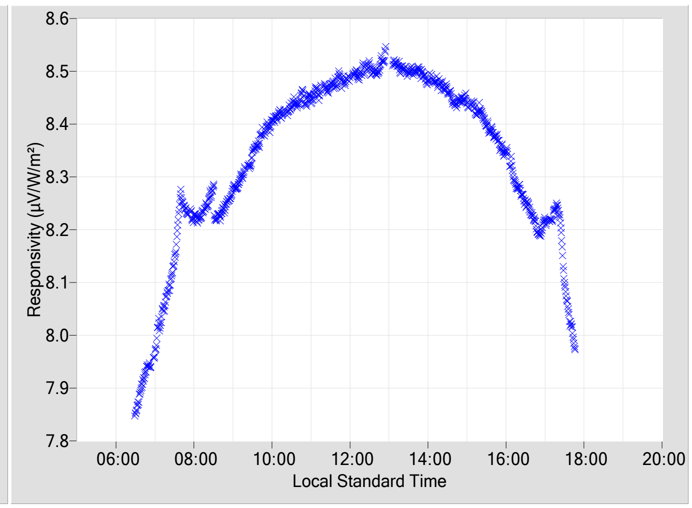


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3213	0.40	105.72	8.3994	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3010	0.43	103.71	8.3788	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2785	0.44	101.87	8.3541	0.41	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2562	0.43	100.00	8.3484	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2373	0.43	98.30	8.2988	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2478	0.46	94.97	8.2773	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2432	0.45	92.12	8.2488	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2214	0.47	90.55	8.2233	0.49	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2227	0.49	89.08	8.1915	0.52	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2372	0.51	87.62	8.2136	0.55	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2391	0.54	86.18	8.2216	0.58	271.29
22	8.4962	0.37	170.27	8.5054	0.36	189.67	68	8.1240	0.57	84.77	8.2293	N/A	272.75
24	8.4854	0.38	151.57	8.5123	0.38	208.53	70	8.0732	N/A	83.37	8.0855	N/A	274.18
26	8.4692	0.38	142.27	8.5001	0.37	217.71	72	8.0160	N/A	81.97	8.0106	N/A	275.67
28	8.4671	0.37	135.61	8.4995	0.37	224.61	74	7.9580	N/A	80.64	N/A	N/A	N/A
30	8.4455	0.37	130.27	8.4838	0.37	229.99	76	7.9379	N/A	79.11	N/A	N/A	N/A
32	8.4397	0.37	125.56	8.4801	0.40	234.41	78	7.8880	N/A	77.68	N/A	N/A	N/A
34	8.4328	0.38	121.91	8.4666	0.37	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4237	0.37	118.44	8.4474	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4125	0.37	115.43	8.4462	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3933	0.38	112.77	8.4461	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3853	0.38	110.16	8.4358	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3561	0.39	107.88	8.4286	0.40	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

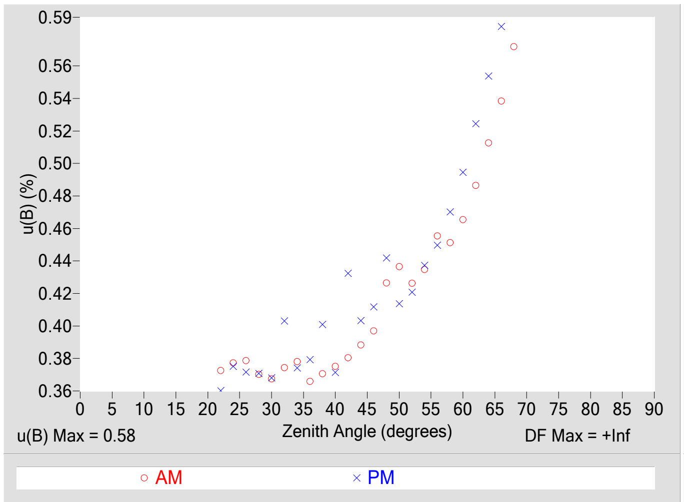


Figure 4. Residuals from Spline Interpolation

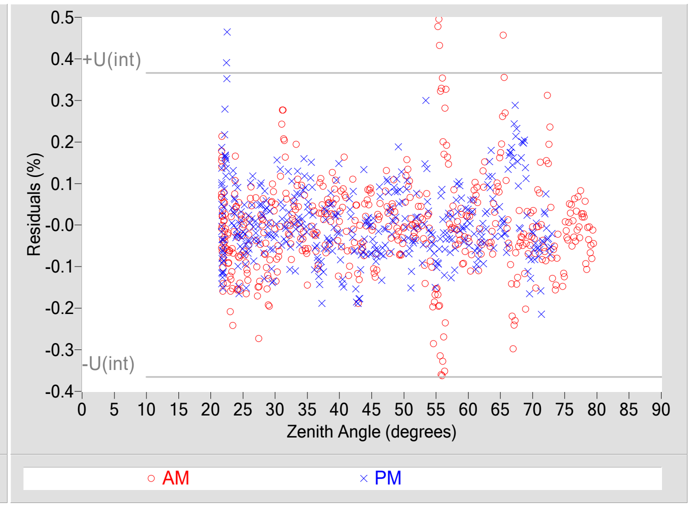


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	100561
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

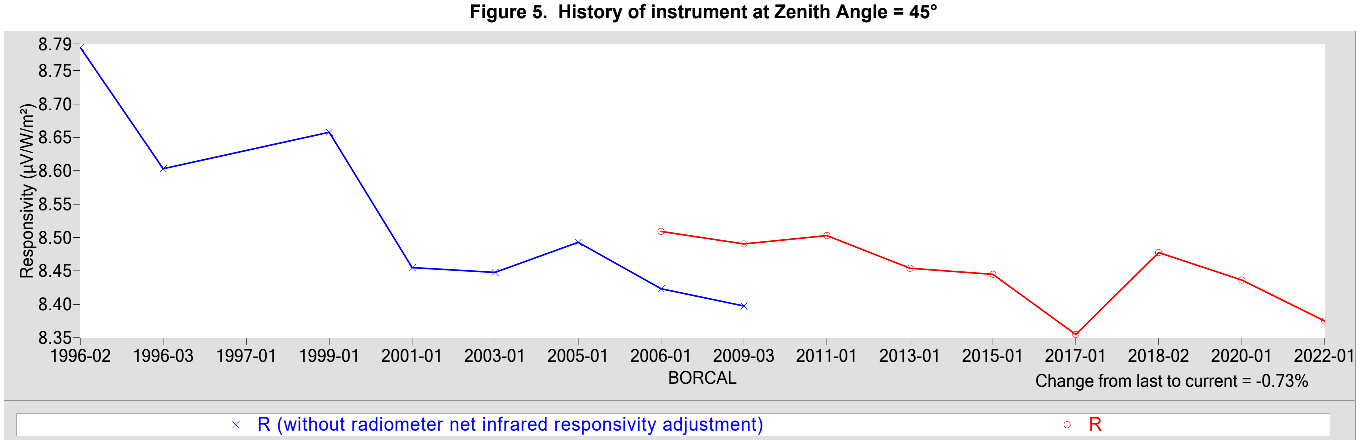
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3749	0.54800

† Rnet determination date: 04/04/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.3 / -1.8
Expanded Uncertainty, U (%)	+2.3 / -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:**	30897F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

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

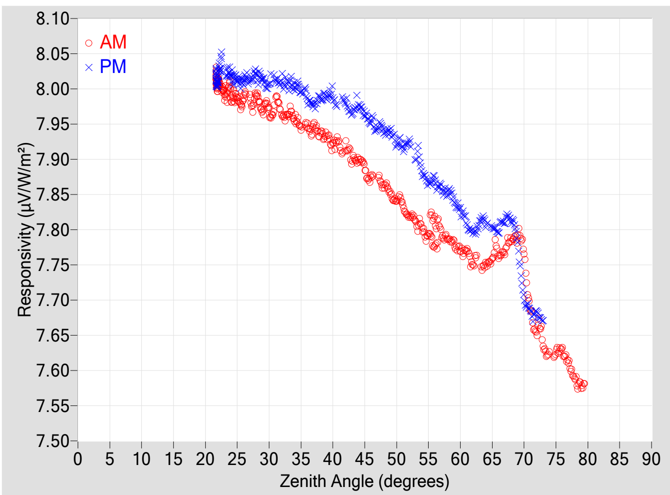


Figure 2. Responsivity vs Local Standard Time

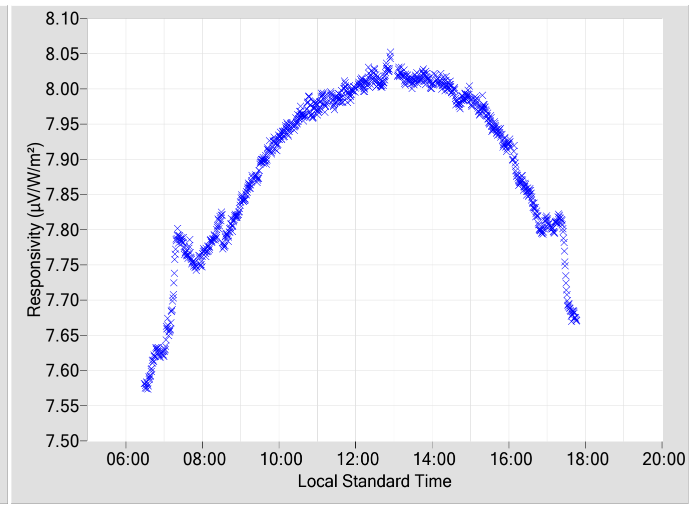


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8745	0.40	105.72	7.9552	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8619	0.43	103.71	7.9394	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8417	0.44	101.87	7.9217	0.42	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8190	0.43	100.00	7.9232	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8036	0.44	98.30	7.8820	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.7959	0.46	94.97	7.8690	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7883	0.45	92.12	7.8528	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7721	0.47	90.55	7.8264	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7534	0.49	89.08	7.7977	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7499	0.52	87.62	7.8083	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7645	0.54	86.18	7.7994	0.59	271.29
22	8.0075	0.37	170.07	8.0147	0.36	189.67	68	7.7854	0.57	84.77	7.8126	N/A	272.75
24	7.9963	0.38	151.57	8.0208	0.38	208.53	70	7.7640	N/A	83.37	7.7034	N/A	274.18
26	7.9868	0.38	142.27	8.0118	0.37	217.71	72	7.6561	N/A	81.97	7.6819	N/A	275.67
28	7.9906	0.37	135.61	8.0187	0.37	224.61	74	7.6248	N/A	80.64	N/A	N/A	N/A
30	7.9696	0.37	130.27	8.0088	0.37	229.99	76	7.6267	N/A	79.11	N/A	N/A	N/A
32	7.9637	0.38	125.56	8.0097	0.40	234.41	78	7.5876	N/A	77.68	N/A	N/A	N/A
34	7.9567	0.38	121.91	8.0018	0.38	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9474	0.37	118.44	7.9869	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9365	0.37	115.43	7.9876	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9210	0.38	112.77	7.9903	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9170	0.38	110.16	7.9808	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8987	0.39	107.88	7.9784	0.41	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

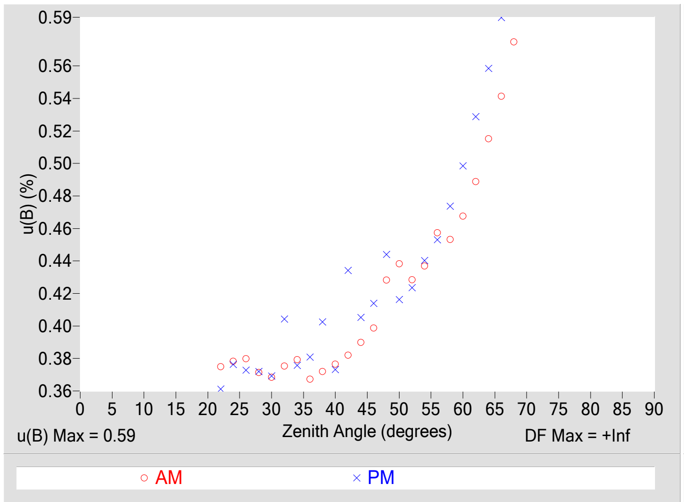


Figure 4. Residuals from Spline Interpolation

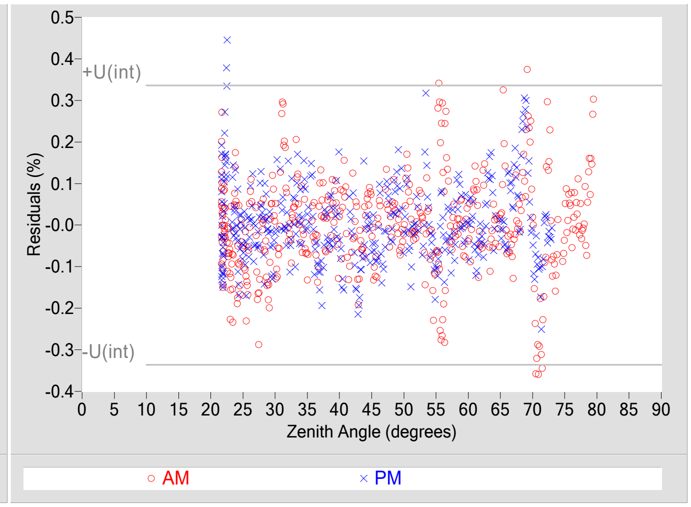


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	141911
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

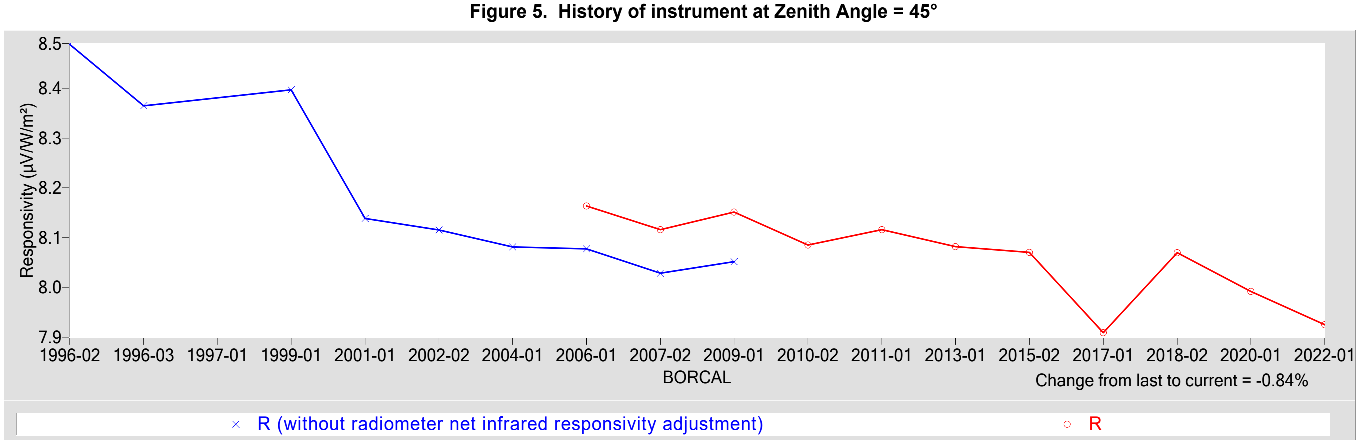
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9249	0.59840

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.1 / -1.9
Expanded Uncertainty, U (%)	+2.0 / -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:** 30899F3

Calibration Date: 5/7/2022 **Due Date:** 5/7/2023

Customer: SGP **Environmental Conditions:** see page 4

Test Dates: 4/30, 5/7

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

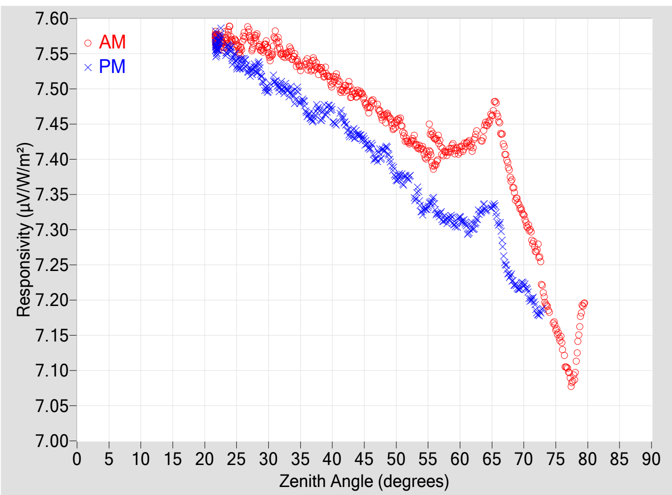


Figure 2. Responsivity vs Local Standard Time

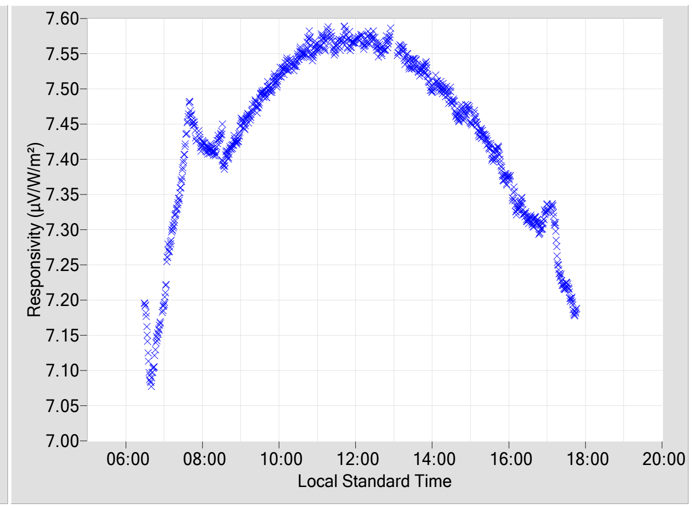


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4758	0.42	105.81	7.4176	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4605	0.41	103.79	7.4130	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4520	0.44	101.83	7.3725	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4238	0.43	100.01	7.3743	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4154	0.44	98.26	7.3269	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4106	0.47	95.11	7.3353	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4089	0.45	92.08	7.3139	0.50	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4143	0.47	90.56	7.3165	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4194	0.49	89.10	7.3035	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4477	0.51	87.64	7.3303	0.55	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4578	0.54	86.19	7.3104	0.59	271.30
22	7.5696	0.36	170.80	7.5587	0.37	189.45	68	7.3718	0.61	84.78	7.2314	N/A	272.76
24	7.5766	0.38	151.44	7.5540	0.37	208.66	70	7.3198	N/A	83.38	7.2217	N/A	274.20
26	7.5680	0.37	142.41	7.5380	0.36	217.79	72	7.2722	N/A	81.94	7.1839	N/A	275.64
28	7.5740	0.39	135.64	7.5281	0.36	224.64	74	7.1864	N/A	80.65	N/A	N/A	N/A
30	7.5504	0.38	130.17	7.4995	0.38	229.87	76	7.1394	N/A	79.17	N/A	N/A	N/A
32	7.5520	0.40	125.77	7.5034	0.39	234.42	78	7.0977	N/A	77.69	N/A	N/A	N/A
34	7.5448	0.41	121.83	7.4884	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5353	0.39	118.46	7.4643	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5275	0.39	115.54	7.4634	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5091	0.39	112.71	7.4642	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5010	0.38	110.26	7.4527	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4928	0.39	107.97	7.4362	0.44	252.15	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

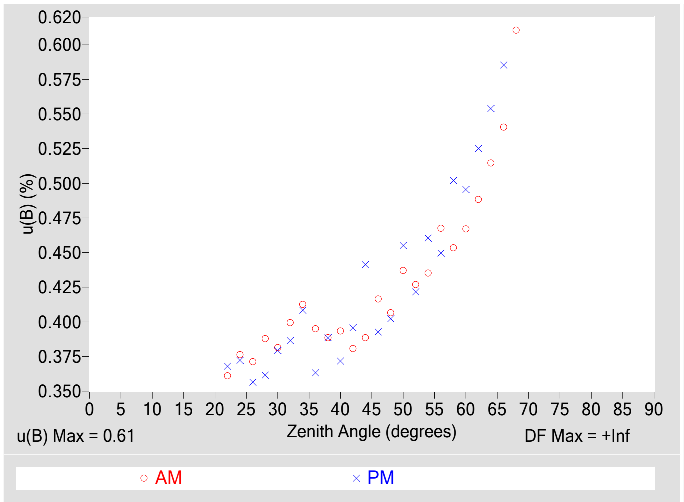


Figure 4. Residuals from Spline Interpolation

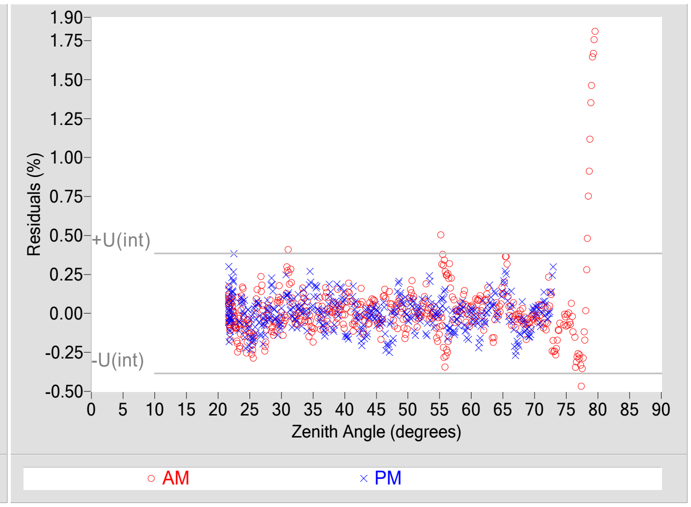


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	97986
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

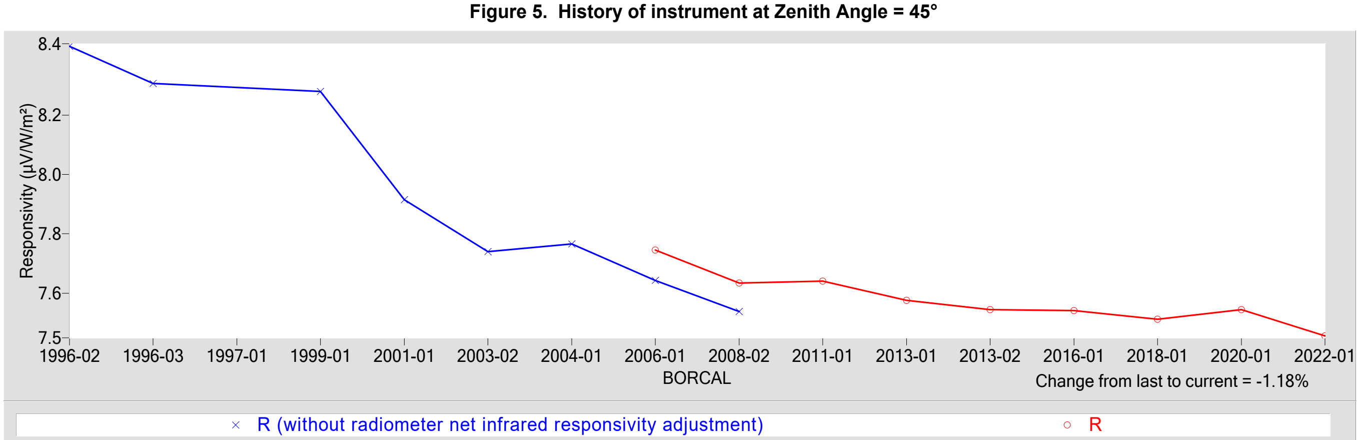
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.4560	0.52200

† Rnet determination date: 04/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.3 / -1.9
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:**	30901F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

30901F3 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

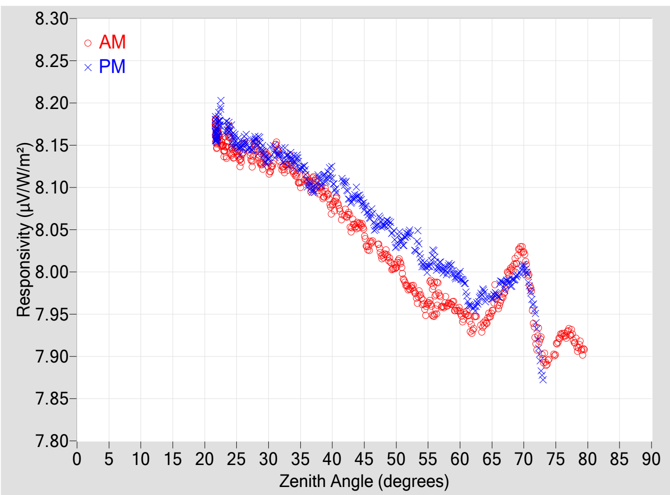


Figure 2. Responsivity vs Local Standard Time

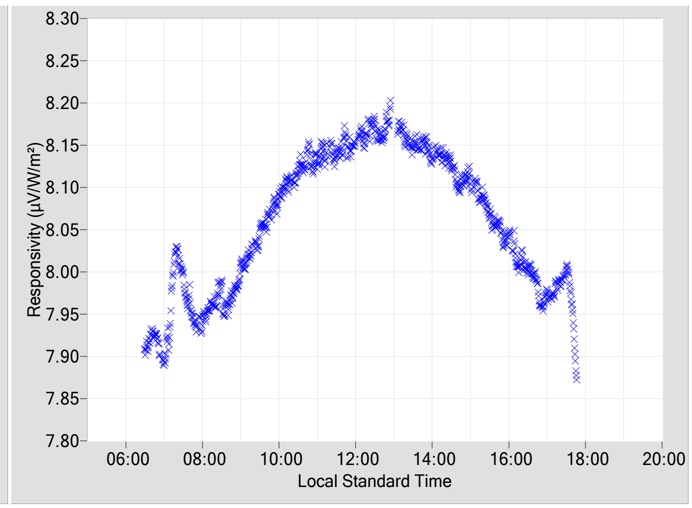


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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
0	N/A	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A
10	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	N/A	N/A	N/A
16	N/A	N/A	N/A	N/A	N/A	N/A
18	N/A	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A	N/A
22	8.1623	0.37	170.27	8.1655	0.36	189.67
24	8.1540	0.38	151.57	8.1676	0.38	208.53
26	8.1443	0.38	142.27	8.1518	0.37	217.71
28	8.1493	0.37	135.61	8.1527	0.37	224.61
30	8.1263	0.37	130.27	8.1357	0.37	229.99
32	8.1253	0.37	125.56	8.1387	0.40	234.41
34	8.1188	0.38	121.91	8.1295	0.37	238.29
36	8.1097	0.37	118.44	8.1099	0.38	241.58
38	8.0979	0.37	115.43	8.1099	0.40	244.59
40	8.0776	0.38	112.77	8.1121	0.37	247.39
42	8.0687	0.38	110.16	8.1035	0.43	249.90
44	8.0555	0.39	107.88	8.0911	0.40	252.20

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
46	8.0335	0.40	105.72	8.0677	0.41	254.40
48	8.0190	0.43	103.71	8.0546	0.44	256.37
50	8.0069	0.44	101.87	8.0326	0.41	258.32
52	7.9808	0.43	100.00	8.0457	0.42	260.10
54	7.9685	0.43	98.30	8.0109	0.44	261.87
56	7.9662	0.46	94.97	8.0165	0.45	263.58
58	7.9632	0.45	92.12	8.0031	0.47	265.17
60	7.9525	0.47	90.55	7.9947	0.49	266.75
62	7.9352	0.49	89.08	7.9590	0.52	268.31
64	7.9395	0.51	87.62	7.9699	0.55	269.82
66	7.9619	0.54	86.18	7.9753	0.58	271.29
68	8.0039	0.57	84.77	7.9864	N/A	272.75
70	8.0221	N/A	83.37	8.0065	N/A	274.18
72	7.9172	N/A	81.97	7.9307	N/A	275.67
74	7.8960	N/A	80.64	N/A	N/A	N/A
76	7.9260	N/A	79.11	N/A	N/A	N/A
78	7.9167	N/A	77.68	N/A	N/A	N/A
80	N/A	N/A	N/A	N/A	N/A	N/A
82	N/A	N/A	N/A	N/A	N/A	N/A
84	N/A	N/A	N/A	N/A	N/A	N/A
86	N/A	N/A	N/A	N/A	N/A	N/A
88	N/A	N/A	N/A	N/A	N/A	N/A
90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

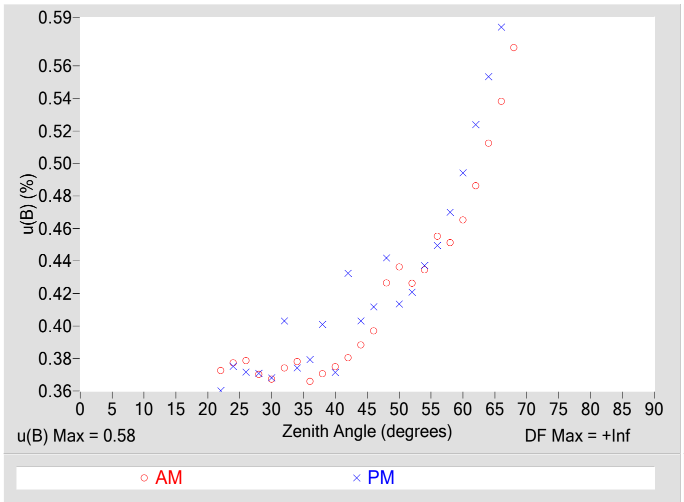


Figure 4. Residuals from Spline Interpolation

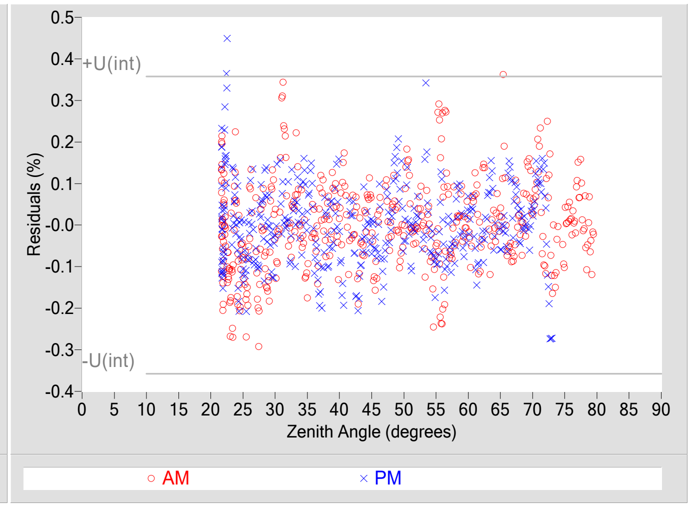


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	108347
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

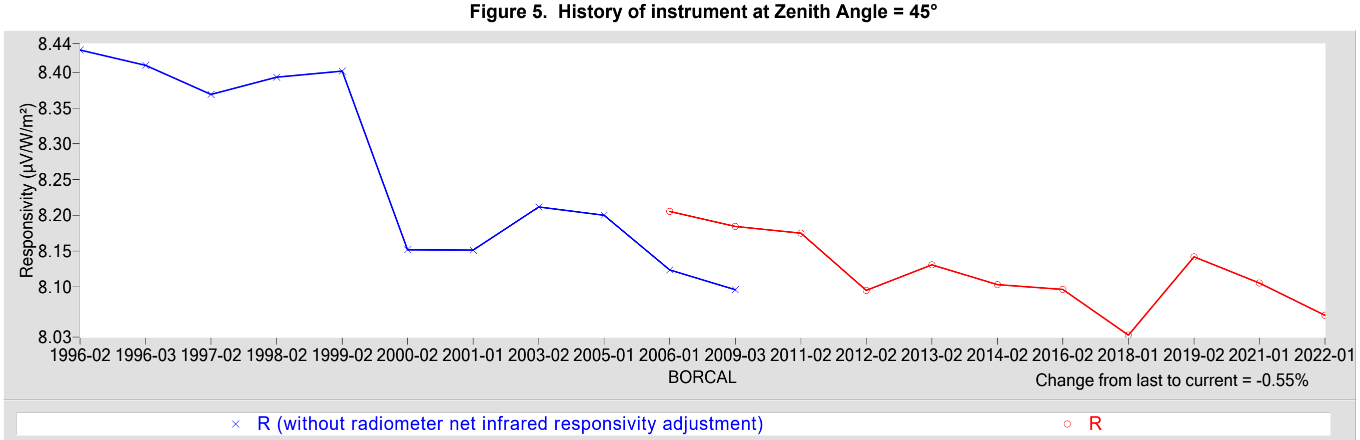
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0605	0.52300

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+0.97 / -1.3
Expanded Uncertainty, U (%)	+1.9 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30903F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

30903F3 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

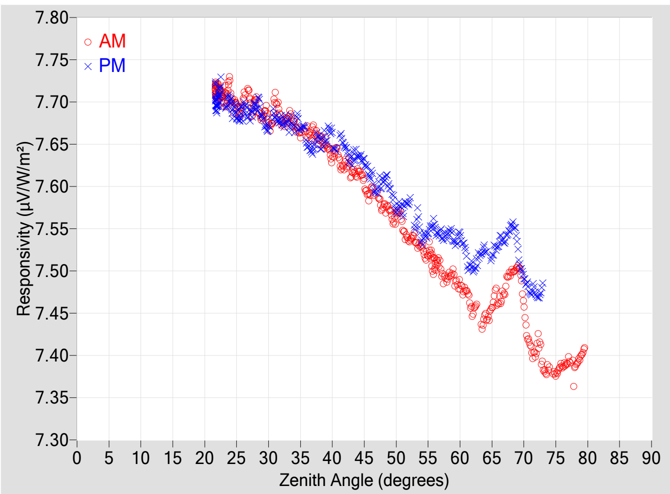


Figure 2. Responsivity vs Local Standard Time

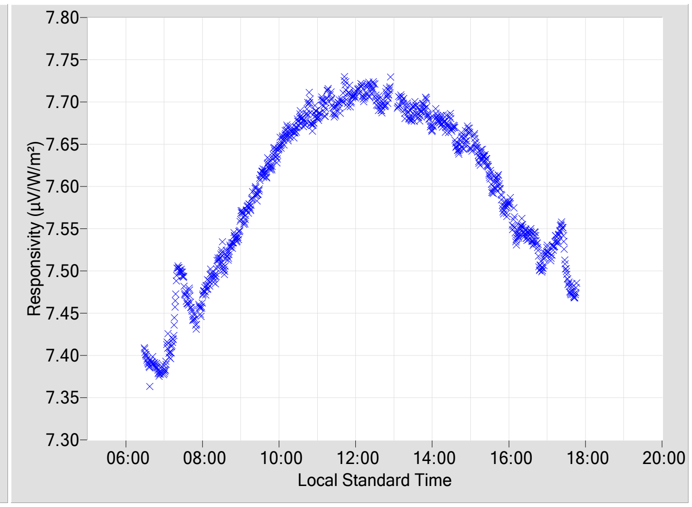


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5925	0.42	105.81	7.6134	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5757	0.41	103.79	7.6070	0.40	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5651	0.44	101.83	7.5722	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5365	0.43	100.01	7.5818	0.42	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5280	0.44	98.26	7.5371	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5070	0.47	95.11	7.5528	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4903	0.46	92.08	7.5429	0.50	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4824	0.47	90.56	7.5423	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4522	0.49	89.10	7.5037	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4449	0.52	87.64	7.5245	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4631	0.54	86.19	7.5325	0.59	271.30
22	7.7131	0.36	170.80	7.6993	0.37	189.45	68	7.4983	0.61	84.78	7.5535	N/A	272.76
24	7.7126	0.38	151.44	7.6994	0.37	208.66	70	7.4598	N/A	83.38	7.4919	N/A	274.20
26	7.6990	0.37	142.41	7.6910	0.36	217.79	72	7.4102	N/A	81.94	7.4708	N/A	275.64
28	7.7018	0.39	135.64	7.6940	0.36	224.64	74	7.3860	N/A	80.65	N/A	N/A	N/A
30	7.6764	0.38	130.17	7.6705	0.38	229.87	76	7.3875	N/A	79.12	N/A	N/A	N/A
32	7.6787	0.40	125.77	7.6771	0.39	234.42	78	7.3812	N/A	77.69	N/A	N/A	N/A
34	7.6752	0.41	121.83	7.6702	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6652	0.40	118.46	7.6494	0.36	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6554	0.39	115.54	7.6513	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6351	0.39	112.71	7.6573	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6253	0.38	110.26	7.6474	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6159	0.39	107.97	7.6376	0.44	252.15	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

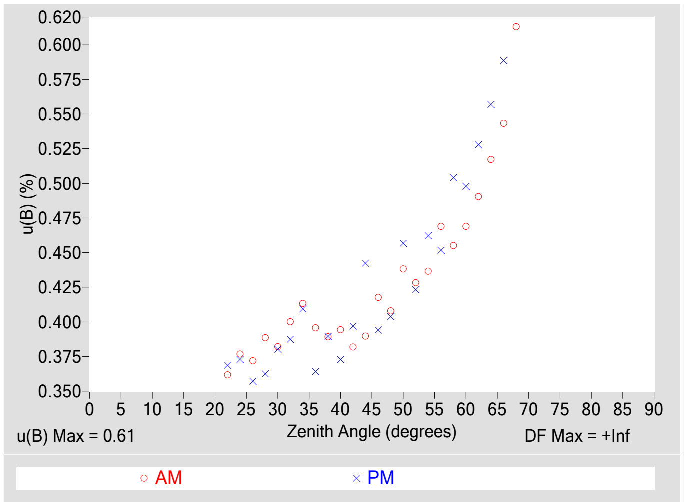


Figure 4. Residuals from Spline Interpolation

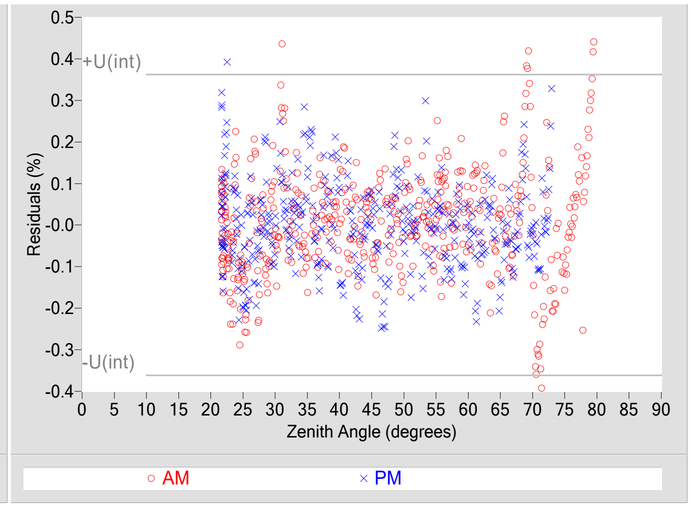


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	124577
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

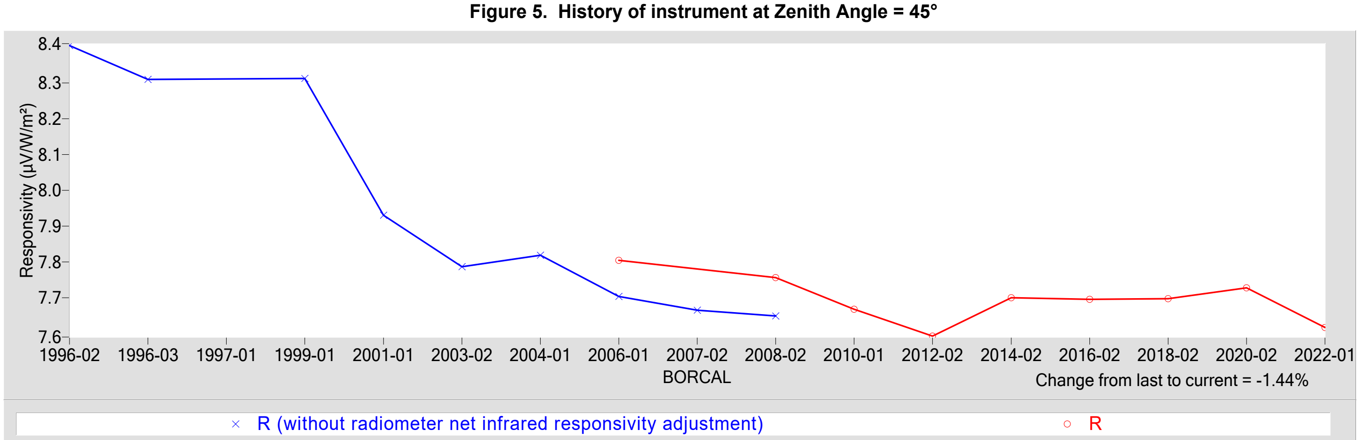
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6166	0.58651

† Rnet determination date: 04/18/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+0.82 / -1.8
Expanded Uncertainty, U (%)	+1.8 / -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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

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

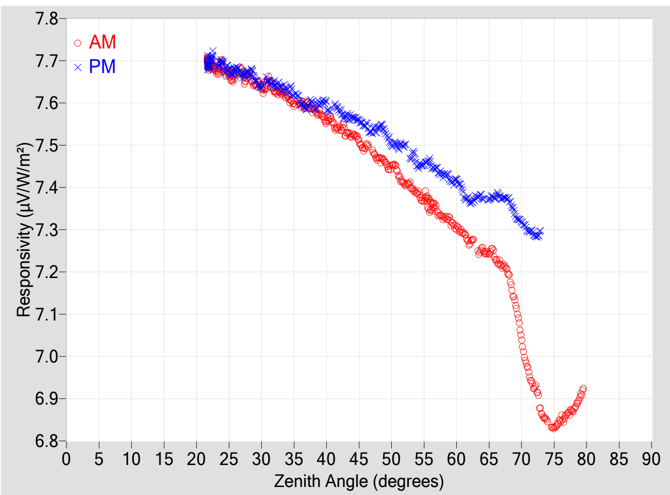


Figure 2. Responsivity vs Local Standard Time

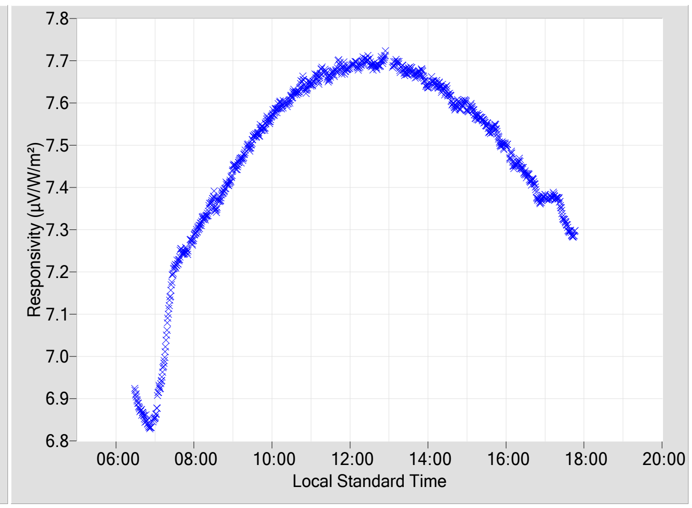


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.4947	0.42	105.81	7.5486	0.40	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4684	0.41	103.79	7.5421	0.41	256.39
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4505	0.44	101.83	7.5013	0.46	258.28
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4080	0.43	100.01	7.4996	0.43	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3867	0.44	98.26	7.4513	0.46	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3560	0.47	95.11	7.4579	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3279	0.46	92.08	7.4292	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3051	0.47	90.56	7.4181	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2693	0.49	89.10	7.3679	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2517	0.52	87.64	7.3756	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.2303	0.55	86.19	7.3791	0.59	271.30
22	7.6926	0.36	170.80	7.6910	0.37	189.45	68	7.1933	0.62	84.78	7.3706	N/A	272.76
24	7.6864	0.38	151.44	7.6926	0.37	208.66	70	7.0436	N/A	83.38	7.3180	N/A	274.20
26	7.6696	0.37	142.41	7.6793	0.36	217.79	72	6.9268	N/A	81.94	7.2868	N/A	275.64
28	7.6658	0.39	135.64	7.6700	0.36	224.64	74	6.8497	N/A	80.65	N/A	N/A	N/A
30	7.6353	0.38	130.17	7.6400	0.38	229.87	76	6.8512	N/A	79.12	N/A	N/A	N/A
32	7.6295	0.40	125.77	7.6449	0.39	234.42	78	6.8734	N/A	77.69	N/A	N/A	N/A
34	7.6143	0.41	121.83	7.6279	0.41	238.21	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5983	0.40	118.46	7.5993	0.37	241.70	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5841	0.39	115.54	7.5929	0.39	244.74	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5572	0.40	112.71	7.5946	0.37	247.33	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5402	0.38	110.26	7.5835	0.40	249.84	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5228	0.39	107.97	7.5670	0.44	252.15	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

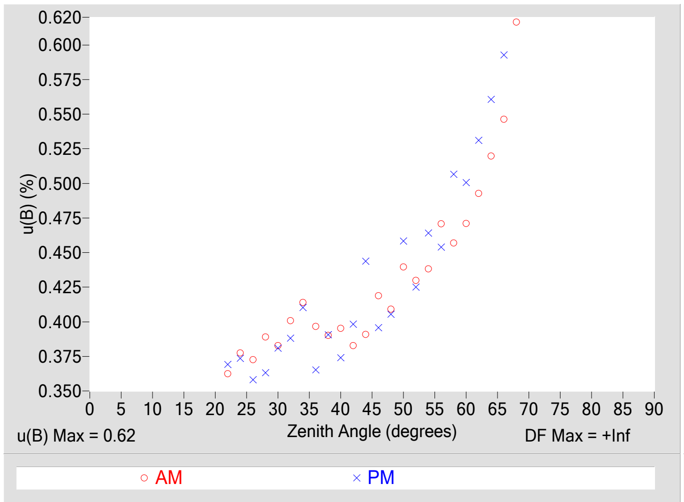


Figure 4. Residuals from Spline Interpolation

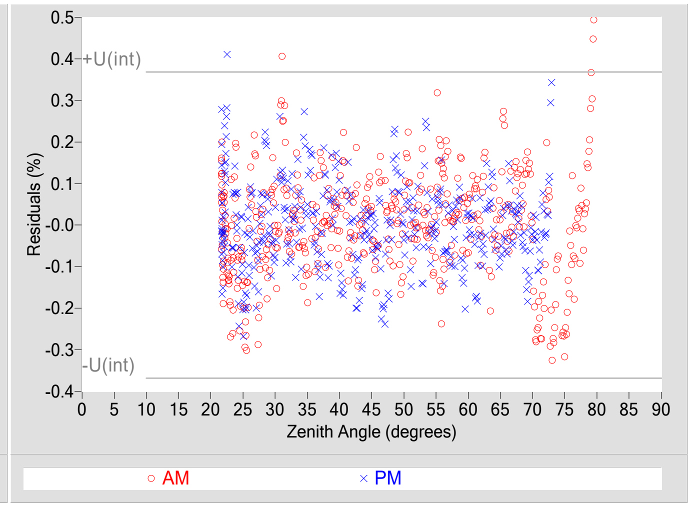


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	119146
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

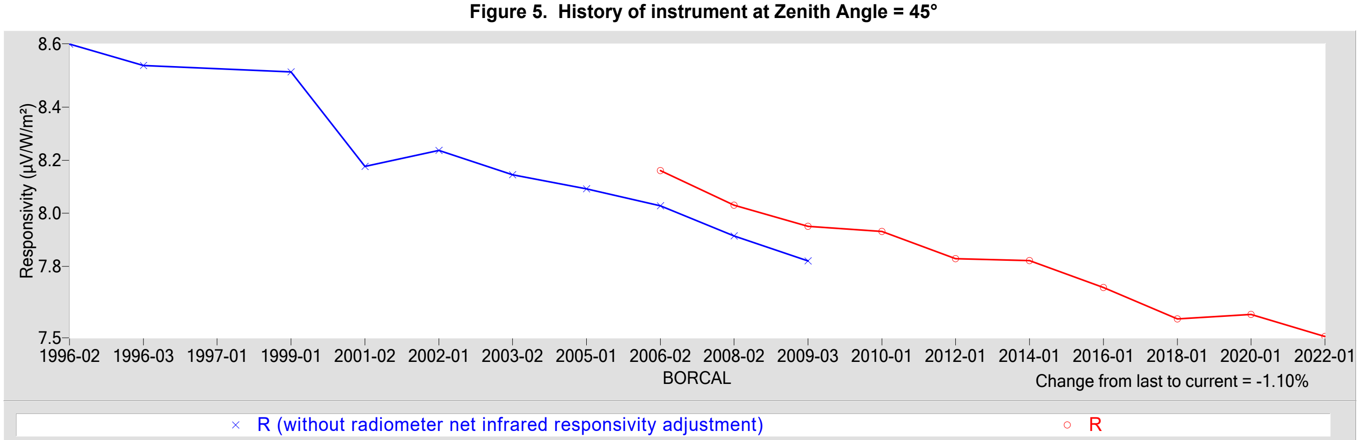
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5343	0.63036

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.5 / -3.0
Expanded Uncertainty, U (%)	+2.5 / -4.0
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:**	30934F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

30934F3 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

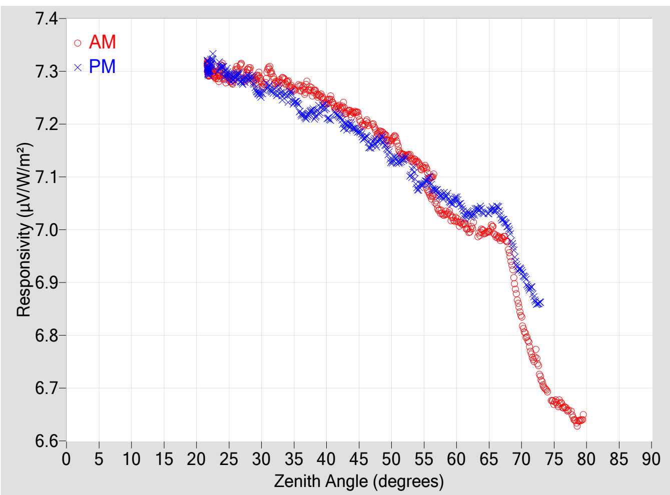


Figure 2. Responsivity vs Local Standard Time

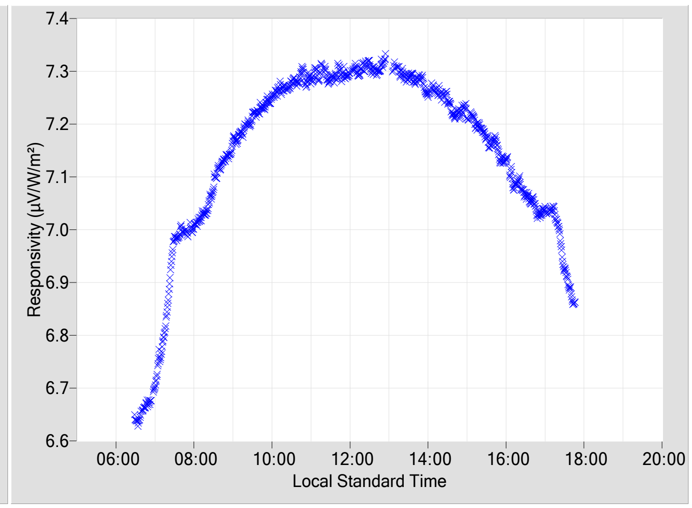


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.2011	0.40	105.82	7.1749	0.39	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.1835	0.41	103.74	7.1693	0.40	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.1691	0.44	101.84	7.1295	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.1397	0.43	100.02	7.1348	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.1276	0.44	98.27	7.0793	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.0813	0.44	95.12	7.0901	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.0287	0.45	92.08	7.0630	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.0181	0.47	90.57	7.0594	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9984	0.52	89.10	7.0290	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9973	0.52	87.65	7.0338	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.9896	0.54	86.20	7.0392	0.59	271.31
22	7.3028	0.35	170.78	7.3037	0.36	189.46	68	6.9644	0.61	84.79	7.0006	N/A	272.77
24	7.2993	0.36	151.53	7.3047	0.37	208.73	70	6.8293	N/A	83.34	6.9212	N/A	274.21
26	7.2961	0.37	142.33	7.2903	0.37	217.78	72	6.7592	N/A	81.95	6.8678	N/A	275.64
28	7.3036	0.37	135.53	7.2879	0.38	224.57	74	6.6946	N/A	80.61	N/A	N/A	N/A
30	7.2794	0.38	130.20	7.2571	0.35	229.89	76	6.6732	N/A	79.13	N/A	N/A	N/A
32	7.2820	0.39	125.67	7.2610	0.38	234.37	78	6.6434	N/A	77.70	N/A	N/A	N/A
34	7.2779	0.38	121.85	7.2473	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.2690	0.41	118.48	7.2204	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.2625	0.39	115.47	7.2201	0.38	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.2412	0.41	112.72	7.2236	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2318	0.38	110.27	7.2142	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2195	0.39	107.98	7.1952	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

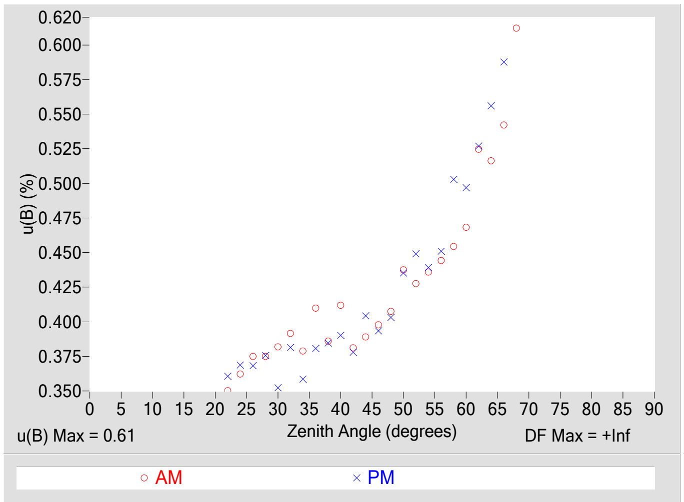


Figure 4. Residuals from Spline Interpolation

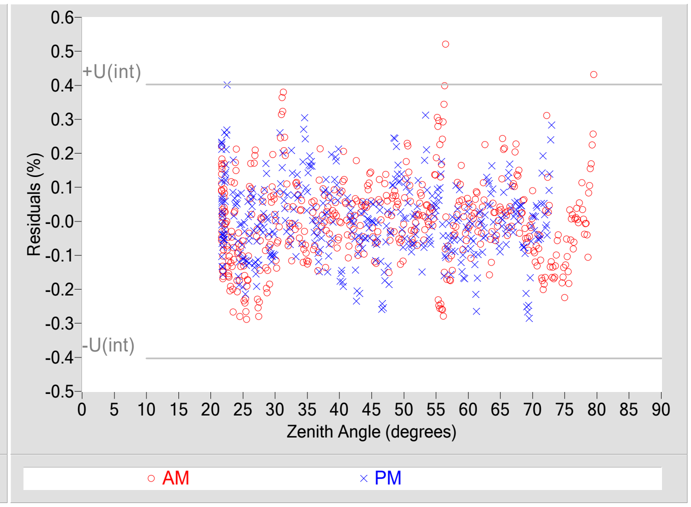


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	83638
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

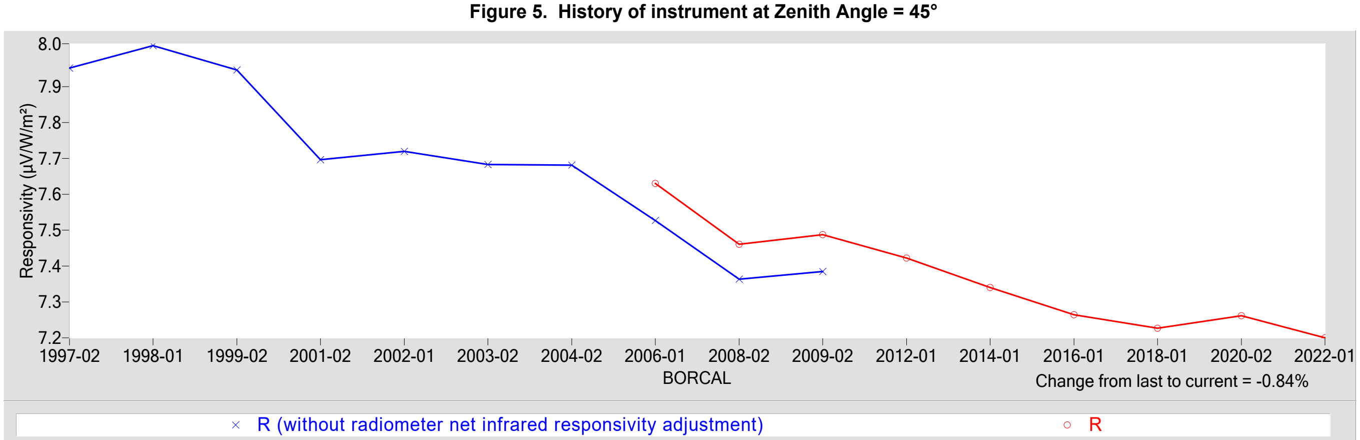
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.2004	0.53000

† Rnet determination date: 04/18/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.1 / -2.5
Expanded Uncertainty, U (%)	+2.1 / -3.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30940F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

30940F3 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

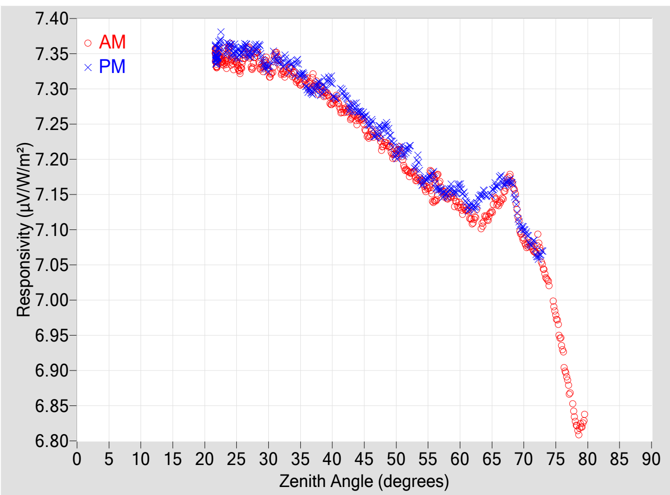


Figure 2. Responsivity vs Local Standard Time

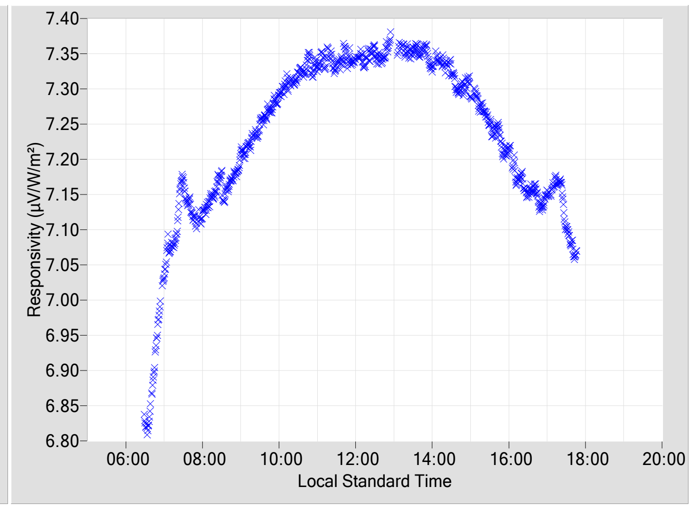


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.2358	0.40	105.82	7.2514	0.40	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2203	0.41	103.74	7.2451	0.41	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2085	0.44	101.84	7.2052	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.1804	0.43	100.02	7.2166	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.1688	0.44	98.27	7.1673	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1566	0.45	95.12	7.1720	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1457	0.46	92.08	7.1524	0.51	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1333	0.47	90.57	7.1621	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1120	0.53	89.10	7.1326	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.1165	0.52	87.65	7.1502	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.1364	0.55	86.20	7.1673	0.59	271.31
22	7.3432	0.35	170.78	7.3468	0.36	189.46	68	7.1714	0.62	84.79	7.1672	N/A	272.77
24	7.3493	0.36	151.53	7.3594	0.37	208.73	70	7.0840	N/A	83.34	7.1005	N/A	274.21
26	7.3411	0.38	142.33	7.3567	0.37	217.78	72	7.0762	N/A	81.95	7.0636	N/A	275.64
28	7.3494	0.38	135.53	7.3579	0.38	224.57	74	7.0236	N/A	80.61	N/A	N/A	N/A
30	7.3255	0.38	130.20	7.3311	0.35	229.89	76	6.9343	N/A	79.13	N/A	N/A	N/A
32	7.3262	0.39	125.67	7.3392	0.38	234.37	78	6.8316	N/A	77.70	N/A	N/A	N/A
34	7.3205	0.38	121.85	7.3252	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3104	0.41	118.48	7.3004	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3015	0.39	115.47	7.3013	0.39	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.2803	0.41	112.72	7.3024	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2693	0.38	110.27	7.2905	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2555	0.39	107.98	7.2717	0.41	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

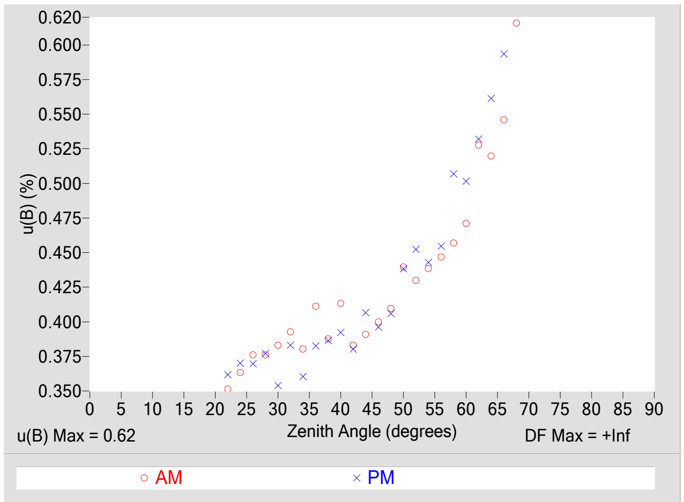


Figure 4. Residuals from Spline Interpolation

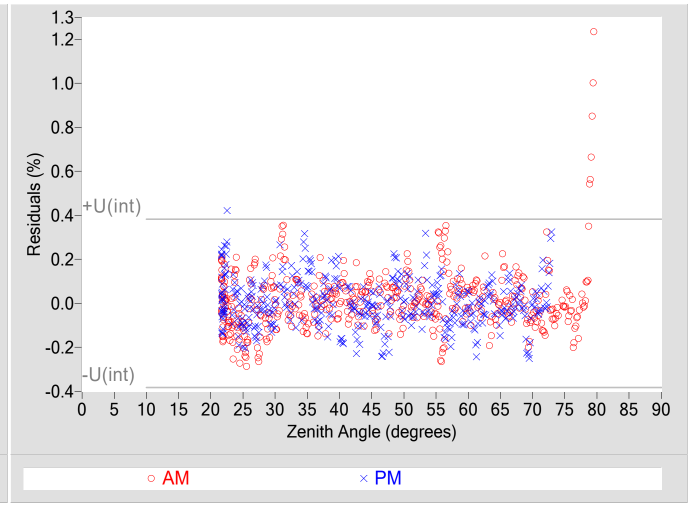


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	102995
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

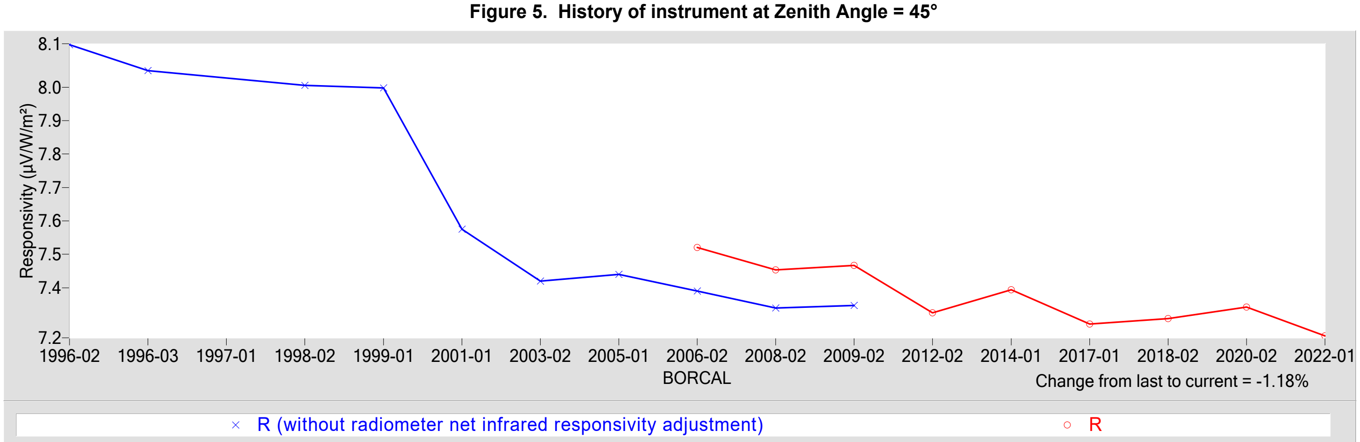
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.2557	0.61870

† Rnet determination date: 06/07/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.2 / -1.7
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:**	30944F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

30944F3 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

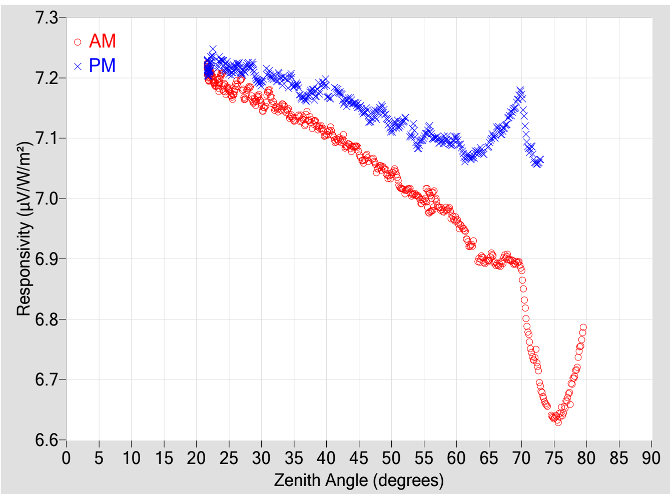


Figure 2. Responsivity vs Local Standard Time

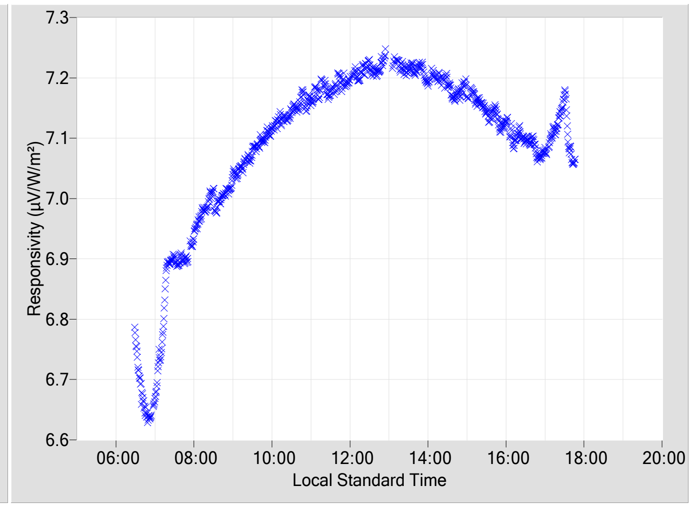


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.0660	0.40	105.82	7.1447	0.39	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.0511	0.41	103.74	7.1462	0.40	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.0394	0.44	101.84	7.1136	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.0128	0.43	100.02	7.1310	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.0042	0.44	98.27	7.0870	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.9925	0.45	95.12	7.1109	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.9794	0.46	92.08	7.0963	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.9634	0.47	90.57	7.1003	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.9228	0.53	89.10	7.0686	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.9003	0.52	87.65	7.0763	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.8920	0.54	86.20	7.1083	0.59	271.31
22	7.2067	0.35	170.78	7.2142	0.36	189.46	68	6.9015	0.61	84.79	7.1345	N/A	272.77
24	7.1945	0.36	151.53	7.2255	0.37	208.73	70	6.8740	N/A	83.34	7.1685	N/A	274.21
26	7.1829	0.38	142.33	7.2170	0.37	217.78	72	6.7377	N/A	81.95	7.0627	N/A	275.64
28	7.1825	0.38	135.53	7.2203	0.38	224.57	74	6.6570	N/A	80.61	N/A	N/A	N/A
30	7.1546	0.38	130.20	7.1925	0.35	229.89	76	6.6451	N/A	79.13	N/A	N/A	N/A
32	7.1528	0.39	125.67	7.1998	0.38	234.37	78	6.7005	N/A	77.70	N/A	N/A	N/A
34	7.1449	0.38	121.85	7.1896	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.1334	0.41	118.48	7.1691	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.1260	0.39	115.47	7.1743	0.39	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.1060	0.41	112.72	7.1817	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.0965	0.38	110.27	7.1762	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.0834	0.39	107.98	7.1601	0.41	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

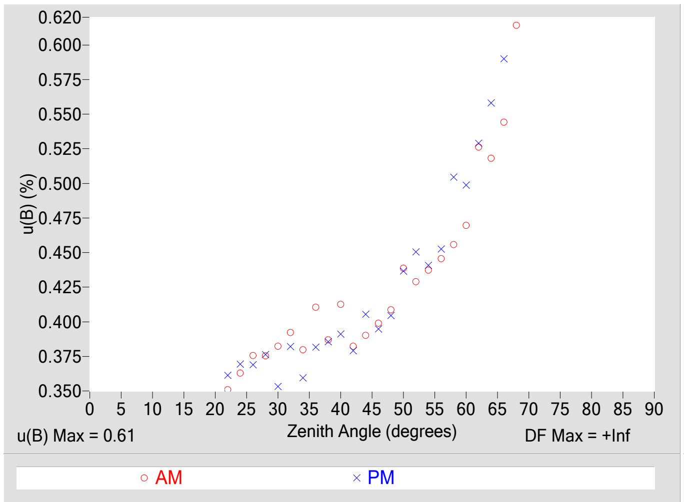


Figure 4. Residuals from Spline Interpolation

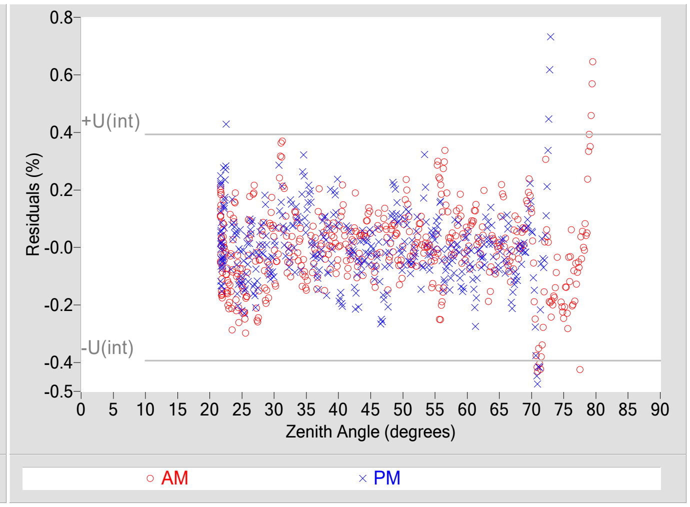


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	92249
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

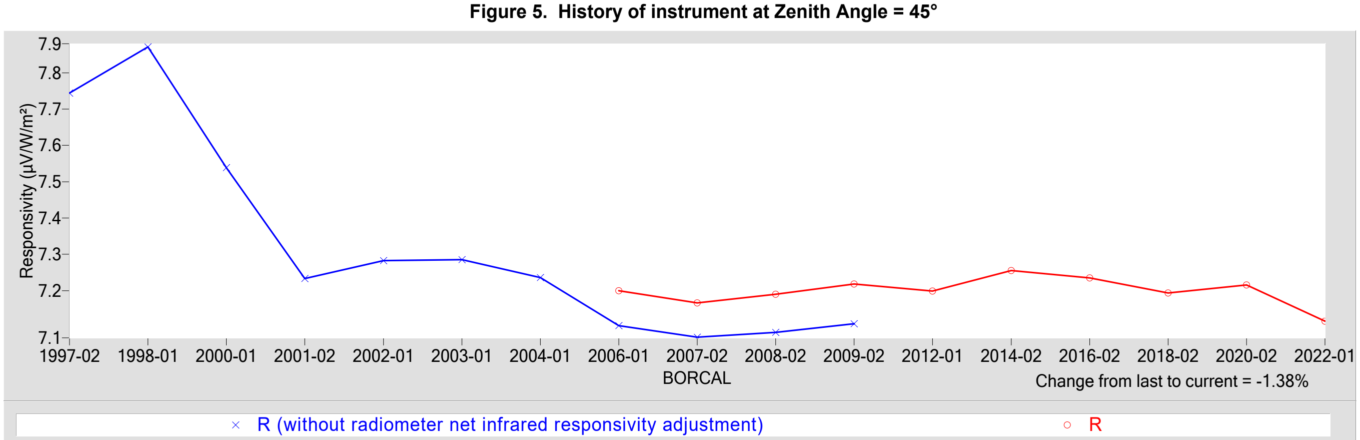
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.1157	0.56695

† Rnet determination date: 04/18/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.2 / -2.1
Expanded Uncertainty, U (%)	+2.2 / -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: 30945F3
Calibration Date: 5/7/2022
Due Date: 5/7/2023
Customer: SGP
Environmental Conditions: see page 4
Test Dates: 4/30, 5/7

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

30945F3 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

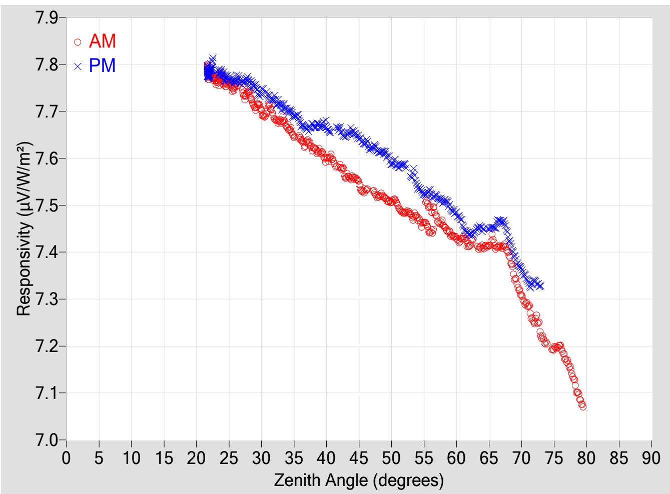


Figure 2. Responsivity vs Local Standard Time

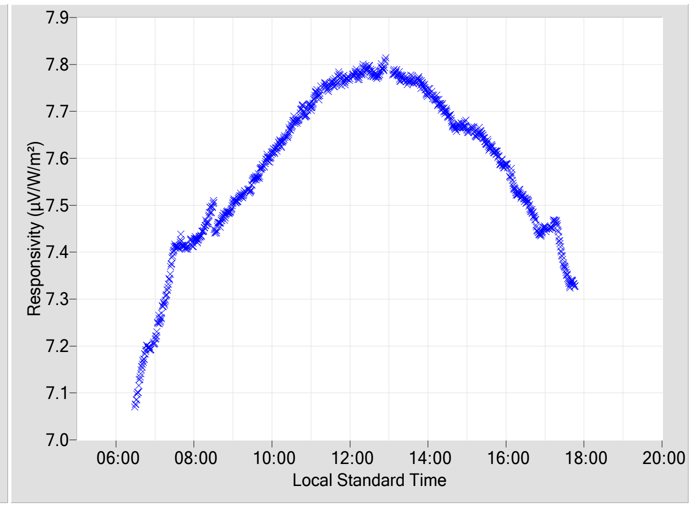


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5324	0.40	105.72	7.6336	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5190	0.43	103.71	7.6135	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5076	0.44	101.87	7.5889	0.41	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4844	0.43	100.00	7.5854	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4739	0.44	98.30	7.5403	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4705	0.46	94.97	7.5259	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4588	0.45	92.12	7.5088	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4291	0.47	90.55	7.4806	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4172	0.49	89.08	7.4390	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4097	0.51	87.62	7.4491	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4127	0.54	86.18	7.4549	0.59	271.29
22	7.7804	0.37	170.27	7.7818	0.36	189.67	68	7.3954	0.57	84.77	7.4308	N/A	272.75
24	7.7703	0.38	151.57	7.7794	0.38	208.53	70	7.3083	N/A	83.37	7.3633	N/A	274.18
26	7.7547	0.38	142.27	7.7665	0.37	217.71	72	7.2528	N/A	81.97	7.3377	N/A	275.67
28	7.7406	0.37	135.61	7.7632	0.37	224.61	74	7.2066	N/A	80.64	N/A	N/A	N/A
30	7.7014	0.37	130.27	7.7407	0.37	229.99	76	7.1971	N/A	79.11	N/A	N/A	N/A
32	7.6841	0.37	125.56	7.7239	0.40	234.41	78	7.1298	N/A	77.68	N/A	N/A	N/A
34	7.6669	0.38	121.91	7.7002	0.37	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6415	0.37	118.44	7.6755	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6211	0.37	115.43	7.6707	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5991	0.38	112.77	7.6677	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5828	0.38	110.16	7.6620	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5583	0.39	107.88	7.6574	0.40	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

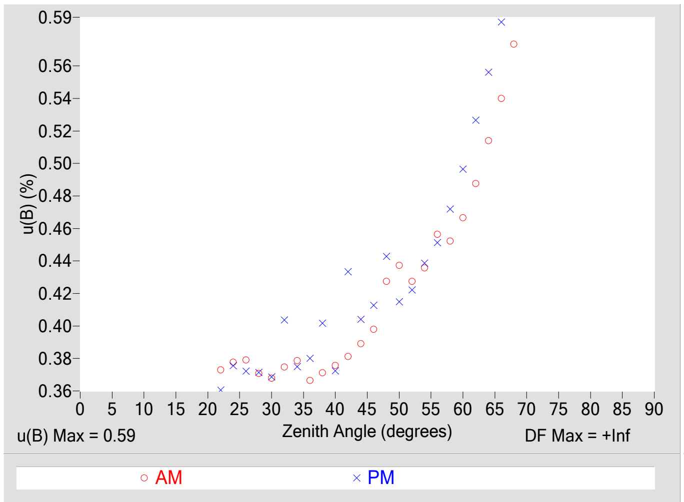


Figure 4. Residuals from Spline Interpolation

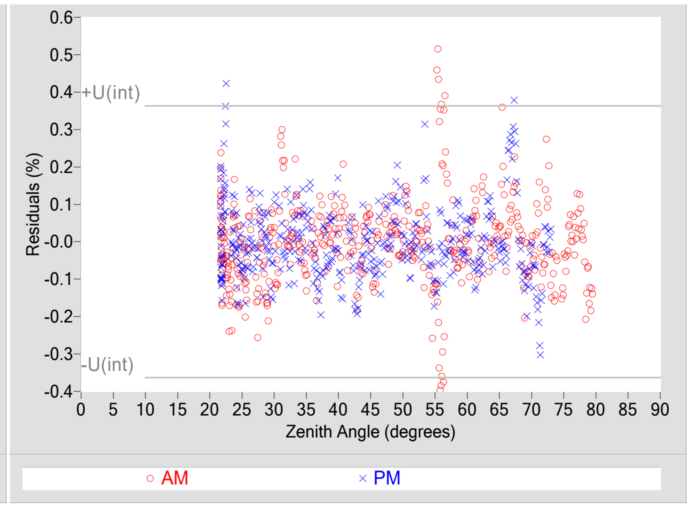


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	105194
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

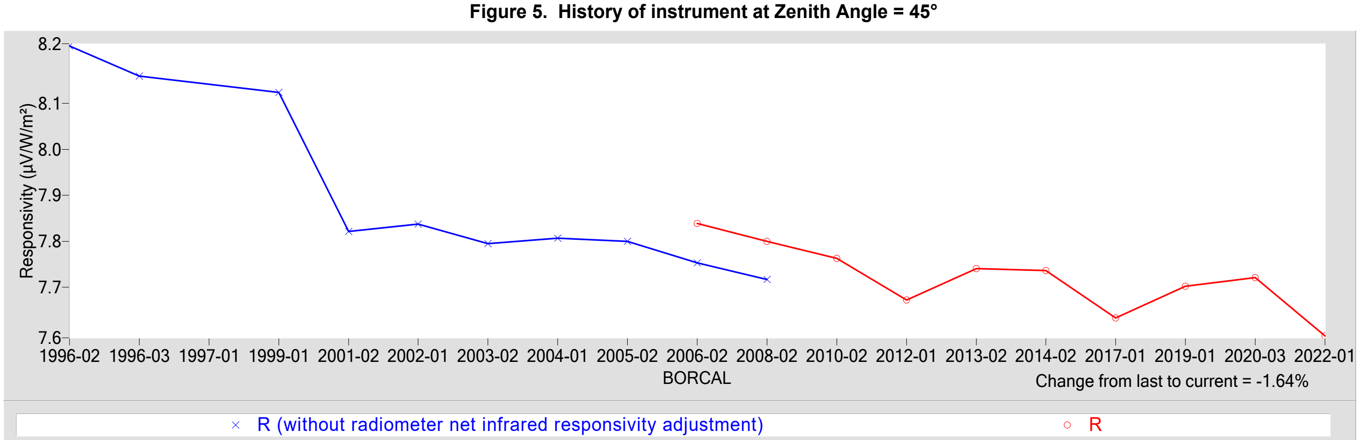
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5944	0.53402

† Rnet determination date: 07/10/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.9 / -2.2
Expanded Uncertainty, U (%)	+2.9 / -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:**	30946F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

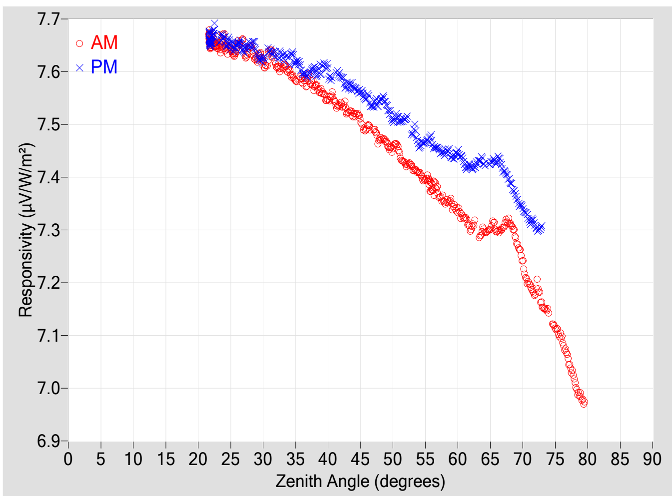


Figure 2. Responsivity vs Local Standard Time

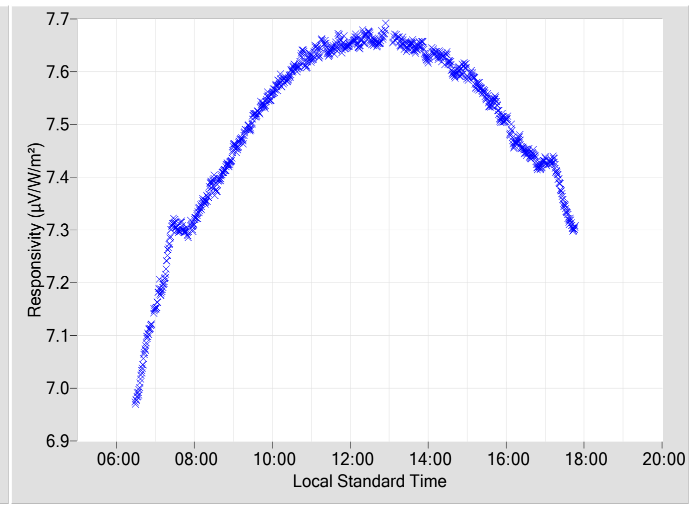


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.4931	0.40	105.82	7.5513	0.40	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4719	0.41	103.74	7.5459	0.41	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4563	0.44	101.84	7.5080	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4243	0.43	100.02	7.5114	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4085	0.44	98.27	7.4607	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3817	0.45	95.12	7.4688	0.46	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3525	0.46	92.08	7.4464	0.51	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3375	0.47	90.57	7.4467	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3033	0.53	89.10	7.4196	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2994	0.52	87.65	7.4272	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.2984	0.55	86.20	7.4314	0.60	271.31
22	7.6584	0.35	170.78	7.6582	0.36	189.46	68	7.3138	0.62	84.79	7.3916	N/A	272.77
24	7.6557	0.36	151.53	7.6624	0.37	208.73	70	7.2353	N/A	83.34	7.3405	N/A	274.21
26	7.6469	0.38	142.33	7.6517	0.37	217.78	72	7.1876	N/A	81.95	7.3052	N/A	275.64
28	7.6469	0.38	135.53	7.6502	0.38	224.57	74	7.1466	N/A	80.61	N/A	N/A	N/A
30	7.6178	0.38	130.20	7.6235	0.35	229.89	76	7.0961	N/A	79.13	N/A	N/A	N/A
32	7.6123	0.39	125.67	7.6322	0.38	234.37	78	7.0135	N/A	77.70	N/A	N/A	N/A
34	7.6008	0.38	121.85	7.6203	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5841	0.41	118.48	7.5990	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5739	0.39	115.47	7.6006	0.39	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5475	0.41	112.72	7.6011	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5367	0.38	110.27	7.5908	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5179	0.39	107.98	7.5715	0.41	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

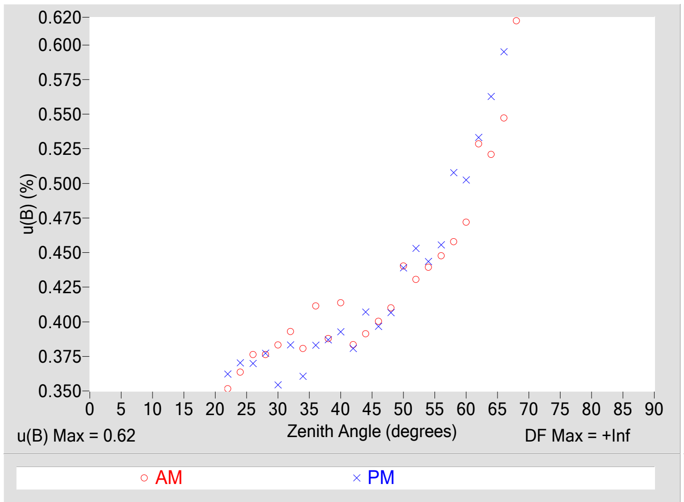


Figure 4. Residuals from Spline Interpolation

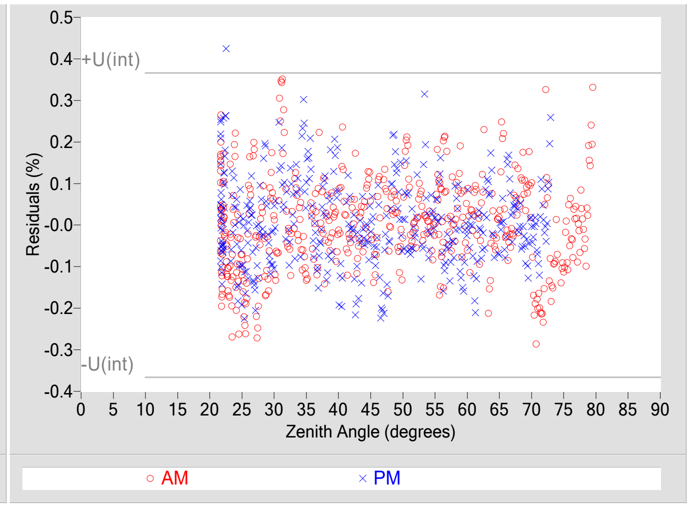


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	122224
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

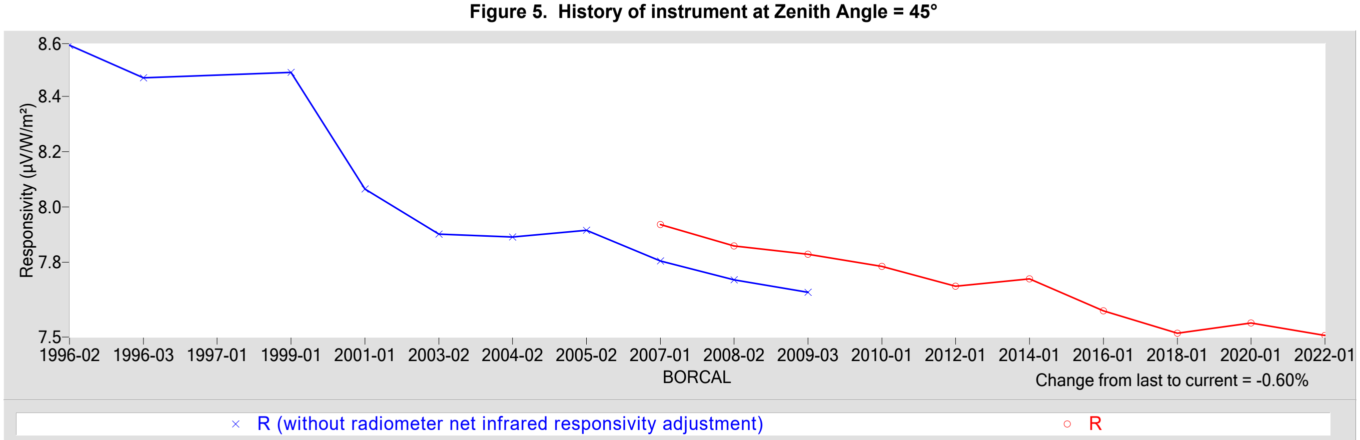
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5358	0.66251

† Rnet determination date: 04/24/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.00
Offset Uncertainty, U(off) (%)	+1.3 / -2.6
Expanded Uncertainty, U (%)	+2.3 / -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:**	30947F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

30947F3 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

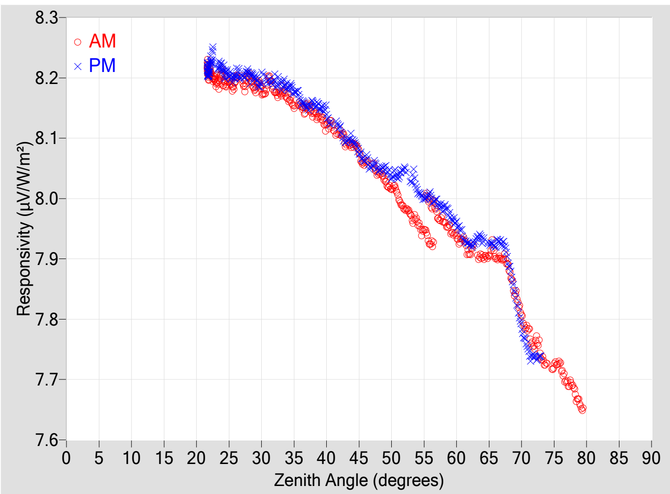


Figure 2. Responsivity vs Local Standard Time

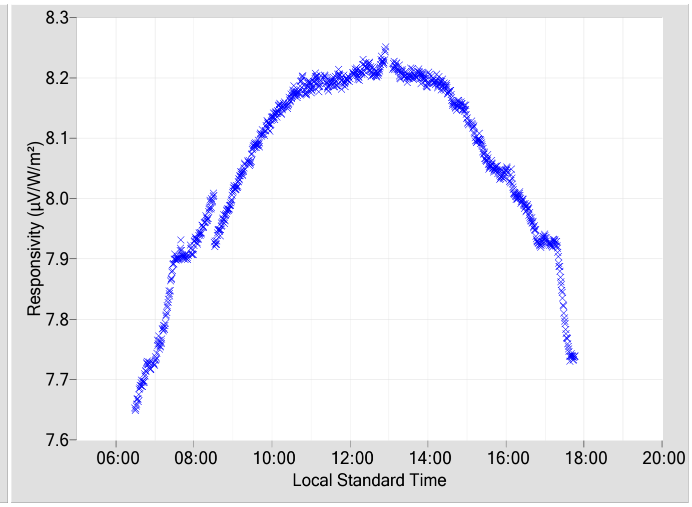


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0605	0.40	105.72	8.0653	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0414	0.43	103.71	8.0477	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0168	0.44	101.87	8.0351	0.41	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9833	0.43	100.00	8.0481	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9619	0.44	98.30	8.0128	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9625	0.46	94.97	8.0033	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9636	0.45	92.12	7.9842	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9369	0.47	90.55	7.9570	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9112	0.49	89.08	7.9244	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9022	0.51	87.62	7.9311	0.55	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9035	0.54	86.18	7.9236	0.59	271.29
22	8.2091	0.37	170.27	8.2135	0.36	189.67	68	7.8855	0.57	84.77	7.8929	N/A	272.75
24	8.1999	0.38	151.57	8.2154	0.38	208.53	70	7.8081	N/A	83.37	7.7870	N/A	274.18
26	8.1953	0.38	142.27	8.2041	0.37	217.71	72	7.7564	N/A	81.97	7.7380	N/A	275.67
28	8.2017	0.37	135.61	8.2078	0.37	224.47	74	7.7270	N/A	80.64	N/A	N/A	N/A
30	8.1821	0.37	130.27	8.1964	0.37	229.99	76	7.7227	N/A	79.11	N/A	N/A	N/A
32	8.1769	0.37	125.56	8.1936	0.40	234.41	78	7.6852	N/A	77.68	N/A	N/A	N/A
34	8.1673	0.38	121.91	8.1841	0.37	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1548	0.37	118.44	8.1627	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1409	0.37	115.43	8.1581	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1211	0.38	112.77	8.1414	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1088	0.38	110.16	8.1173	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0886	0.39	107.88	8.0975	0.40	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

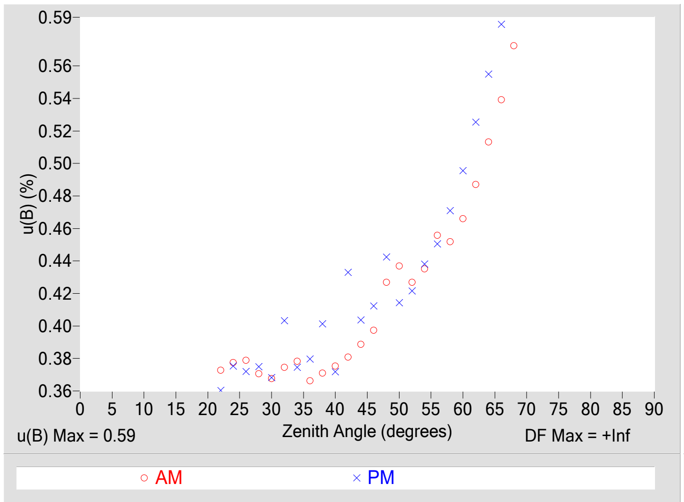


Figure 4. Residuals from Spline Interpolation

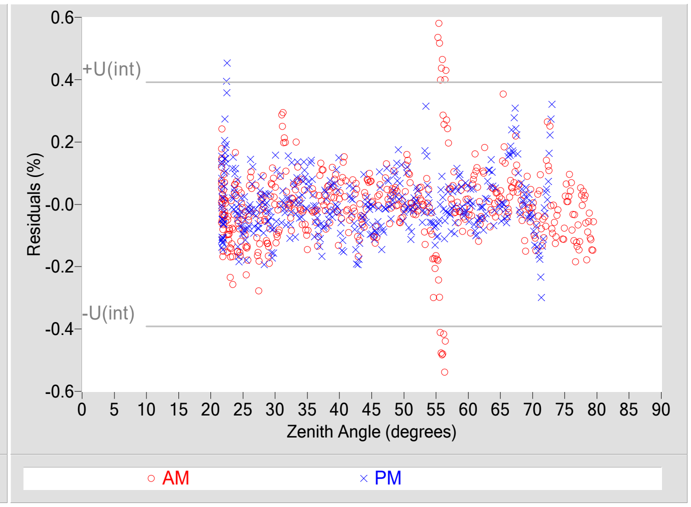


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	79049
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

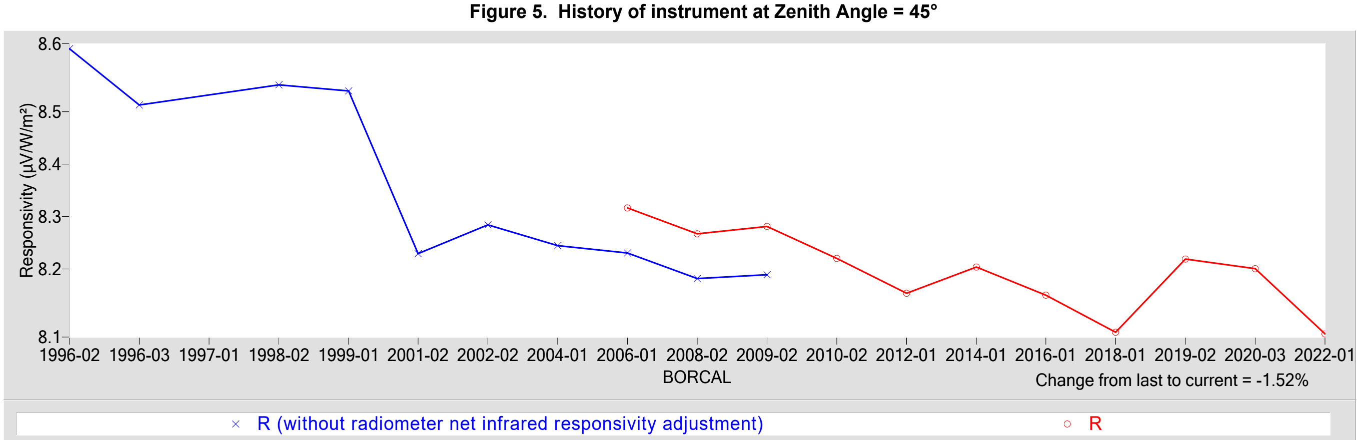
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.0758	0.54900

† Rnet determination date: 04/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.5 / -1.7
Expanded Uncertainty, U (%)	+2.5 / -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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30951F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

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

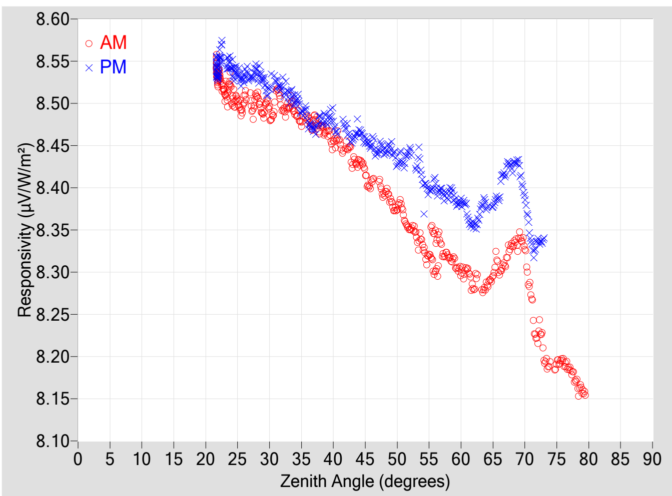


Figure 2. Responsivity vs Local Standard Time

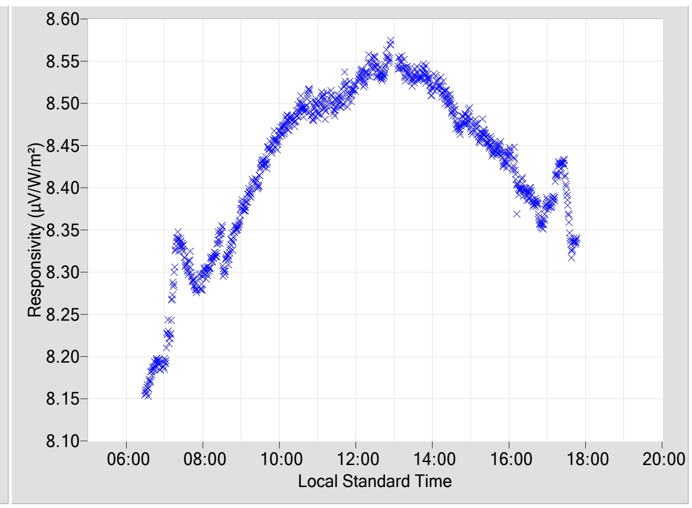


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4071	0.40	105.72	8.4530	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3928	0.43	103.71	8.4423	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3755	0.44	101.87	8.4295	0.42	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3514	0.43	100.00	8.4423	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3331	0.44	98.30	8.3994	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3240	0.46	94.97	8.4034	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3193	0.45	92.12	8.3929	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3019	0.47	90.55	8.3822	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2848	0.49	89.08	8.3566	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2836	0.52	87.62	8.3777	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3025	0.54	86.18	8.3923	0.59	271.29
22	8.5340	0.37	170.27	8.5402	0.36	189.67	68	8.3316	0.57	84.77	8.4241	N/A	272.75
24	8.5153	0.38	151.57	8.5446	0.38	208.53	70	8.3261	N/A	83.37	8.3876	N/A	274.18
26	8.5031	0.38	142.27	8.5313	0.37	217.71	72	8.2223	N/A	81.97	8.3364	N/A	275.67
28	8.5087	0.37	135.61	8.5360	0.37	224.61	74	8.1912	N/A	80.64	N/A	N/A	N/A
30	8.4913	0.37	130.27	8.5196	0.37	229.99	76	8.1943	N/A	79.11	N/A	N/A	N/A
32	8.4937	0.38	125.56	8.5186	0.40	234.41	78	8.1695	N/A	77.68	N/A	N/A	N/A
34	8.4905	0.38	121.91	8.5022	0.38	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4821	0.37	118.44	8.4803	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4701	0.37	115.43	8.4819	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4532	0.38	112.77	8.4802	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4492	0.38	110.16	8.4705	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4300	0.39	107.88	8.4690	0.41	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

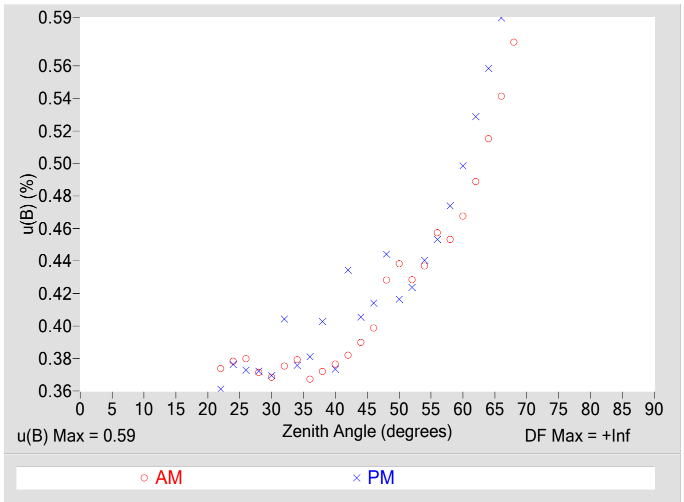


Figure 4. Residuals from Spline Interpolation

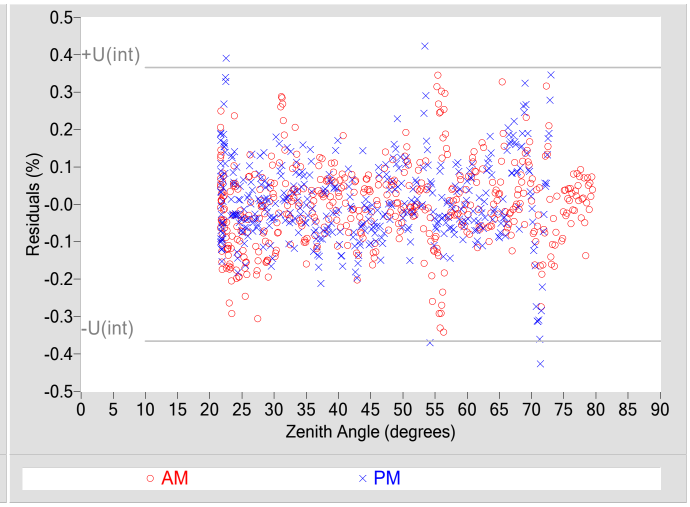


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	103839
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

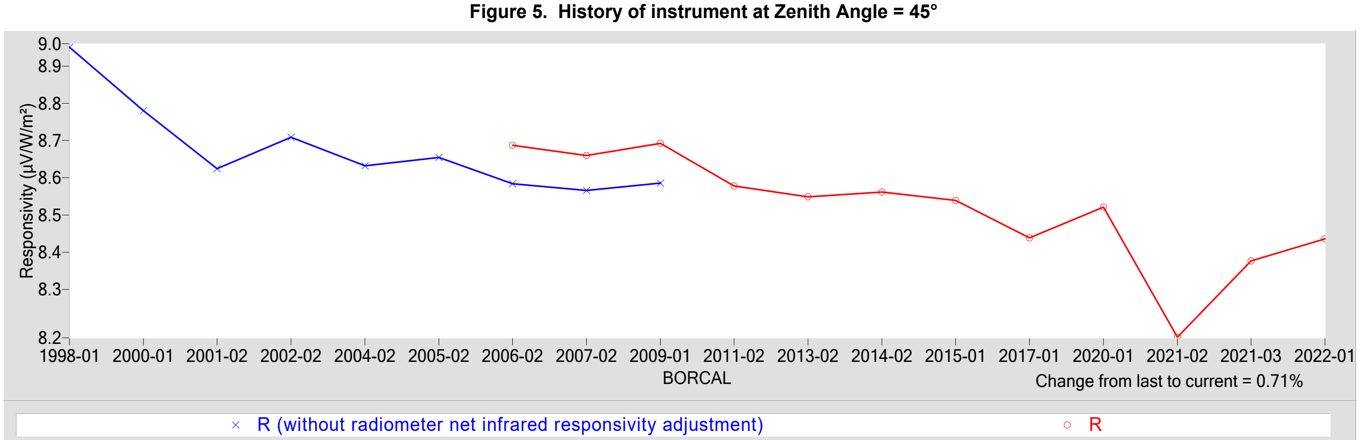
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4356	0.64270

† Rnet determination date: 07/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.00 / -1.6
Expanded Uncertainty, U (%)	+2.0 / -2.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30952F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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
30952F3 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

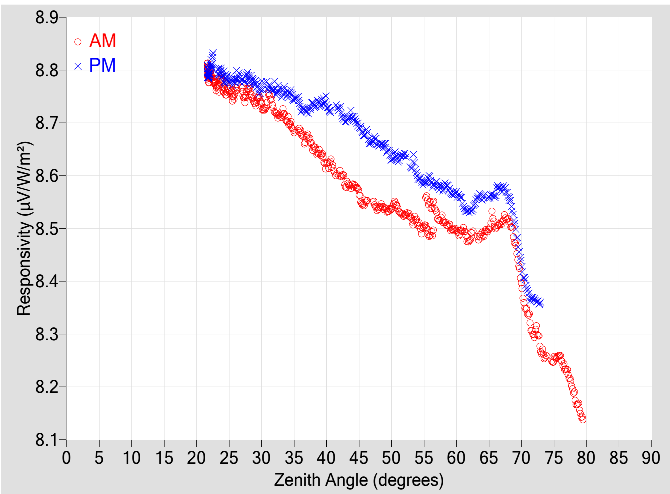


Figure 2. Responsivity vs Local Standard Time

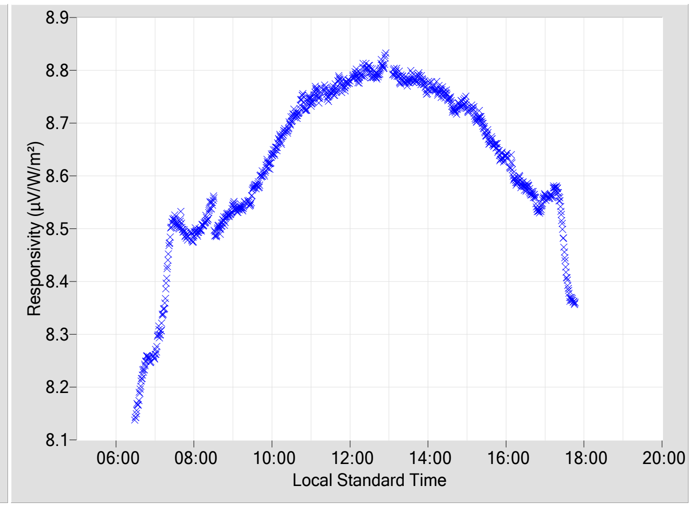


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5504	0.40	105.72	8.6798	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5381	0.43	103.71	8.6577	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5377	0.44	101.87	8.6322	0.41	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5257	0.43	100.00	8.6391	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5124	0.44	98.30	8.5981	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5193	0.46	94.97	8.5910	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5154	0.45	92.12	8.5782	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4957	0.47	90.55	8.5647	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4812	0.49	89.08	8.5338	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4865	0.51	87.62	8.5596	0.55	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5048	0.54	86.18	8.5652	0.59	271.29
22	8.7908	0.37	170.27	8.7966	0.36	189.67	68	8.5153	0.57	84.77	8.5599	N/A	272.75
24	8.7745	0.38	151.57	8.7919	0.38	208.53	70	8.3962	N/A	83.37	8.4322	N/A	274.18
26	8.7606	0.38	142.27	8.7834	0.37	217.71	72	8.3001	N/A	81.97	8.3653	N/A	275.67
28	8.7635	0.37	135.61	8.7850	0.37	224.61	74	8.2587	N/A	80.64	N/A	N/A	N/A
30	8.7358	0.37	130.27	8.7674	0.37	229.99	76	8.2550	N/A	79.11	N/A	N/A	N/A
32	8.7211	0.37	125.56	8.7639	0.40	234.41	78	8.1902	N/A	77.68	N/A	N/A	N/A
34	8.7041	0.38	121.91	8.7535	0.37	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6828	0.37	118.44	8.7313	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6530	0.37	115.43	8.7350	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6218	0.38	112.77	8.7362	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6028	0.38	110.16	8.7254	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5810	0.39	107.88	8.7122	0.40	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

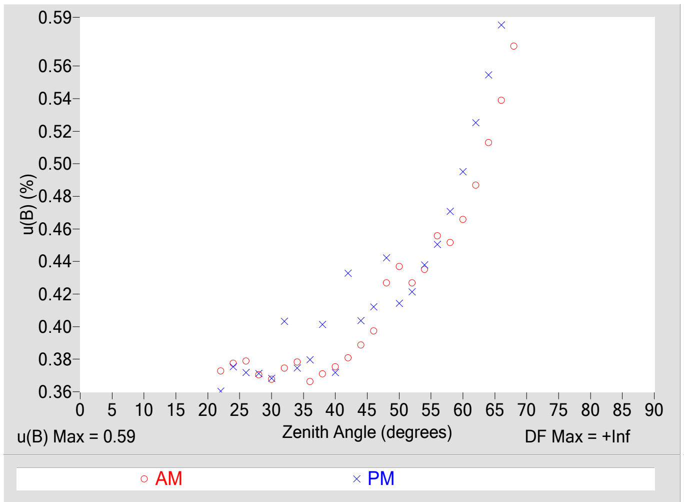


Figure 4. Residuals from Spline Interpolation

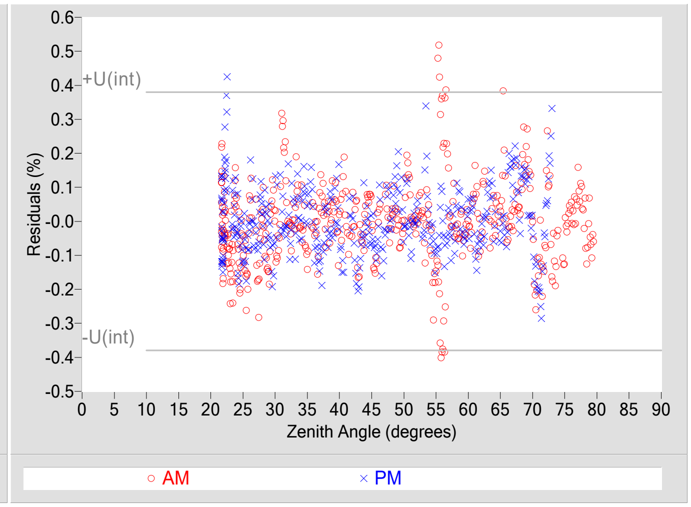


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	88495
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

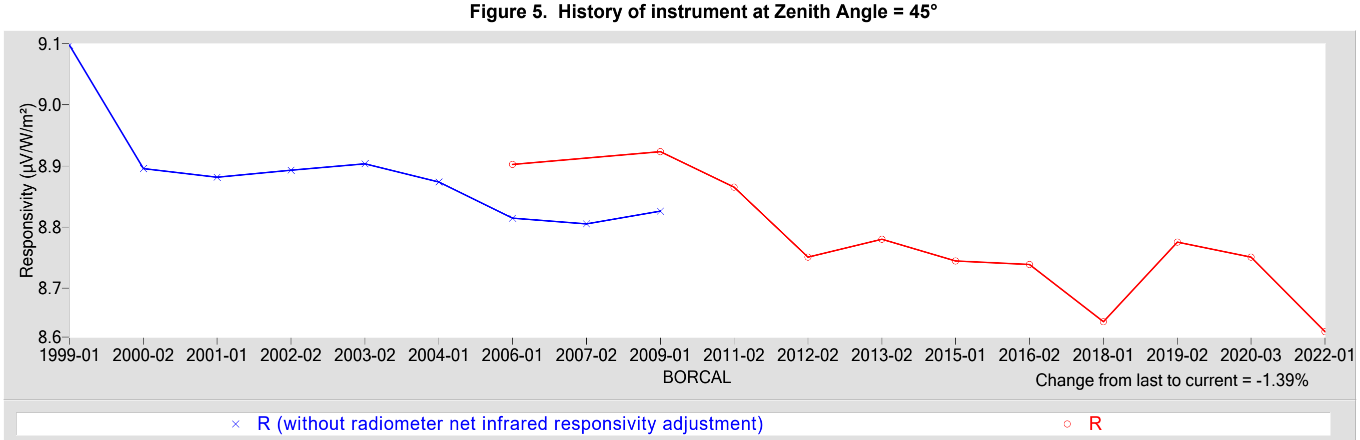
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6289	0.58666

† Rnet determination date: 04/05/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.6 / -1.5
Expanded Uncertainty, U (%)	+2.6 / -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:**	30954F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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* [1]

where,

V = radiometer output voltage (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

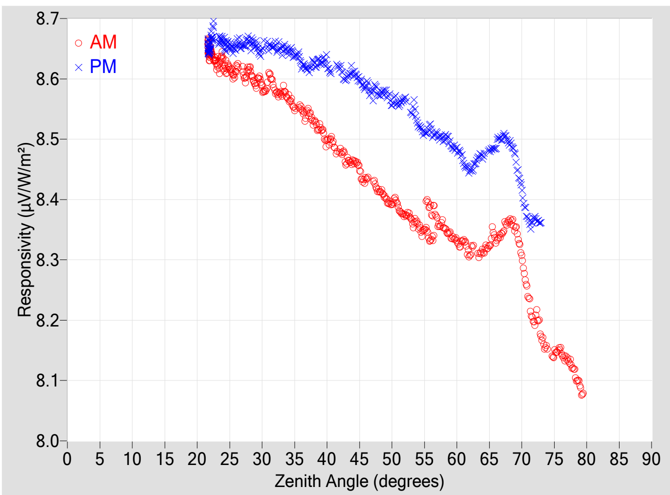


Figure 2. Responsivity vs Local Standard Time

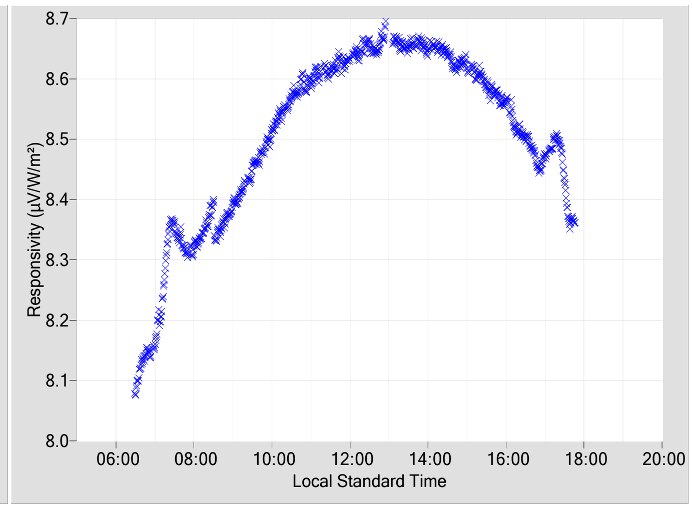


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4337	0.40	105.72	8.5893	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4137	0.43	103.71	8.5739	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3937	0.44	101.87	8.5589	0.42	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3740	0.43	100.00	8.5662	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3592	0.44	98.30	8.5251	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3608	0.46	94.97	8.5161	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3563	0.45	92.12	8.5015	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3308	0.47	90.55	8.4821	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3123	0.49	89.08	8.4491	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3127	0.51	87.62	8.4725	0.56	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3347	0.54	86.18	8.4882	0.59	271.29
22	8.6446	0.37	170.27	8.6533	0.36	189.67	68	8.3646	0.57	84.77	8.4948	N/A	272.75
24	8.6287	0.38	151.57	8.6620	0.38	208.53	70	8.3061	N/A	83.37	8.4176	N/A	274.18
26	8.6153	0.38	142.27	8.6550	0.37	217.71	72	8.1986	N/A	81.97	8.3683	N/A	275.67
28	8.6159	0.37	135.61	8.6608	0.37	224.61	74	8.1553	N/A	80.64	N/A	N/A	N/A
30	8.5883	0.37	130.27	8.6500	0.37	229.99	76	8.1492	N/A	79.11	N/A	N/A	N/A
32	8.5795	0.38	125.56	8.6534	0.40	234.41	78	8.1167	N/A	77.68	N/A	N/A	N/A
34	8.5685	0.38	121.91	8.6446	0.38	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5512	0.37	118.44	8.6262	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5282	0.37	115.43	8.6270	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4968	0.38	112.77	8.6258	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4800	0.38	110.16	8.6172	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4622	0.39	107.88	8.6121	0.40	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

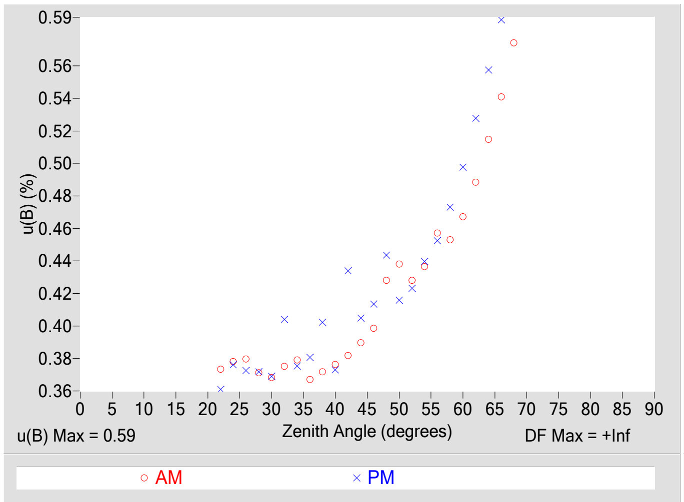


Figure 4. Residuals from Spline Interpolation

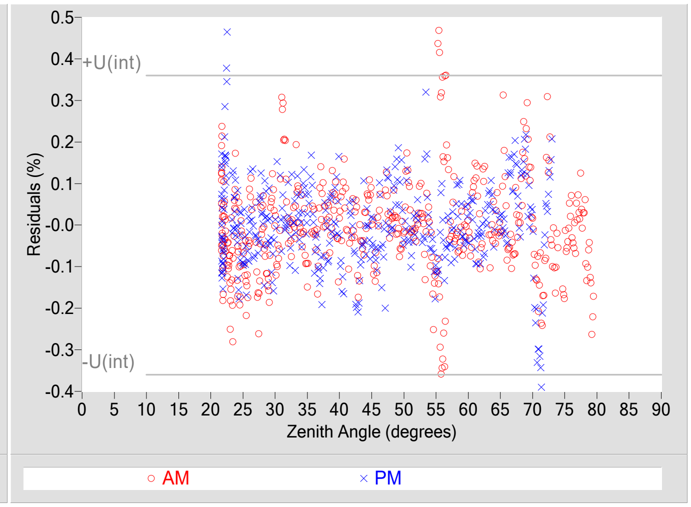


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	109604
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

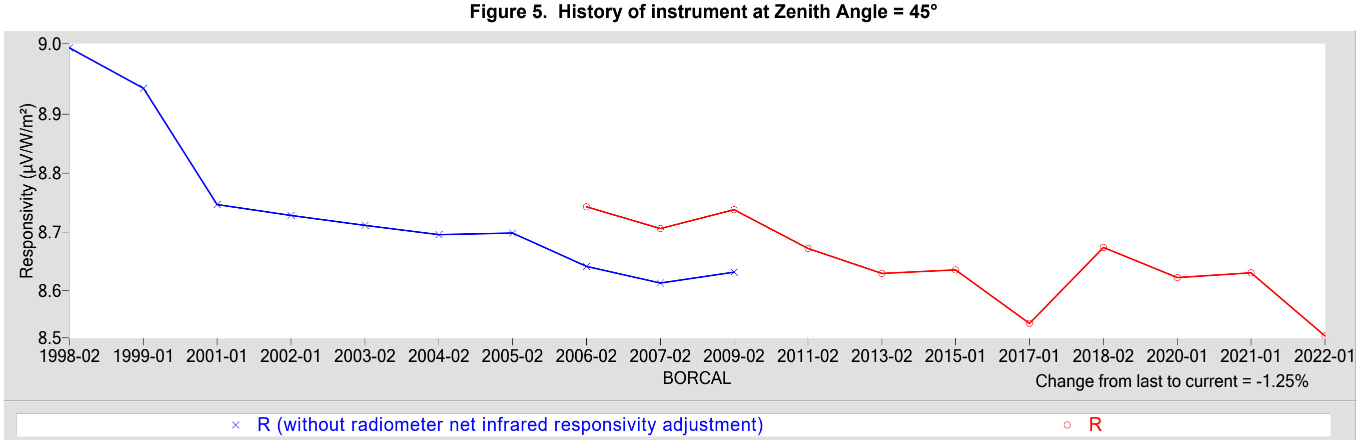
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5232	0.63330

† Rnet determination date: 06/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.5 / -2.3
Expanded Uncertainty, U (%)	+2.5 / -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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	30958F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

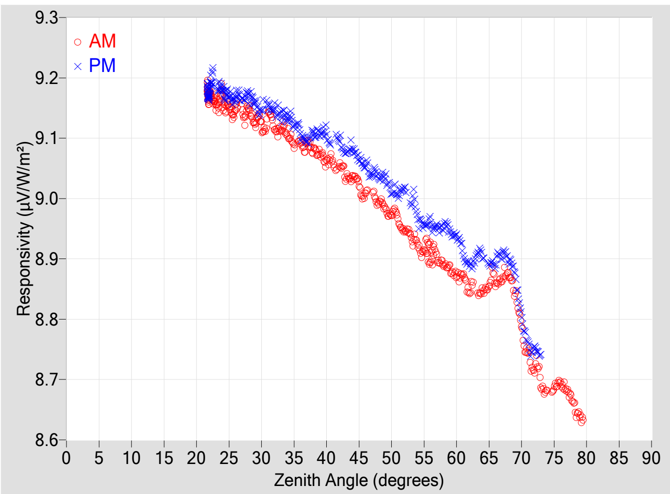


Figure 2. Responsivity vs Local Standard Time

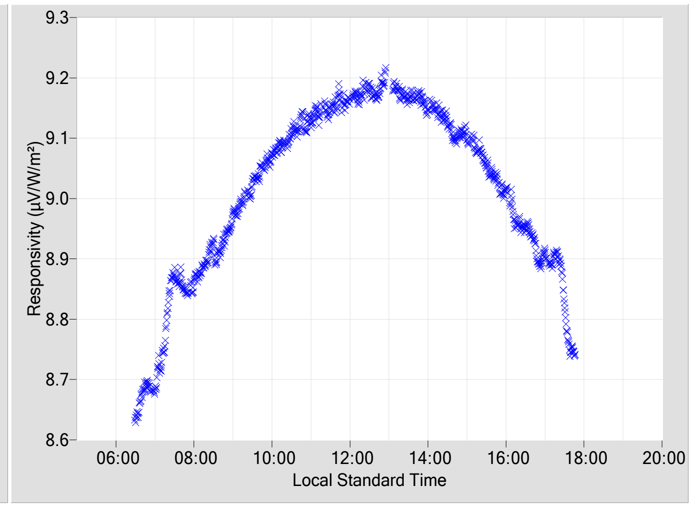


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0090	0.40	105.72	9.0555	0.41	254.40
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9924	0.43	103.71	9.0349	0.44	256.37
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9739	0.44	101.87	9.0101	0.41	258.32
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.9466	0.43	100.00	9.0152	0.42	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.9261	0.44	98.30	8.9666	0.44	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9088	0.46	94.97	8.9590	0.45	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8911	0.45	92.12	8.9539	0.47	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8740	0.47	90.55	8.9361	0.50	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8491	0.49	89.08	8.8926	0.53	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8459	0.51	87.62	8.9031	0.55	269.82
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8617	0.54	86.18	8.8923	0.59	271.29
22	9.1701	0.37	170.07	9.1770	0.36	189.67	68	8.8728	0.57	84.77	8.8977	N/A	272.75
24	9.1659	0.38	151.57	9.1805	0.38	208.53	70	8.7889	N/A	83.37	8.8063	N/A	274.18
26	9.1494	0.38	142.27	9.1674	0.37	217.71	72	8.7171	N/A	81.97	8.7523	N/A	275.67
28	9.1492	0.37	135.61	9.1689	0.37	224.61	74	8.6824	N/A	80.64	N/A	N/A	N/A
30	9.1234	0.37	130.27	9.1488	0.37	229.99	76	8.6939	N/A	79.11	N/A	N/A	N/A
32	9.1150	0.37	125.56	9.1465	0.40	234.41	78	8.6592	N/A	77.68	N/A	N/A	N/A
34	9.1066	0.38	121.91	9.1320	0.37	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0928	0.37	118.44	9.1082	0.38	241.58	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0800	0.37	115.43	9.1082	0.40	244.59	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0610	0.38	112.77	9.1065	0.37	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0546	0.38	110.16	9.0957	0.43	249.90	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0343	0.39	107.88	9.0832	0.40	252.20	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

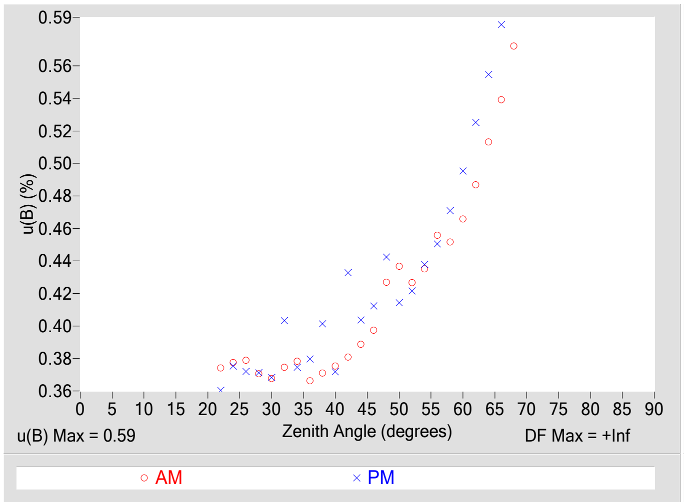


Figure 4. Residuals from Spline Interpolation

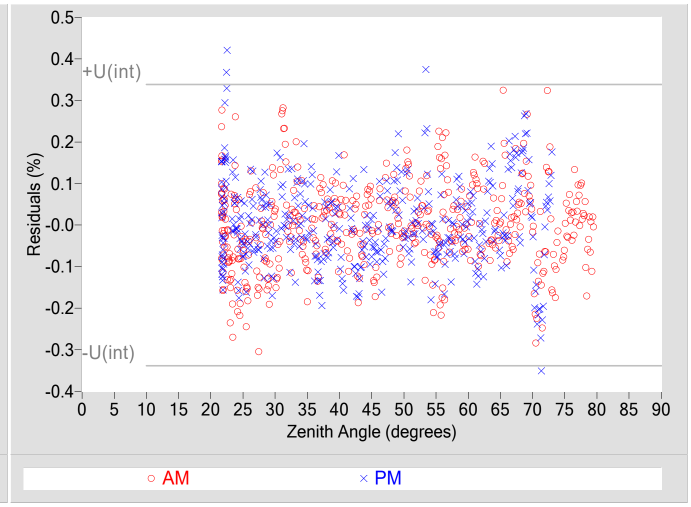


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	134836
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

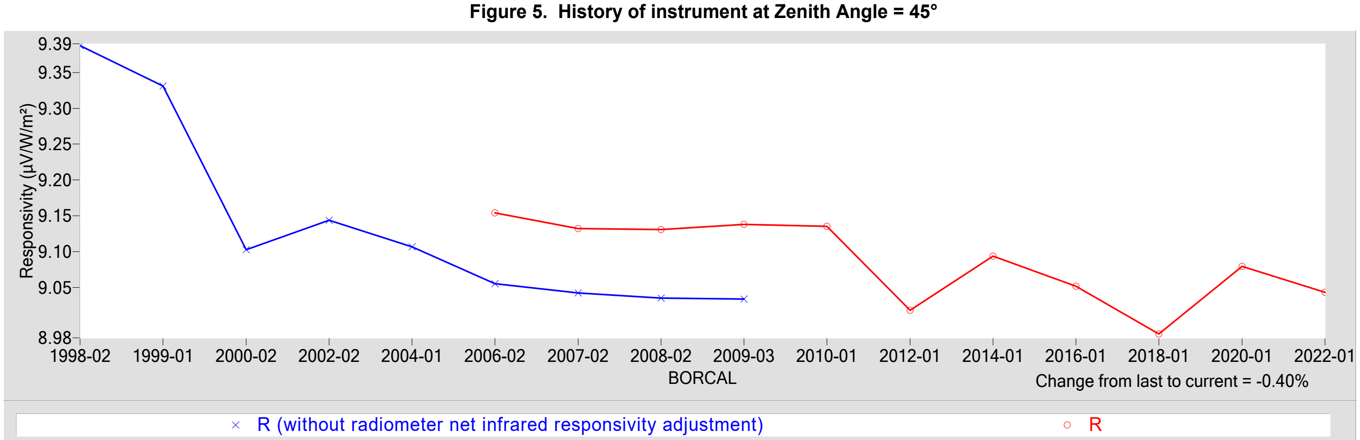
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.0433	0.61540

† Rnet determination date: 06/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.2 / -1.9
Expanded Uncertainty, U (%)	+2.1 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31099F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

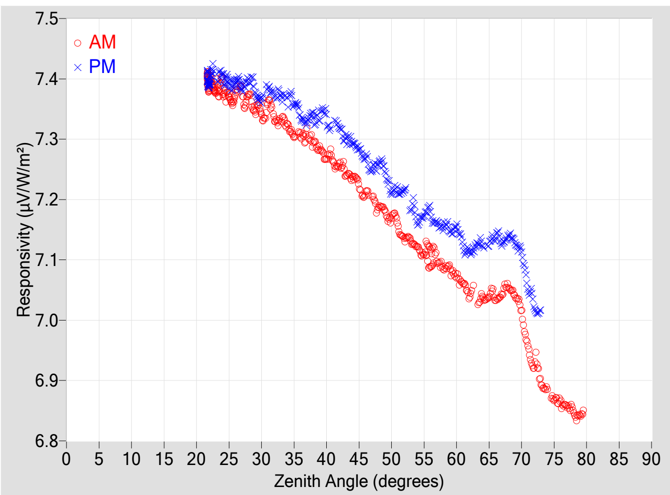


Figure 2. Responsivity vs Local Standard Time

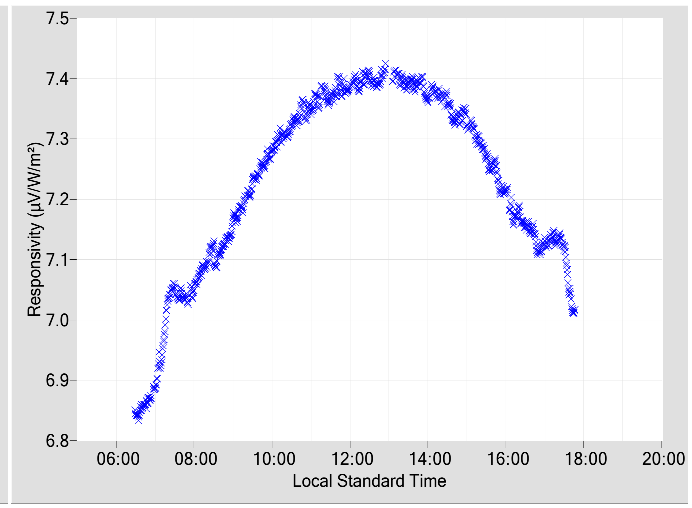


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	7.2088	0.40	105.82	7.2696	0.39	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.1866	0.41	103.74	7.2611	0.40	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.1699	0.44	101.84	7.2119	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.1352	0.43	100.02	7.2159	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.1211	0.44	98.27	7.1623	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1030	0.45	95.12	7.1778	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.0859	0.46	92.08	7.1547	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.0734	0.47	90.57	7.1547	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.0411	0.53	89.10	7.1134	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.0380	0.52	87.65	7.1244	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.0349	0.54	86.20	7.1378	0.59	271.31
22	7.3936	0.35	170.78	7.3954	0.36	189.46	68	7.0544	0.61	84.79	7.1396	N/A	272.77
24	7.3863	0.36	151.53	7.4049	0.37	208.73	70	7.0103	N/A	83.34	7.1107	N/A	274.21
26	7.3746	0.38	142.33	7.3944	0.37	217.78	72	6.9297	N/A	81.95	7.0206	N/A	275.64
28	7.3728	0.38	135.53	7.3960	0.38	224.57	74	6.8875	N/A	80.61	N/A	N/A	N/A
30	7.3404	0.38	130.20	7.3665	0.35	229.89	76	6.8643	N/A	79.13	N/A	N/A	N/A
32	7.3340	0.39	125.67	7.3732	0.38	234.37	78	6.8488	N/A	77.70	N/A	N/A	N/A
34	7.3225	0.38	121.85	7.3610	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3074	0.41	118.48	7.3354	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.2961	0.39	115.47	7.3344	0.39	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.2684	0.41	112.72	7.3355	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.2564	0.38	110.27	7.3196	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.2350	0.39	107.98	7.2958	0.41	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

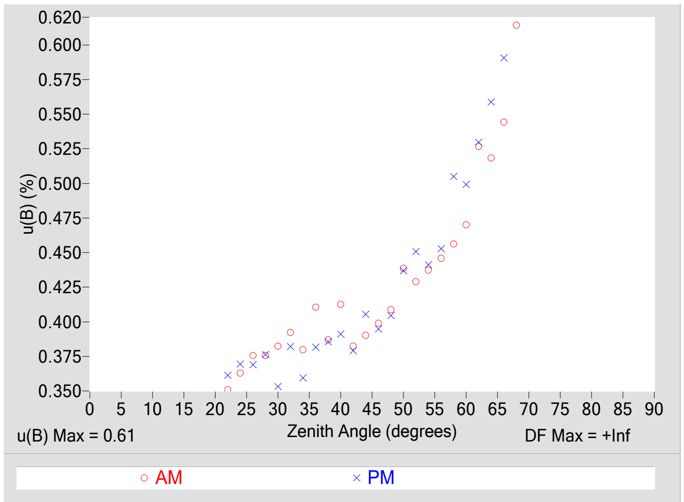


Figure 4. Residuals from Spline Interpolation

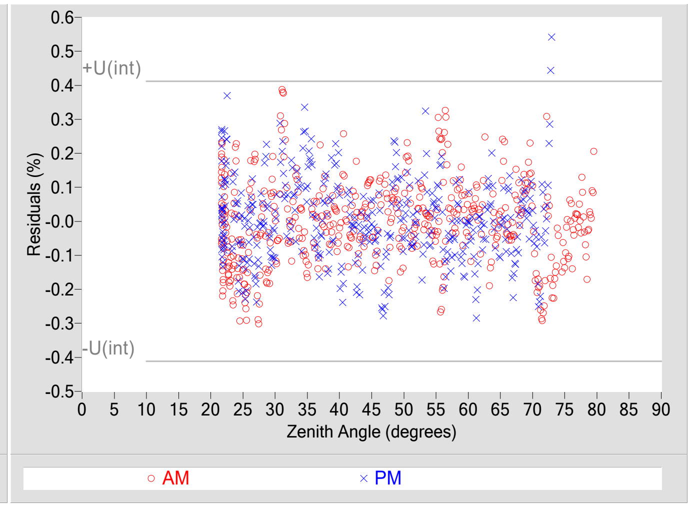


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	77920
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

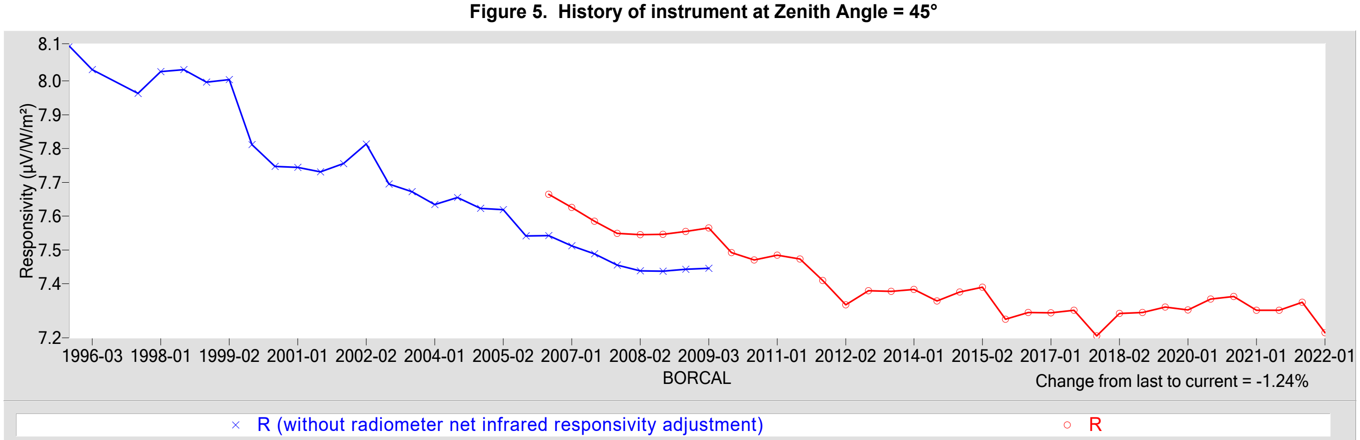
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.2548	0.57866

† Rnet determination date: 05/08/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.6 / -2.5
Expanded Uncertainty, U (%)	+2.6 / -3.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31100F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

where,

V = radiometer output voltage (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

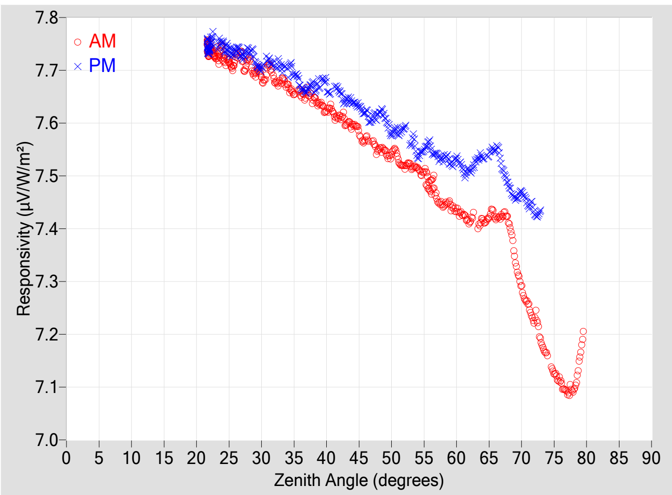


Figure 2. Responsivity vs Local Standard Time

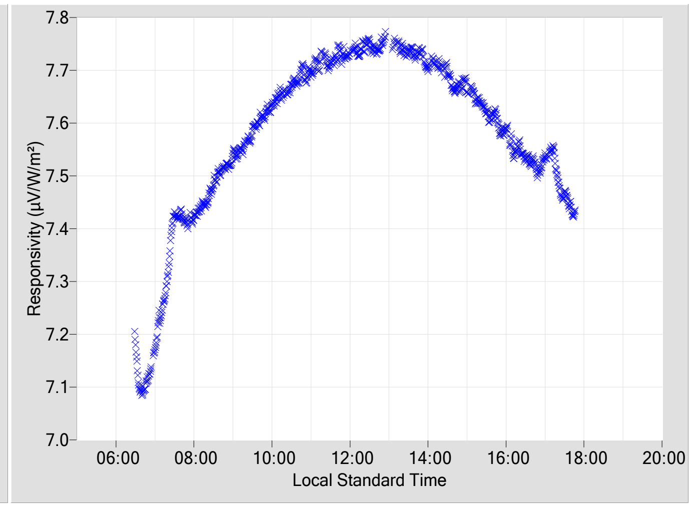


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5689	0.40	105.82	7.6210	0.40	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5499	0.41	103.74	7.6190	0.41	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5409	0.44	101.84	7.5793	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5180	0.43	100.02	7.5917	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5144	0.44	98.27	7.5381	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4810	0.45	95.12	7.5561	0.46	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4434	0.46	92.08	7.5327	0.51	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4350	0.47	90.57	7.5336	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4132	0.53	89.10	7.5093	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4153	0.52	87.65	7.5346	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4208	0.55	86.20	7.5511	0.59	271.31
22	7.7387	0.35	170.78	7.7419	0.36	189.46	68	7.4138	0.62	84.79	7.4821	N/A	272.77
24	7.7323	0.36	151.53	7.7493	0.37	208.73	70	7.2871	N/A	83.34	7.4688	N/A	274.21
26	7.7208	0.38	142.33	7.7369	0.37	217.78	72	7.2310	N/A	81.95	7.4297	N/A	275.64
28	7.7199	0.38	135.53	7.7358	0.38	224.57	74	7.1622	N/A	80.61	N/A	N/A	N/A
30	7.6864	0.38	130.20	7.7044	0.35	229.89	76	7.1121	N/A	79.13	N/A	N/A	N/A
32	7.6812	0.39	125.67	7.7108	0.38	234.37	78	7.0940	N/A	77.70	N/A	N/A	N/A
34	7.6709	0.38	121.85	7.6950	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6572	0.41	118.48	7.6674	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6469	0.39	115.47	7.6691	0.39	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6229	0.41	112.72	7.6719	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6107	0.38	110.27	7.6609	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5941	0.39	107.98	7.6408	0.41	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

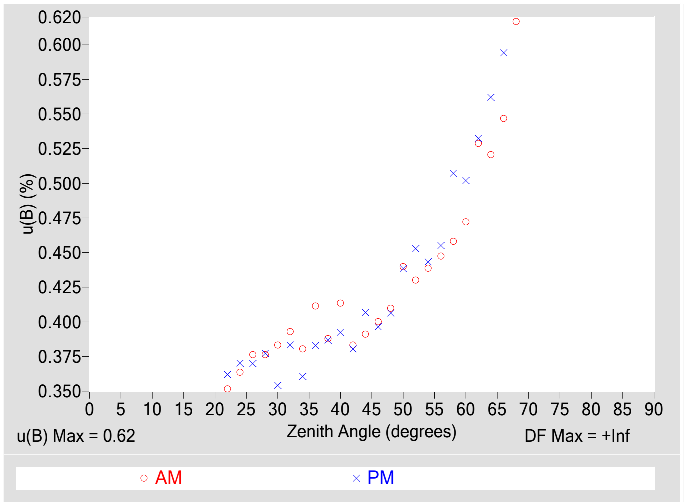


Figure 4. Residuals from Spline Interpolation

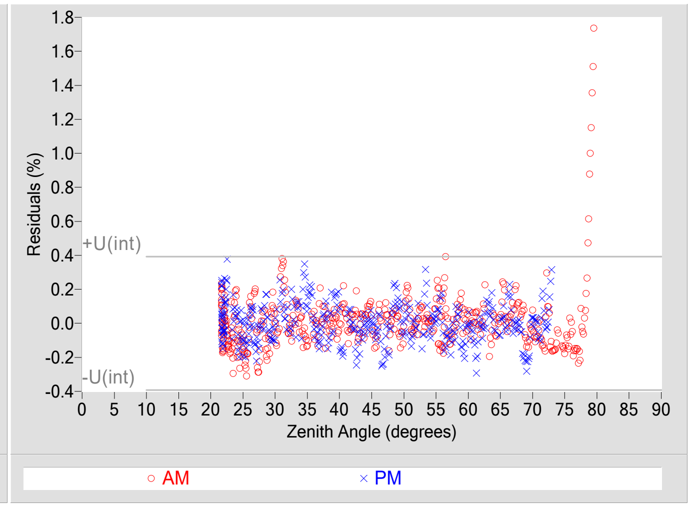


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	95021
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

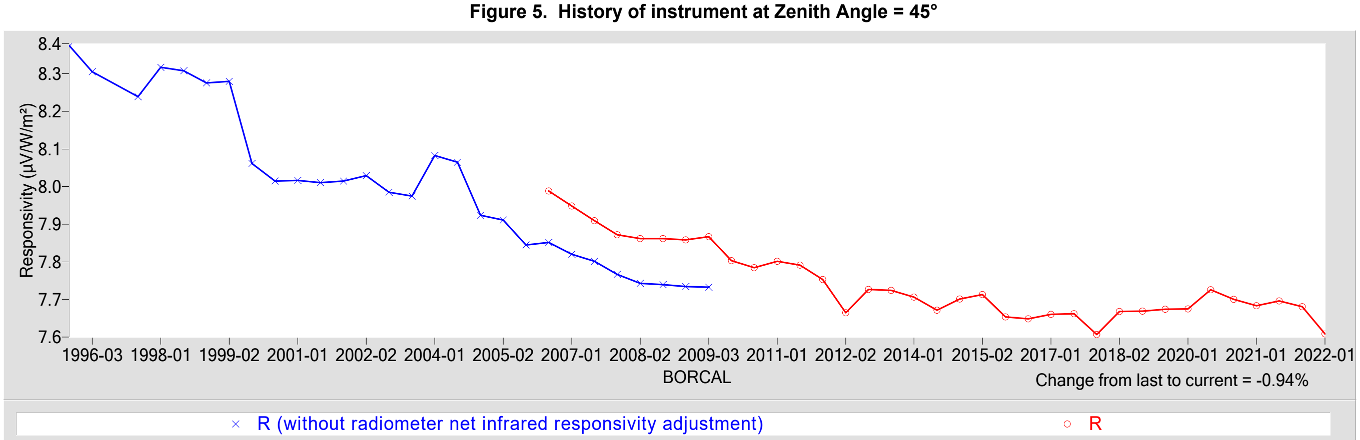
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6086	0.64729

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.3 / -2.3
Expanded Uncertainty, U (%)	+2.3 / -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.

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31101F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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

Calibrated by: Craig Webb

____________________________ ____________

Peter Gotseff, Technical Manager Date

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

Calibration Results

31101F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

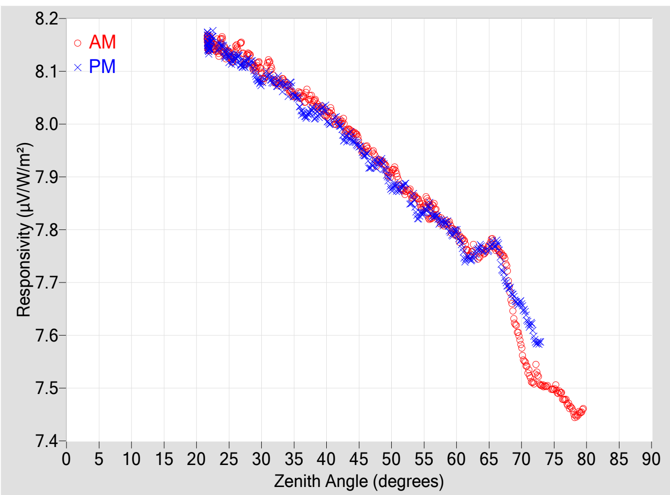


Figure 2. Responsivity vs Local Standard Time

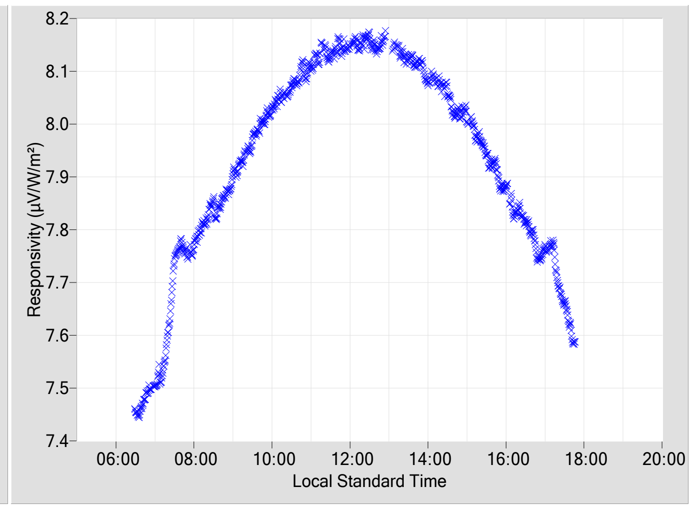


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	7.9518	0.40	105.82	7.9418	0.40	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9298	0.41	103.74	7.9275	0.41	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9082	0.44	101.84	7.8777	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8720	0.43	100.02	7.8853	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8582	0.44	98.27	7.8257	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8339	0.45	95.12	7.8390	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8106	0.46	92.08	7.8131	0.51	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7931	0.47	90.57	7.7962	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7538	0.53	89.10	7.7451	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7601	0.52	87.65	7.7617	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7647	0.54	86.20	7.7723	0.59	271.31
22	8.1527	0.35	170.78	8.1479	0.36	189.46	68	7.7061	0.62	84.79	7.6909	N/A	272.77
24	8.1486	0.36	151.53	8.1439	0.37	208.73	70	7.5728	N/A	83.34	7.6583	N/A	274.21
26	8.1378	0.38	142.33	8.1248	0.37	217.78	72	7.5227	N/A	81.95	7.5938	N/A	275.64
28	8.1320	0.38	135.53	8.1177	0.38	224.57	74	7.5041	N/A	80.61	N/A	N/A	N/A
30	8.0955	0.38	130.20	8.0792	0.35	229.89	76	7.4924	N/A	79.13	N/A	N/A	N/A
32	8.0832	0.39	125.67	8.0810	0.38	234.37	78	7.4529	N/A	77.70	N/A	N/A	N/A
34	8.0711	0.38	121.85	8.0602	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0553	0.41	118.48	8.0263	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0441	0.39	115.47	8.0213	0.39	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0168	0.41	112.72	8.0188	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0039	0.38	110.27	7.9988	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9821	0.39	107.98	7.9732	0.41	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

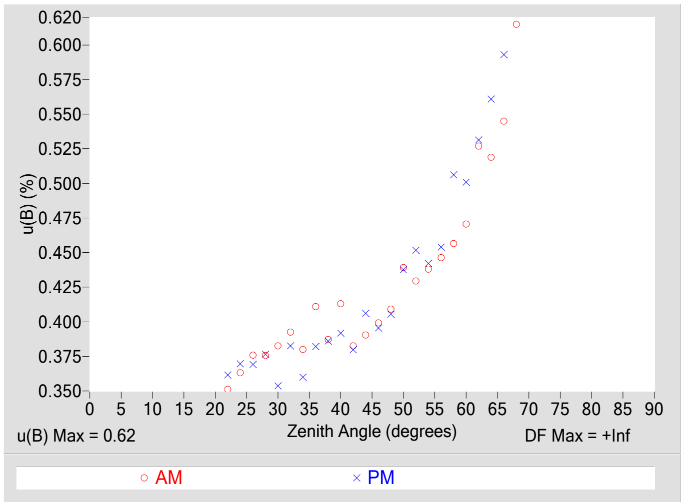


Figure 4. Residuals from Spline Interpolation

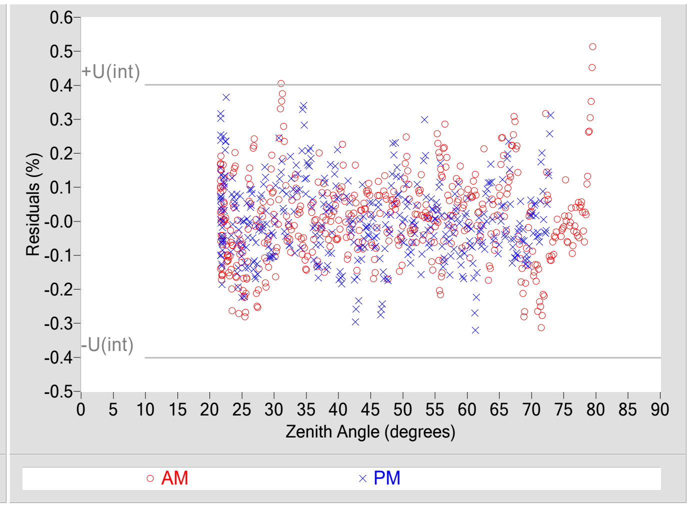


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.62
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	86030
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

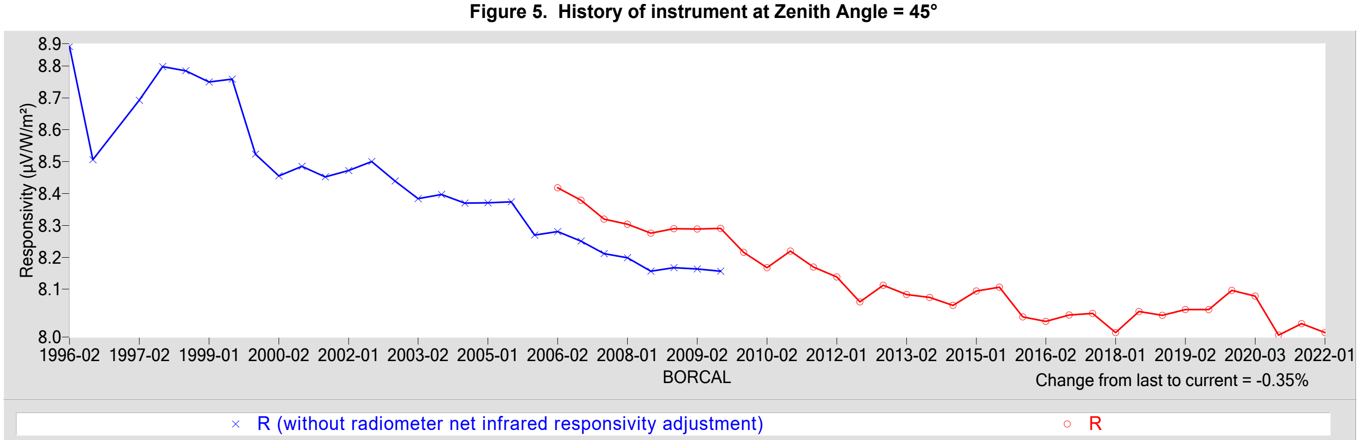
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9640	0.64834

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.7 / -2.1
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: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 31120E6

Calibration Date: 5/7/2022

Due Date: 5/7/2023

Customer: Calibration System

Environmental Conditions: see page 4

Test Dates: 4/30, 5/7

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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* [1]

where,

V = radiometer output voltage (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

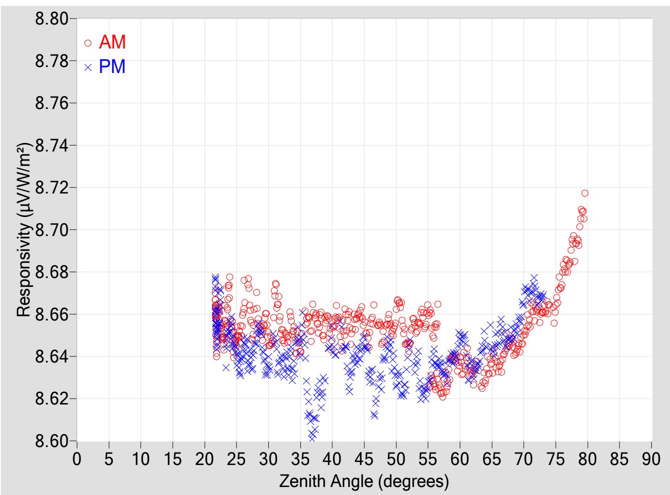


Figure 2. Responsivity vs Local Standard Time

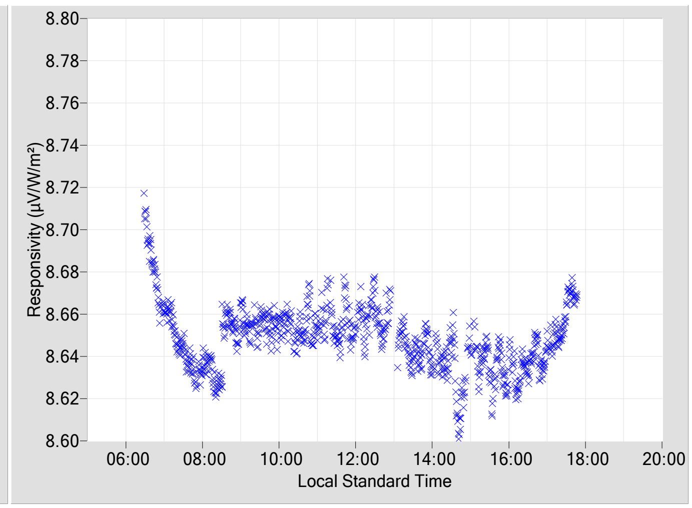


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6535	0.29	105.79	8.6317	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6479	0.29	103.83	8.6370	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6611	0.29	101.81	8.6297	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6456	0.29	100.05	8.6441	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6595	0.29	98.24	8.6236	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6408	0.30	95.29	8.6397	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6275	0.29	92.06	8.6318	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6373	0.31	90.60	8.6486	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6307	0.29	89.08	8.6340	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6324	0.30	87.62	8.6471	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6353	0.30	86.18	8.6486	0.30	271.29
22	8.6566	0.30	170.42	8.6542	0.30	189.39	68	8.6467	0.30	84.77	8.6497	N/A	272.75
24	8.6644	0.28	151.74	8.6537	0.29	208.60	70	8.6496	N/A	83.37	8.6676	N/A	274.18
26	8.6598	0.29	142.26	8.6431	0.29	217.92	72	8.6619	N/A	81.97	8.6685	N/A	275.62
28	8.6627	0.31	135.26	8.6480	0.29	224.68	74	8.6630	N/A	80.64	N/A	N/A	N/A
30	8.6486	0.29	130.14	8.6350	0.29	229.96	76	8.6774	N/A	79.11	N/A	N/A	N/A
32	8.6532	0.28	125.73	8.6380	0.31	234.66	78	8.6923	N/A	77.68	N/A	N/A	N/A
34	8.6495	0.31	121.80	8.6358	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6578	0.31	118.52	8.6242	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6562	0.31	115.51	8.6230	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6507	0.28	112.68	8.6474	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6553	0.30	110.23	8.6446	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6588	0.30	107.94	8.6411	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

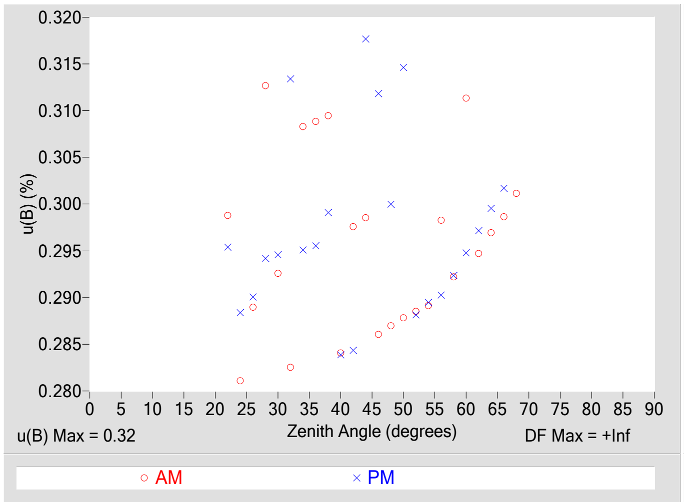


Figure 4. Residuals from Spline Interpolation

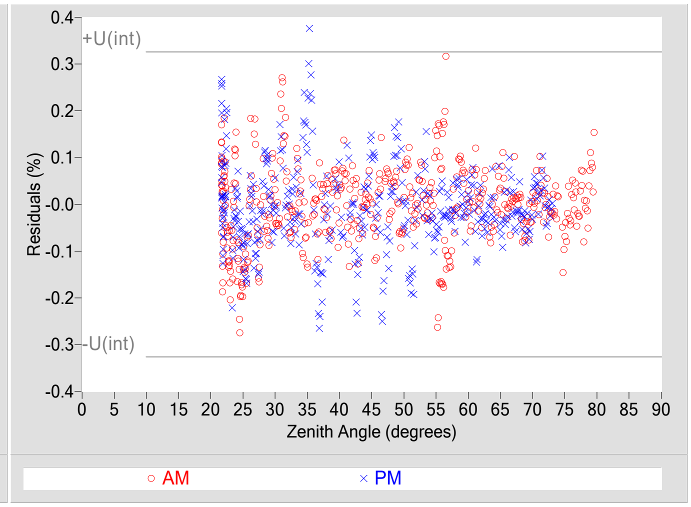


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.36
Effective degrees of freedom, DF(c)	18346
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.70
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

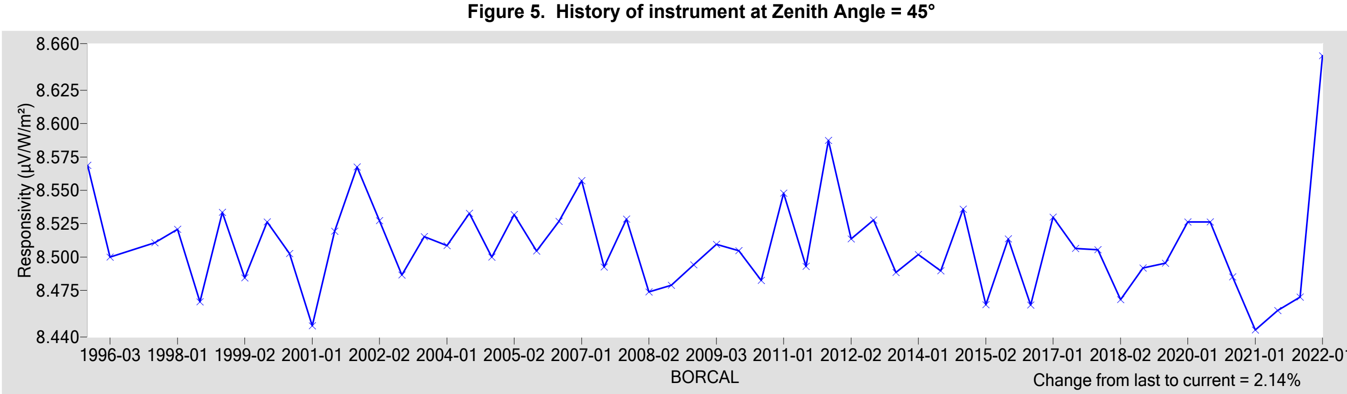
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6510	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.12 / -0.32
Expanded Uncertainty, U (%)	+0.74 / -0.95
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the 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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

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

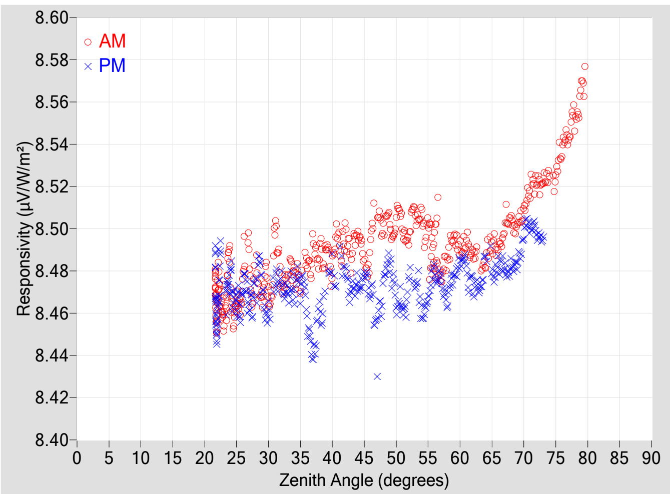


Figure 2. Responsivity vs Local Standard Time

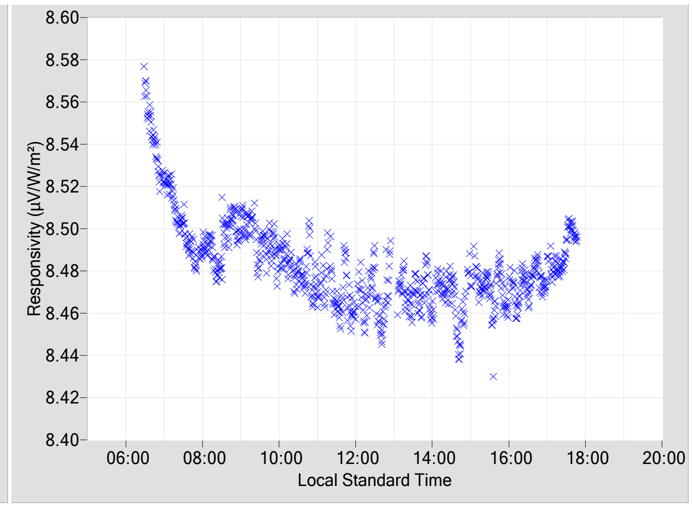


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4928	0.29	105.79	8.4708	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4984	0.29	103.83	8.4743	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5047	0.29	101.81	8.4655	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4960	0.29	100.05	8.4761	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5055	0.29	98.24	8.4608	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4899	0.30	95.29	8.4796	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4857	0.29	92.06	8.4655	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4908	0.31	90.60	8.4840	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4882	0.29	89.08	8.4729	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4862	0.30	87.62	8.4863	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4920	0.30	86.18	8.4823	0.30	271.29
22	8.4664	0.30	170.42	8.4603	0.30	189.39	68	8.5044	0.30	84.77	8.4816	N/A	272.75
24	8.4787	0.28	151.74	8.4764	0.29	208.60	70	8.5083	N/A	83.37	8.4979	N/A	274.18
26	8.4768	0.29	142.26	8.4735	0.29	217.92	72	8.5216	N/A	81.97	8.4977	N/A	275.62
28	8.4810	0.31	135.26	8.4720	0.29	224.68	74	8.5247	N/A	80.64	N/A	N/A	N/A
30	8.4682	0.29	130.14	8.4596	0.29	229.96	76	8.5375	N/A	79.11	N/A	N/A	N/A
32	8.4754	0.28	125.73	8.4748	0.31	234.66	78	8.5525	N/A	77.68	N/A	N/A	N/A
34	8.4785	0.31	121.80	8.4694	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4847	0.31	118.52	8.4582	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4881	0.31	115.51	8.4606	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4826	0.28	112.68	8.4796	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4948	0.30	110.23	8.4804	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4966	0.30	107.94	8.4742	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

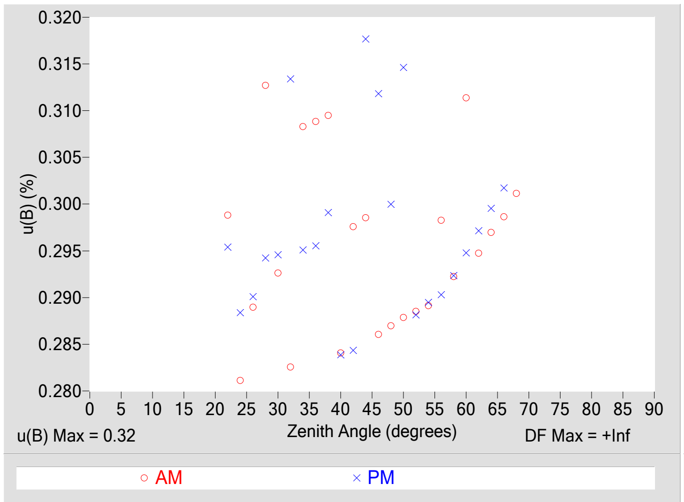


Figure 4. Residuals from Spline Interpolation

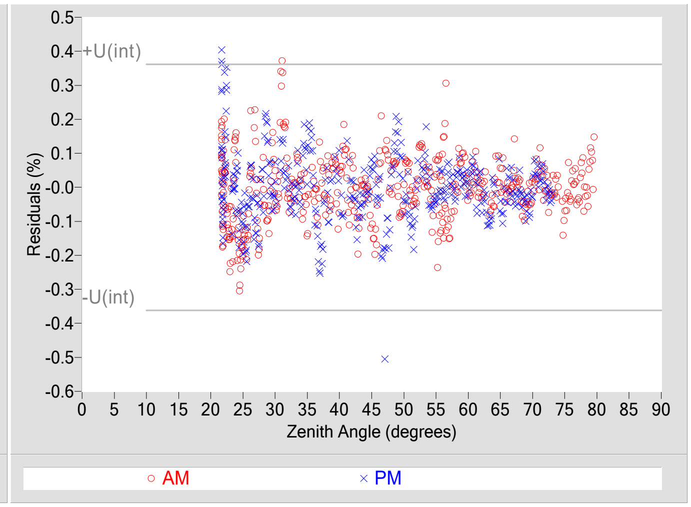


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.37
Effective degrees of freedom, DF(c)	13291
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.72
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

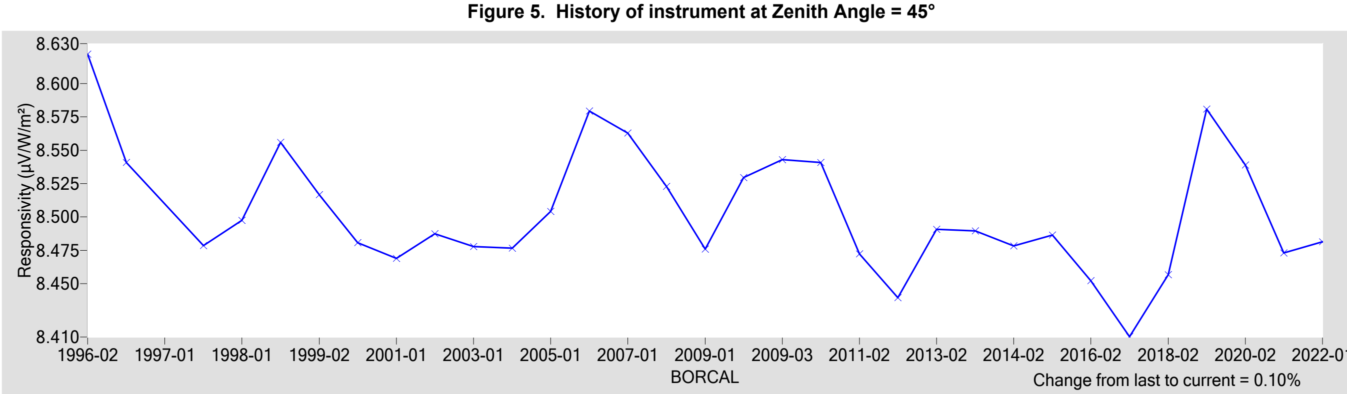
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4813	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.29 / -0.27
Expanded Uncertainty, U (%)	+0.91 / -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:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31146F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

where,

- V = radiometer output voltage (microvolts),
- $Rnet$ = radiometer net infrared responsivity (µV/W/m²), see Table 4,
- $Wnet$ = effective net infrared measured by pygeometer (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

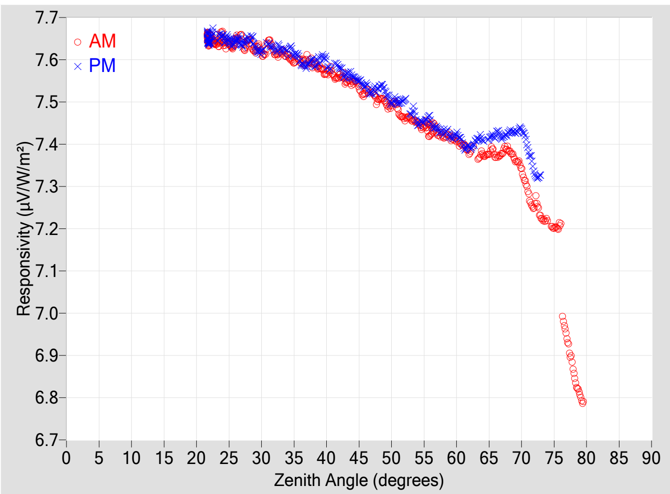


Figure 2. Responsivity vs Local Standard Time

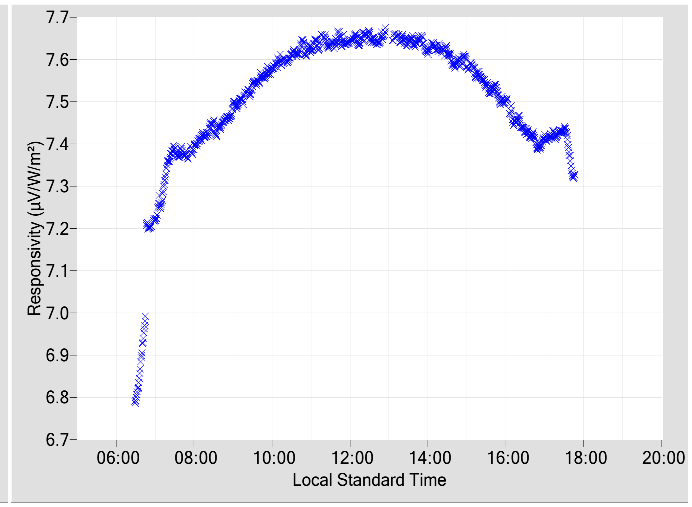


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5216	0.40	105.82	7.5386	0.39	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5053	0.41	103.74	7.5346	0.40	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4928	0.44	101.84	7.4981	0.43	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4611	0.43	100.02	7.5051	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4512	0.44	98.27	7.4490	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4330	0.44	95.12	7.4562	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4173	0.46	92.08	7.4283	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4098	0.47	90.57	7.4241	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3810	0.53	89.10	7.3930	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.3765	0.52	87.65	7.4107	0.55	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3721	0.54	86.20	7.4224	0.59	271.31
22	7.6483	0.35	170.78	7.6455	0.36	189.46	68	7.3869	0.61	84.79	7.4278	N/A	272.77
24	7.6504	0.36	151.53	7.6545	0.37	208.73	70	7.3374	N/A	83.34	7.4340	N/A	274.21
26	7.6442	0.38	142.33	7.6455	0.37	217.78	72	7.2588	N/A	81.95	7.3322	N/A	275.64
28	7.6464	0.37	135.53	7.6479	0.38	224.57	74	7.2215	N/A	80.61	N/A	N/A	N/A
30	7.6182	0.38	130.20	7.6192	0.35	229.89	76	7.2112	N/A	79.18	N/A	N/A	N/A
32	7.6166	0.39	125.67	7.6256	0.38	234.37	78	6.8638	N/A	77.70	N/A	N/A	N/A
34	7.6098	0.38	121.85	7.6153	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5977	0.41	118.48	7.5918	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5914	0.39	115.47	7.5940	0.38	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5675	0.41	112.72	7.5951	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5606	0.38	110.27	7.5823	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5444	0.39	107.98	7.5624	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

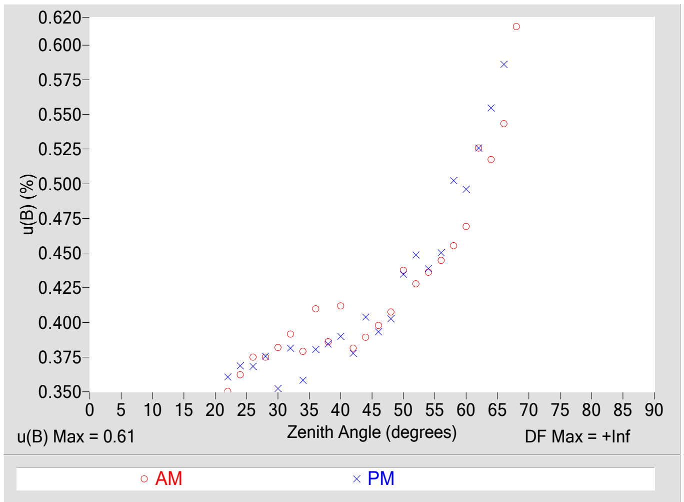


Figure 4. Residuals from Spline Interpolation

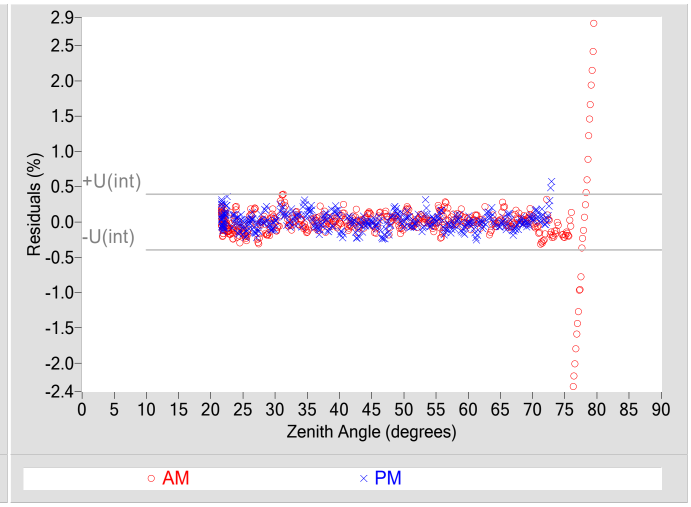


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	90266
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

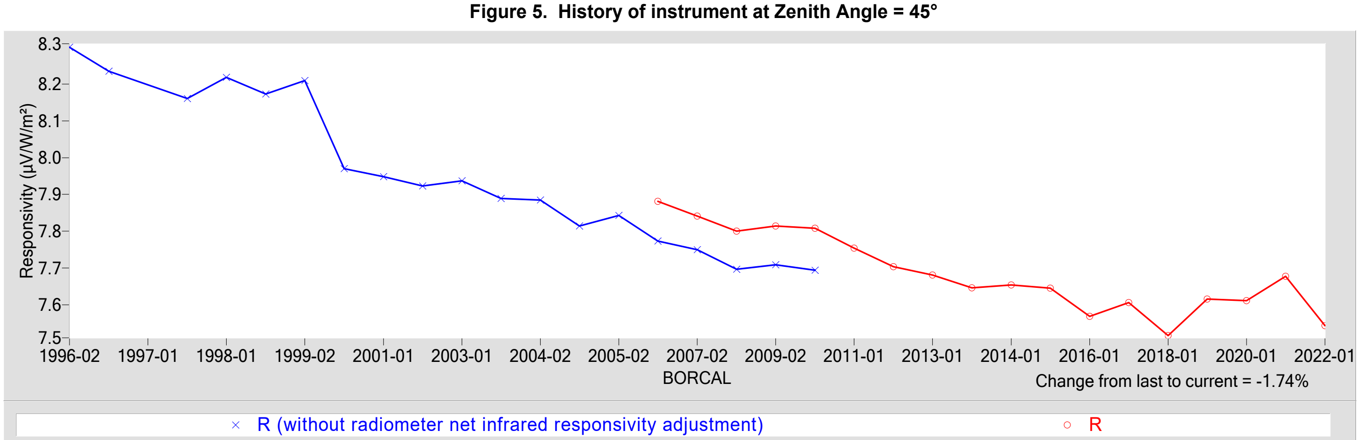
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5435	0.54900

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.1 / -1.8
Expanded Uncertainty, U (%)	+2.1 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31147F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

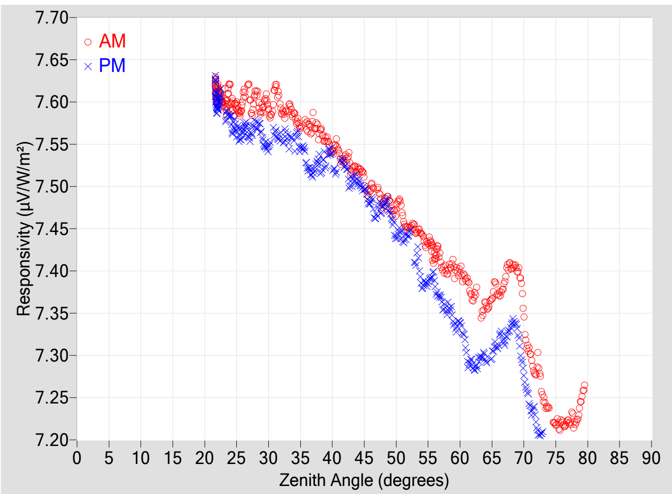


Figure 2. Responsivity vs Local Standard Time

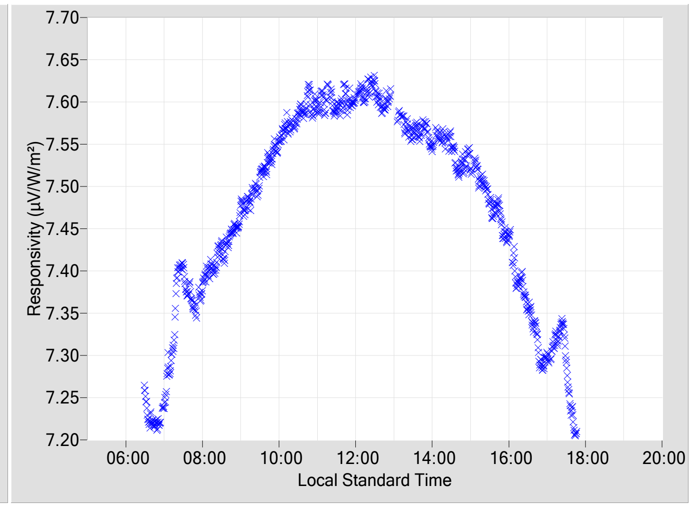


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle	R (μV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.4966	0.40	105.82	7.4823	0.39	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4828	0.41	103.74	7.4778	0.40	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4742	0.44	101.84	7.4407	0.44	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4501	0.43	100.02	7.4445	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4433	0.44	98.27	7.3842	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4188	0.44	95.12	7.3880	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3984	0.46	92.08	7.3542	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3990	0.47	90.57	7.3380	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3677	0.53	89.10	7.2880	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.3585	0.52	87.65	7.2957	0.56	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3726	0.54	86.20	7.3159	0.59	271.31
22	7.6116	0.35	170.78	7.5984	0.36	189.46	68	7.4063	0.61	84.79	7.3362	N/A	272.77
24	7.6064	0.36	151.53	7.5792	0.37	208.73	70	7.3435	N/A	83.34	7.2765	N/A	274.21
26	7.6023	0.38	142.33	7.5659	0.37	217.78	72	7.2860	N/A	81.95	7.2165	N/A	275.64
28	7.6101	0.37	135.53	7.5720	0.38	224.57	74	7.2383	N/A	80.61	N/A	N/A	N/A
30	7.5909	0.38	130.20	7.5469	0.35	229.89	76	7.2212	N/A	79.13	N/A	N/A	N/A
32	7.5904	0.39	125.67	7.5582	0.38	234.37	78	7.2186	N/A	77.70	N/A	N/A	N/A
34	7.5846	0.38	121.85	7.5478	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5728	0.41	118.48	7.5236	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5658	0.39	115.47	7.5260	0.38	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5424	0.41	112.72	7.5326	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5320	0.38	110.27	7.5245	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5178	0.39	107.98	7.5071	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

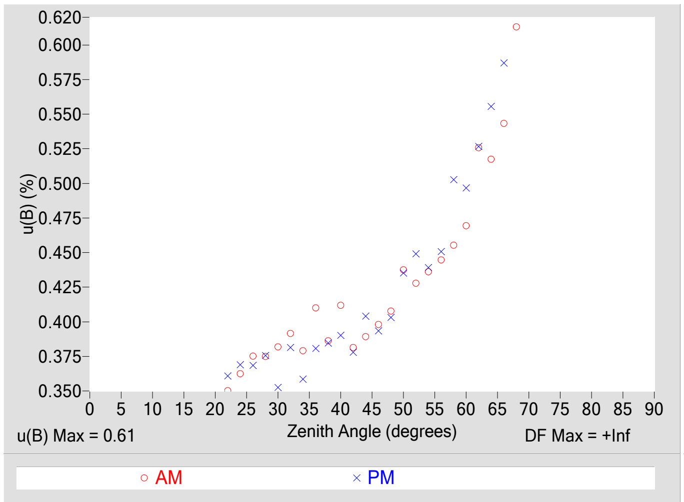


Figure 4. Residuals from Spline Interpolation

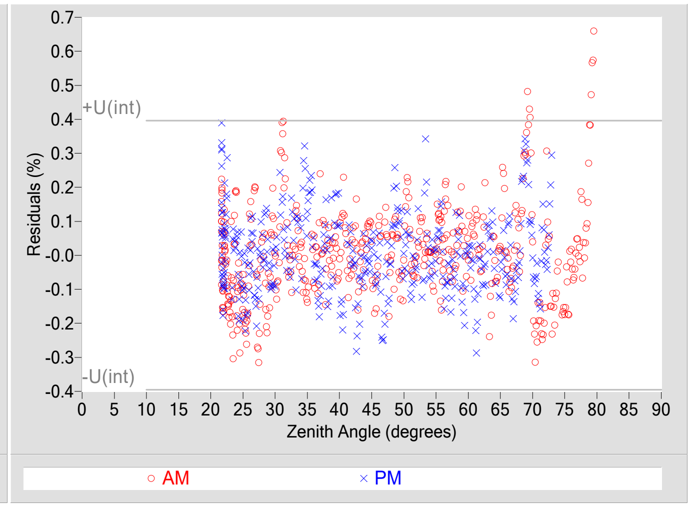


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	89658
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

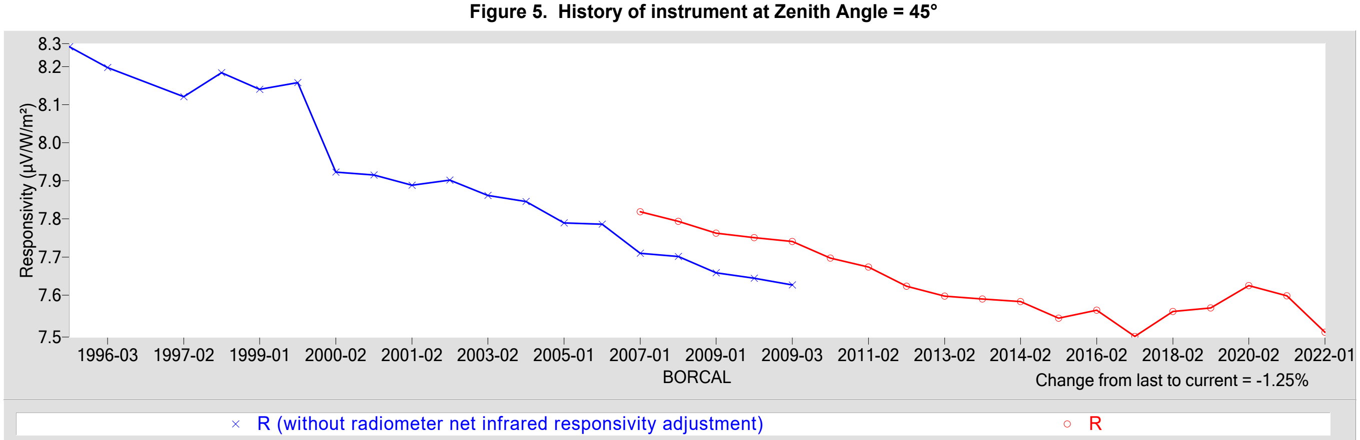
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5028	0.55100

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.2 / -2.2
Expanded Uncertainty, U (%)	+2.2 / -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

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

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

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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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

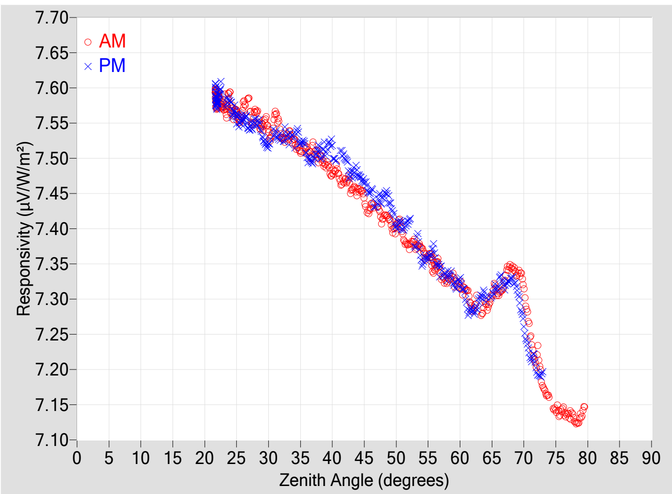


Figure 2. Responsivity vs Local Standard Time

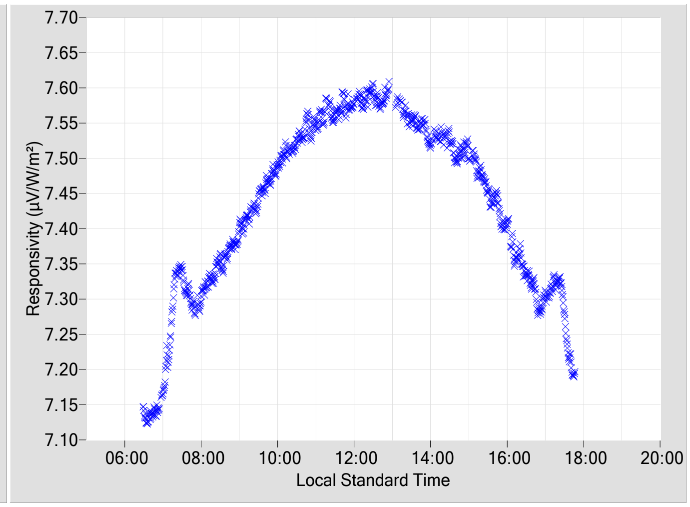


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	7.4297	0.40	105.82	7.4530	0.39	254.36
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4165	0.41	103.74	7.4466	0.40	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4021	0.44	101.84	7.4036	0.43	258.29
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.3757	0.43	100.02	7.4113	0.45	260.12
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3722	0.44	98.27	7.3533	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3459	0.44	95.12	7.3649	0.45	263.54
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3253	0.45	92.08	7.3332	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3190	0.47	90.57	7.3265	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.2864	0.52	89.10	7.2833	0.53	268.30
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.2909	0.52	87.65	7.3029	0.55	269.79
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3067	0.54	86.20	7.3212	0.59	271.31
22	7.5833	0.35	170.78	7.5821	0.36	189.46	68	7.3458	0.61	84.79	7.3291	N/A	272.77
24	7.5793	0.36	151.53	7.5768	0.37	208.73	70	7.3110	N/A	83.34	7.2614	N/A	274.21
26	7.5696	0.37	142.33	7.5552	0.37	217.78	72	7.2171	N/A	81.95	7.1985	N/A	275.64
28	7.5666	0.37	135.53	7.5508	0.38	224.57	74	7.1621	N/A	80.61	N/A	N/A	N/A
30	7.5374	0.38	130.20	7.5195	0.35	229.89	76	7.1437	N/A	79.13	N/A	N/A	N/A
32	7.5326	0.39	125.67	7.5303	0.38	234.37	78	7.1265	N/A	77.70	N/A	N/A	N/A
34	7.5243	0.38	121.85	7.5217	0.36	238.33	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5125	0.41	118.48	7.5023	0.38	241.71	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5023	0.39	115.47	7.5093	0.38	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4776	0.41	112.72	7.5123	0.39	247.34	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4676	0.38	110.27	7.5000	0.38	249.85	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4528	0.39	107.98	7.4801	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

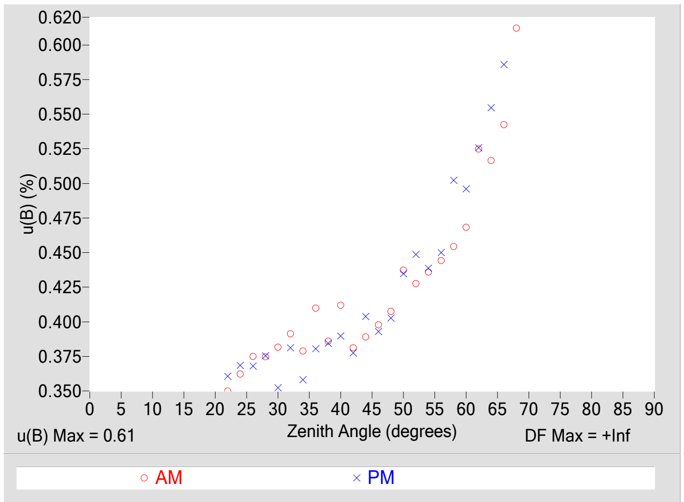


Figure 4. Residuals from Spline Interpolation

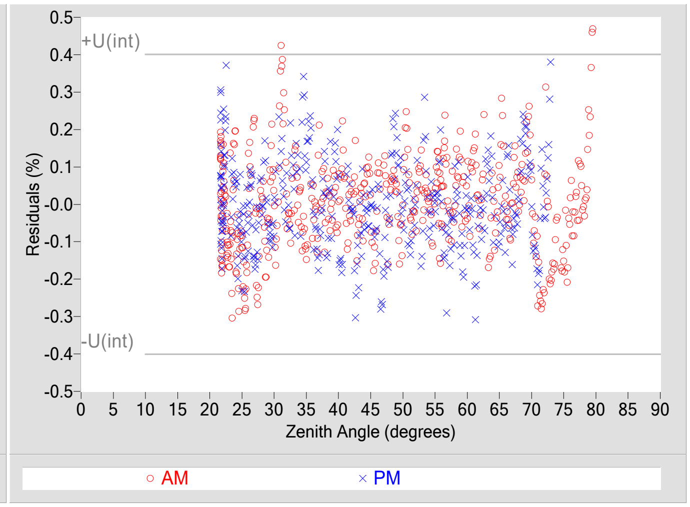


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.61
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.64
Effective degrees of freedom, DF(c)	85163
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

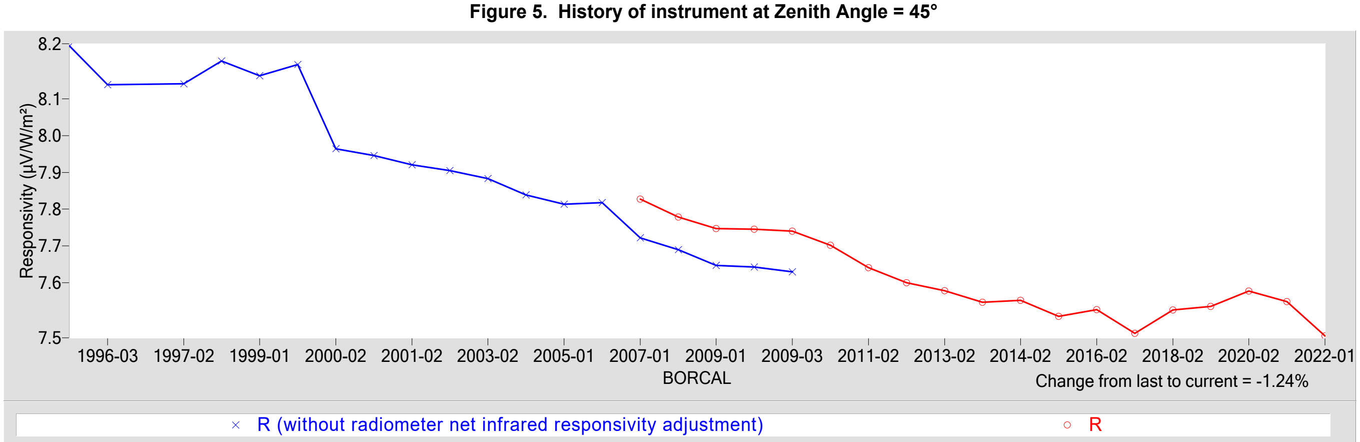
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.4548	0.53300

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.1 / -1.8
Expanded Uncertainty, U (%)	+2.1 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31152F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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

Calibrated by: Craig Webb

______________________________ ____________

Peter Gotseff, Technical Manager Date

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

Calibration Results

31152F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

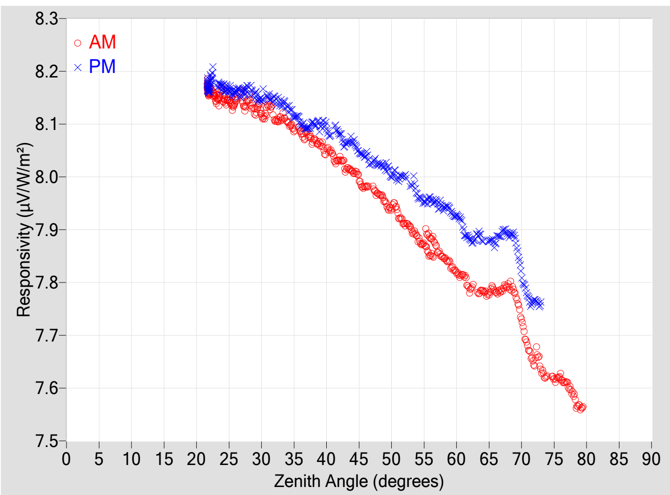


Figure 2. Responsivity vs Local Standard Time

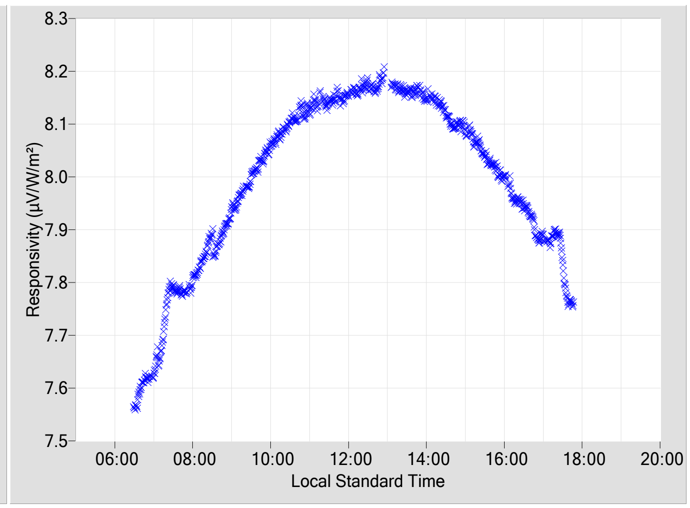


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.9815	0.42	105.74	8.0407	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9673	0.41	103.72	8.0235	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9414	0.44	101.82	8.0016	0.42	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9108	0.45	100.00	8.0010	0.44	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8848	0.44	98.25	7.9638	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8678	0.44	95.11	7.9569	0.48	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8472	0.45	92.07	7.9415	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8192	0.47	90.56	7.9260	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7882	0.49	89.09	7.8838	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7843	0.52	87.63	7.8785	0.56	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7825	0.58	86.19	7.8756	0.59	271.30
22	8.1629	0.36	170.31	8.1721	0.37	189.83	68	7.7920	0.58	84.78	7.8900	N/A	272.76
24	8.1536	0.35	151.40	8.1711	0.36	208.51	70	7.7309	N/A	83.38	7.8157	N/A	274.19
26	8.1429	0.39	142.29	8.1615	0.38	217.74	72	7.6545	N/A	81.94	7.7664	N/A	275.63
28	8.1474	0.35	135.52	8.1652	0.41	224.58	74	7.6223	N/A	80.65	N/A	N/A	N/A
30	8.1201	0.41	130.17	8.1499	0.38	229.98	76	7.6200	N/A	79.12	N/A	N/A	N/A
32	8.1094	0.39	125.58	8.1470	0.40	234.48	78	7.5865	N/A	77.69	N/A	N/A	N/A
34	8.1026	0.40	121.72	8.1311	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0860	0.38	118.45	8.1025	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0682	0.39	115.45	8.1015	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0484	0.38	112.78	8.0924	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0327	0.38	110.18	8.0819	0.42	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0095	0.41	107.89	8.0686	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

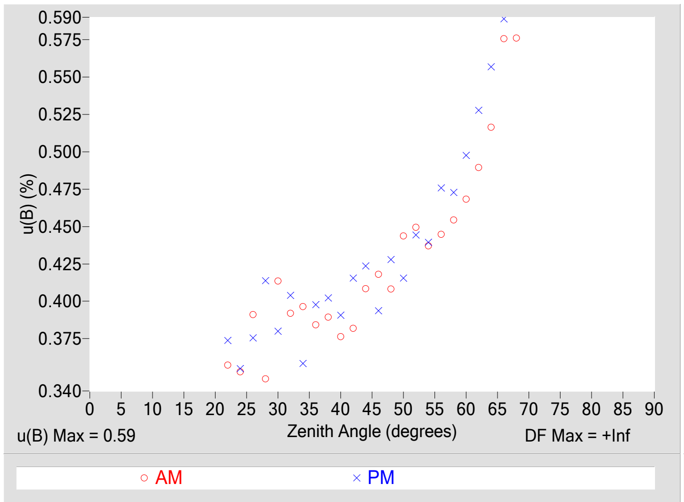


Figure 4. Residuals from Spline Interpolation

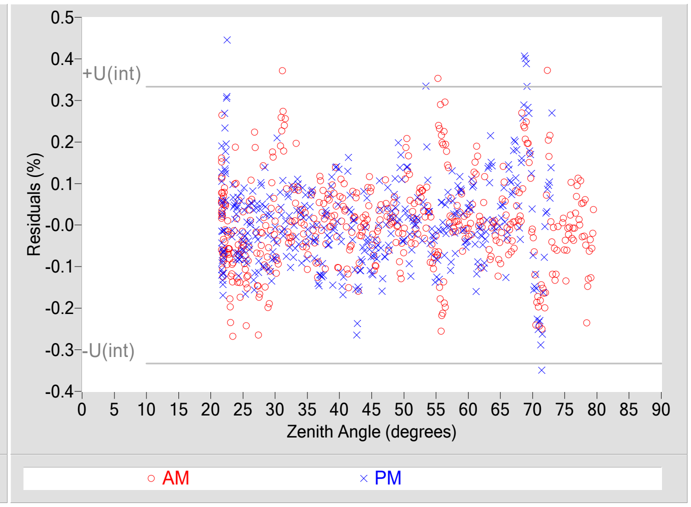


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	145916
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

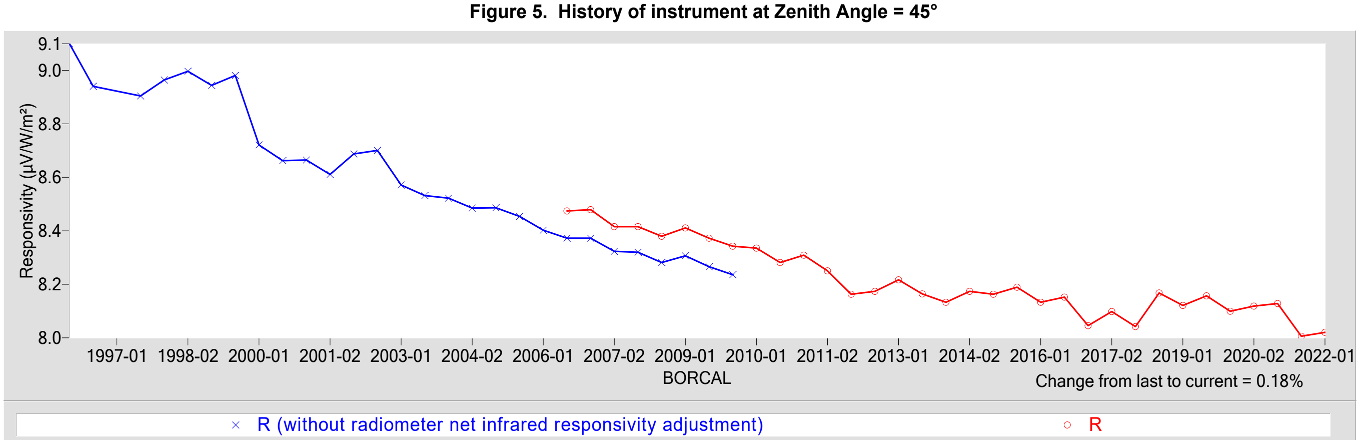
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0209	0.63390

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.6 / -2.5
Expanded Uncertainty, U (%)	+2.6 / -3.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

[7] 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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

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

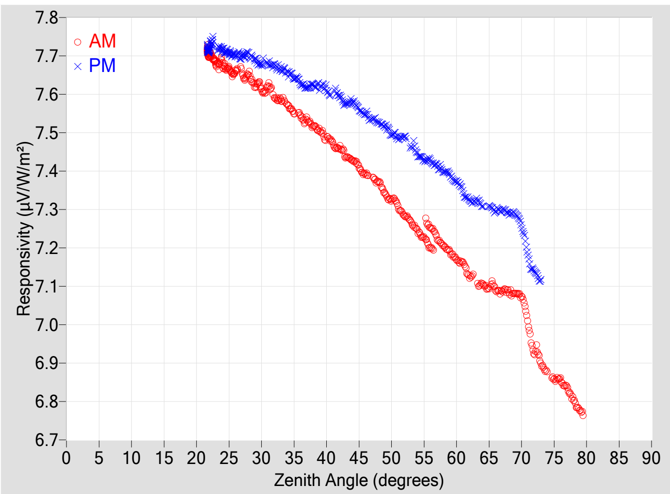


Figure 2. Responsivity vs Local Standard Time

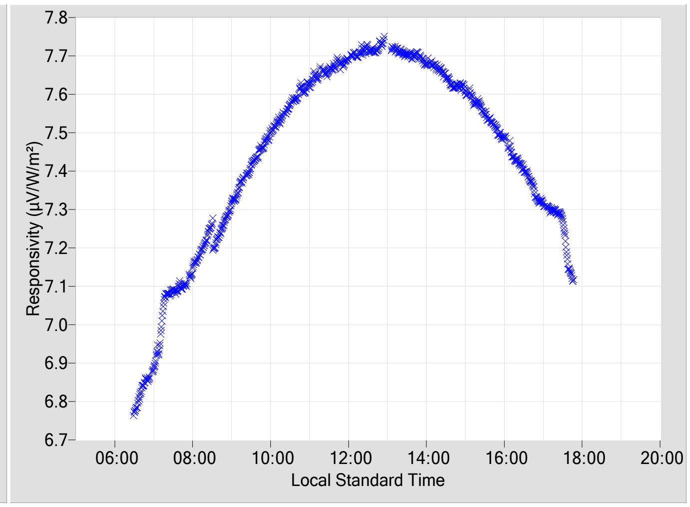


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	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	7.3926	0.42	105.74	7.5494	0.40	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.3718	0.41	103.72	7.5266	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.3254	0.45	101.82	7.4940	0.42	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2836	0.45	100.00	7.4881	0.45	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2446	0.44	98.25	7.4428	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.2259	0.45	95.11	7.4264	0.48	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.2055	0.46	92.07	7.3986	0.48	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1703	0.47	90.56	7.3720	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1264	0.49	89.09	7.3254	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.1063	0.52	87.63	7.3076	0.56	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.0927	0.58	86.19	7.2962	0.60	271.30
22	7.7047	0.36	170.50	7.7185	0.37	189.83	68	7.0859	0.58	84.78	7.2904	N/A	272.76
24	7.6802	0.35	151.40	7.7169	0.36	208.51	70	7.0728	N/A	83.38	7.2556	N/A	274.19
26	7.6593	0.39	142.29	7.7027	0.38	217.74	72	6.9316	N/A	81.94	7.1387	N/A	275.63
28	7.6525	0.35	135.52	7.7033	0.42	224.58	74	6.8795	N/A	80.65	N/A	N/A	N/A
30	7.6143	0.41	130.17	7.6806	0.38	229.98	76	6.8555	N/A	79.12	N/A	N/A	N/A
32	7.5919	0.39	125.58	7.6737	0.41	234.48	78	6.8042	N/A	77.69	N/A	N/A	N/A
34	7.5709	0.40	121.72	7.6552	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.5444	0.39	118.45	7.6282	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5165	0.39	115.45	7.6238	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.4850	0.38	112.78	7.6123	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.4591	0.38	110.18	7.5950	0.42	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.4273	0.41	107.89	7.5809	0.43	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

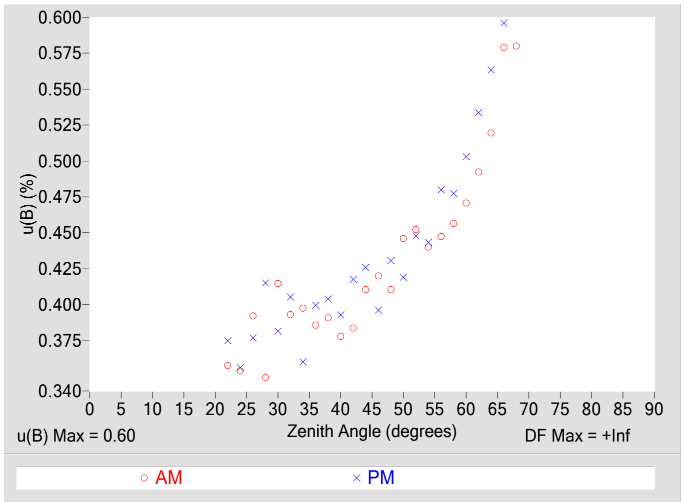


Figure 4. Residuals from Spline Interpolation

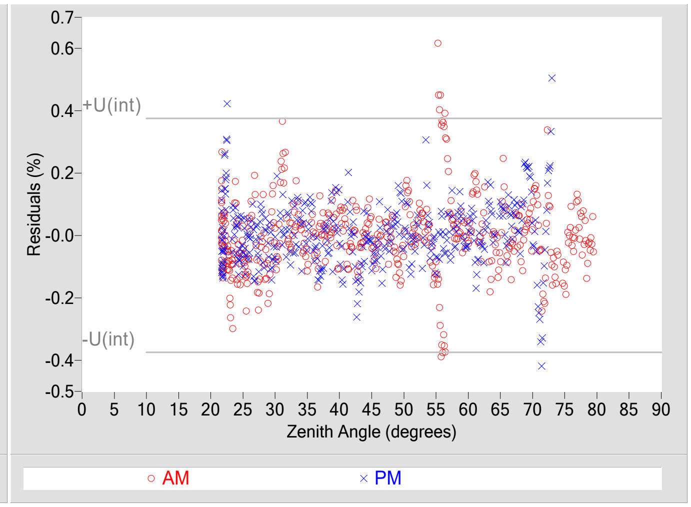


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	98110
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

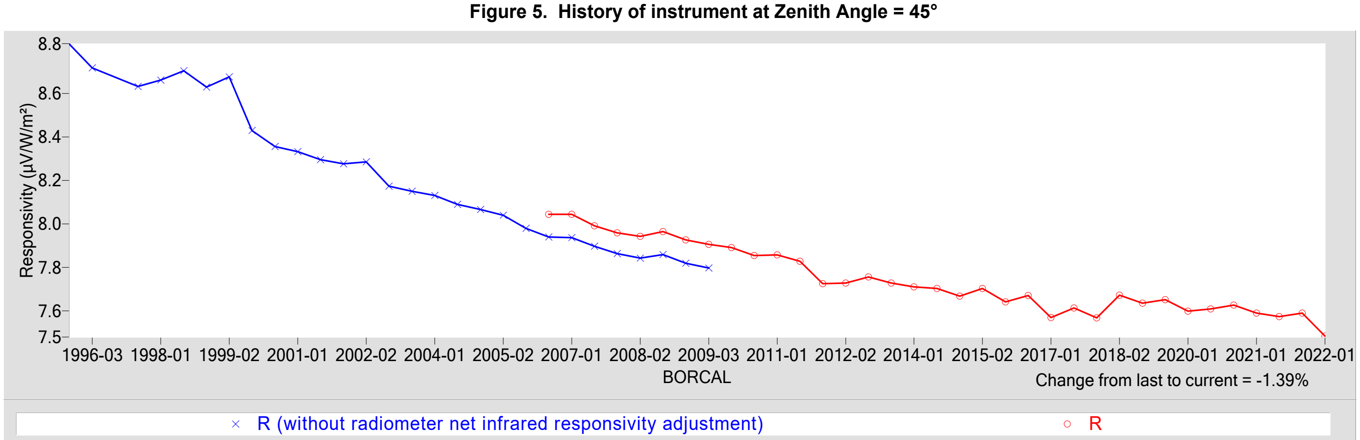
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.4851	0.64286

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+2.6 / -4.2
Expanded Uncertainty, U (%)	+3.6 / -5.2
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:**	31154F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

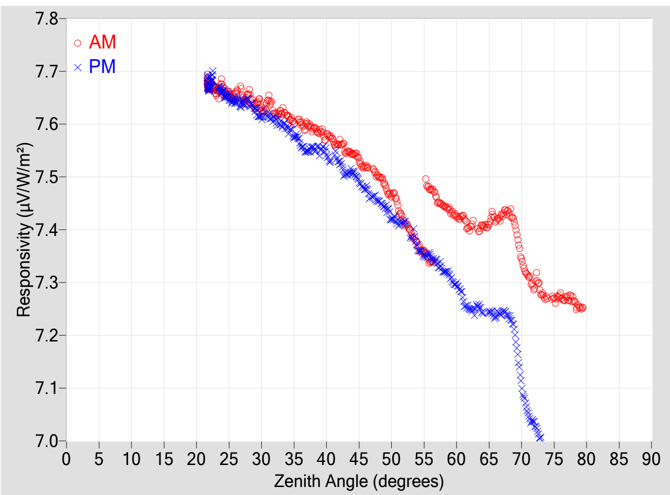


Figure 2. Responsivity vs Local Standard Time

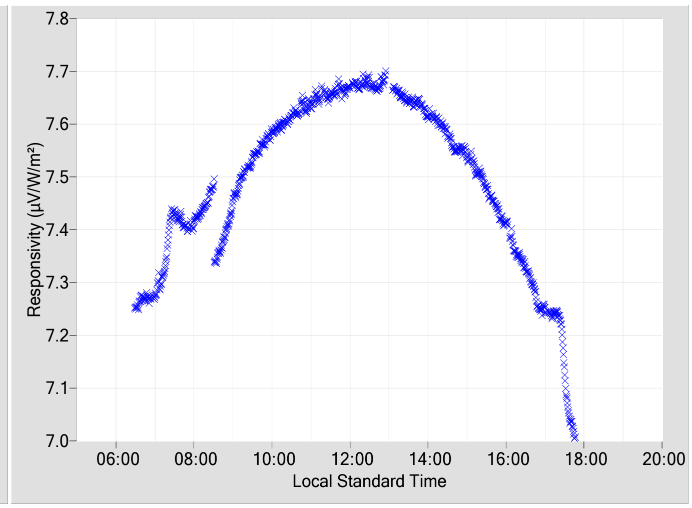


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	7.5194	0.42	105.74	7.4779	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5005	0.41	103.72	7.4542	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4654	0.44	101.82	7.4196	0.42	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4130	0.45	100.00	7.4129	0.44	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3726	0.44	98.25	7.3656	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4074	0.44	95.11	7.3488	0.48	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4454	0.45	92.07	7.3215	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4257	0.47	90.56	7.2953	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4032	0.49	89.09	7.2509	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4082	0.52	87.63	7.2427	0.56	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4198	0.57	86.19	7.2367	0.59	271.30
22	7.6743	0.36	170.31	7.6724	0.37	189.83	68	7.4322	0.57	84.78	7.2356	N/A	272.76
24	7.6680	0.35	151.40	7.6616	0.36	208.51	70	7.3461	N/A	83.38	7.1065	N/A	274.19
26	7.6558	0.39	142.29	7.6439	0.38	217.74	72	7.2978	N/A	81.94	7.0317	N/A	275.63
28	7.6579	0.35	135.52	7.6420	0.41	224.58	74	7.2719	N/A	80.65	N/A	N/A	N/A
30	7.6309	0.41	130.17	7.6160	0.38	229.98	76	7.2736	N/A	79.12	N/A	N/A	N/A
32	7.6211	0.39	125.58	7.6082	0.40	234.48	78	7.2660	N/A	77.69	N/A	N/A	N/A
34	7.6142	0.40	121.72	7.5909	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6036	0.38	118.45	7.5615	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5909	0.39	115.45	7.5539	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5755	0.38	112.78	7.5437	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5632	0.38	110.18	7.5271	0.42	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5432	0.41	107.89	7.5100	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

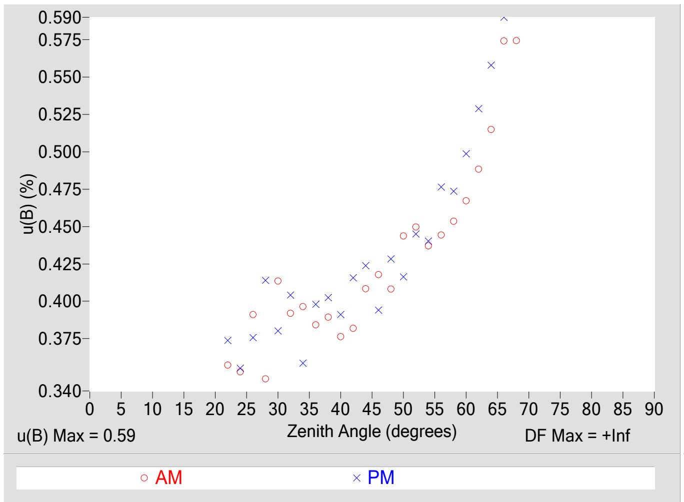


Figure 4. Residuals from Spline Interpolation

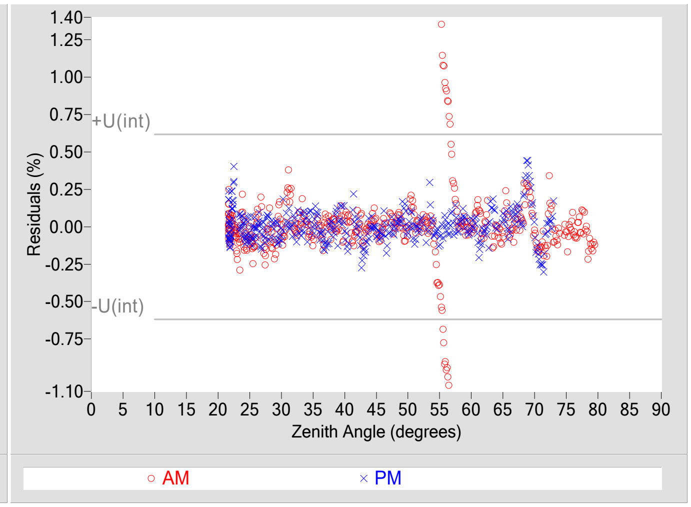


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.31
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	17220
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

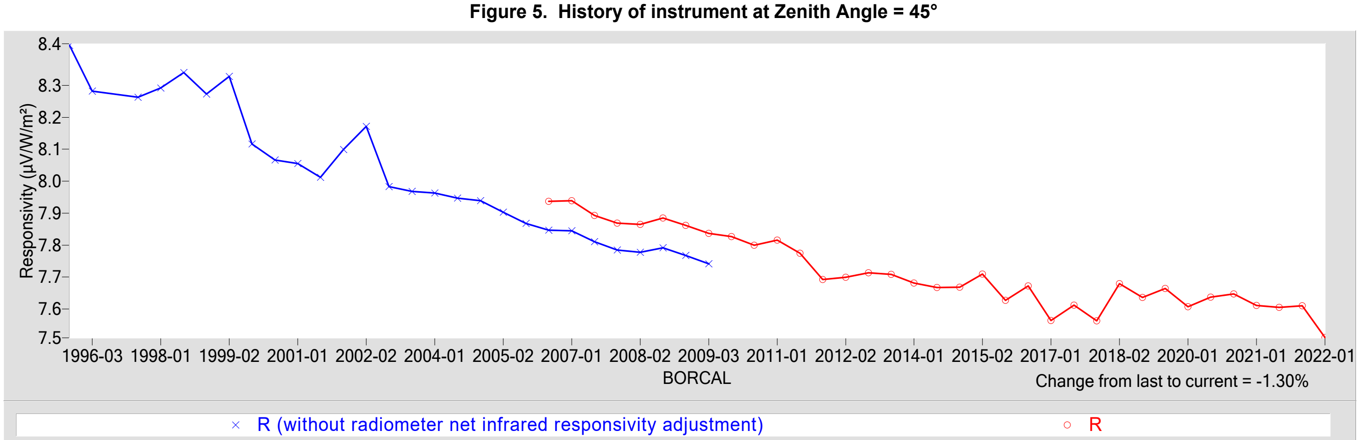
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.5111	0.56158

† Rnet determination date: 05/09/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.6 / -2.9
Expanded Uncertainty, U (%)	+2.6 / -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

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

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

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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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

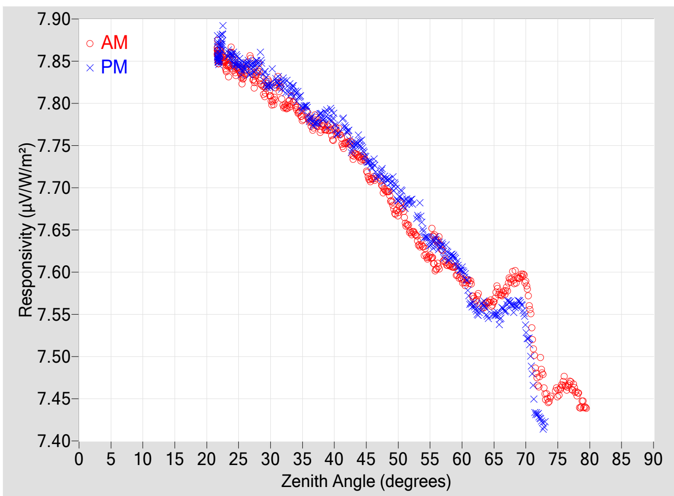


Figure 2. Responsivity vs Local Standard Time

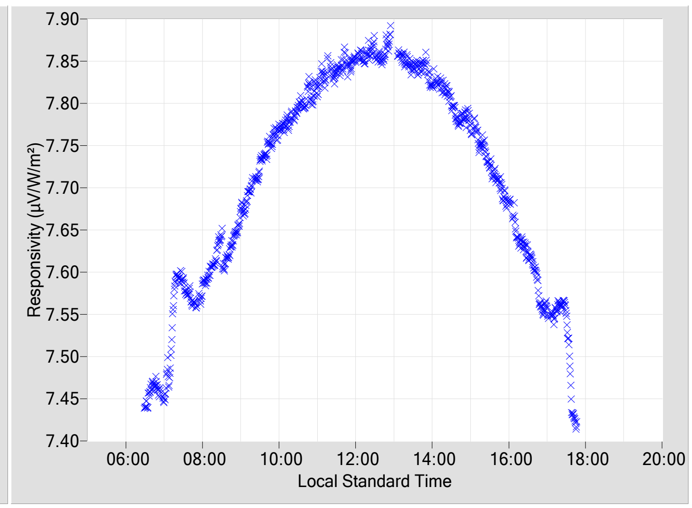


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	7.7108	0.42	105.74	7.7274	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6968	0.41	103.72	7.7103	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6723	0.44	101.82	7.6869	0.41	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6470	0.45	100.00	7.6840	0.44	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6270	0.43	98.25	7.6454	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6212	0.44	95.11	7.6347	0.47	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.6086	0.45	92.07	7.6179	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5918	0.47	90.56	7.6023	0.49	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5671	0.49	89.09	7.5586	0.52	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5641	0.51	87.63	7.5474	0.55	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5736	0.57	86.19	7.5466	0.58	271.30
22	7.8556	0.36	170.31	7.8585	0.37	189.83	68	7.5924	0.57	84.78	7.5584	N/A	272.76
24	7.8510	0.35	151.40	7.8548	0.35	208.51	70	7.5875	N/A	83.38	7.5337	N/A	274.19
26	7.8383	0.39	142.29	7.8442	0.37	217.74	72	7.4760	N/A	81.94	7.4297	N/A	275.63
28	7.8391	0.35	135.52	7.8458	0.41	224.58	74	7.4520	N/A	80.65	N/A	N/A	N/A
30	7.8087	0.41	130.17	7.8244	0.38	229.98	76	7.4687	N/A	79.12	N/A	N/A	N/A
32	7.7985	0.39	125.58	7.8228	0.40	234.48	78	7.4567	N/A	77.69	N/A	N/A	N/A
34	7.7938	0.40	121.72	7.8108	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7820	0.38	118.45	7.7845	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7719	0.39	115.45	7.7853	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.7635	0.37	112.78	7.7773	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.7548	0.38	110.18	7.7677	0.41	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.7350	0.41	107.89	7.7546	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

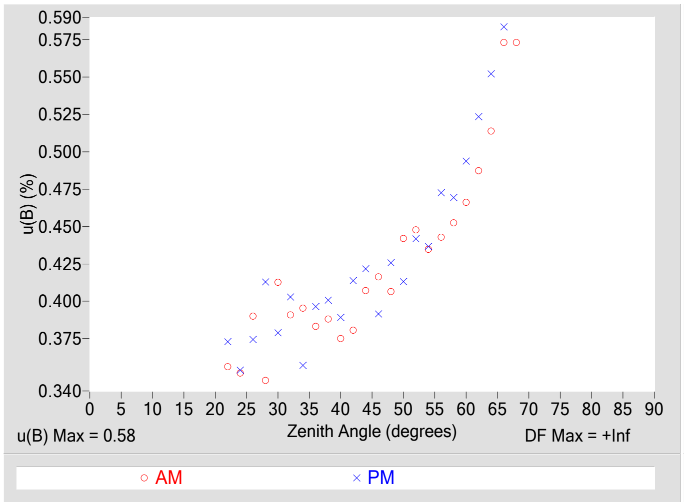


Figure 4. Residuals from Spline Interpolation

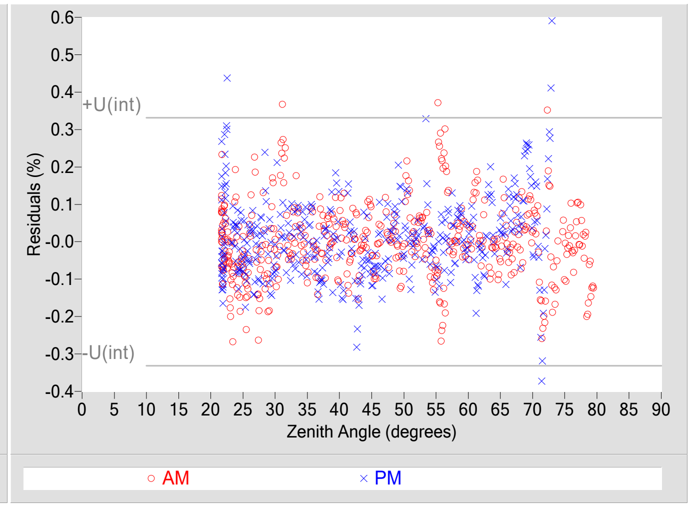


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	142880
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

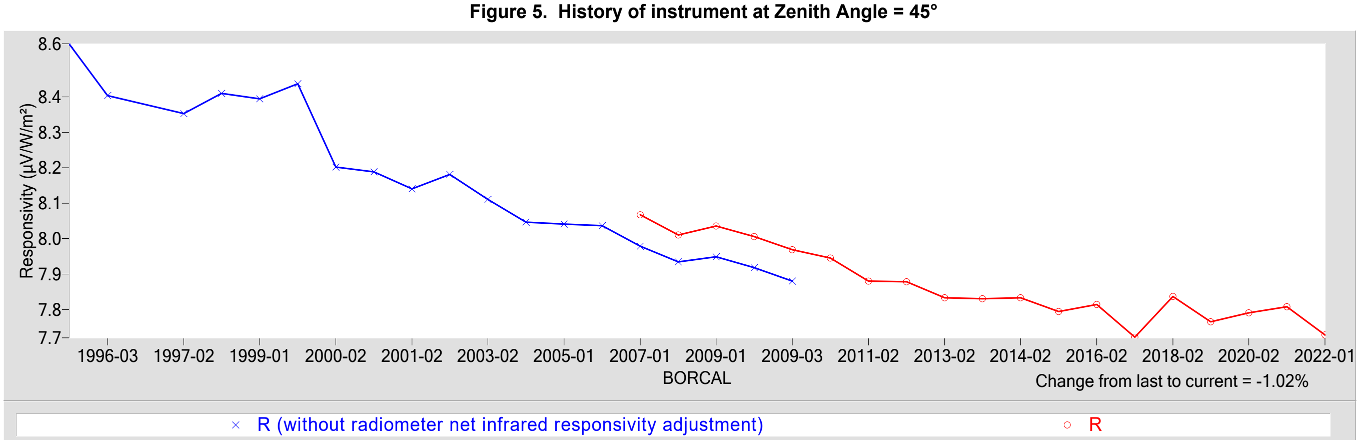
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.7282	0.52400

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.2 / -1.8
Expanded Uncertainty, U (%)	+2.2 / -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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31156F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

where,

V = radiometer output voltage (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

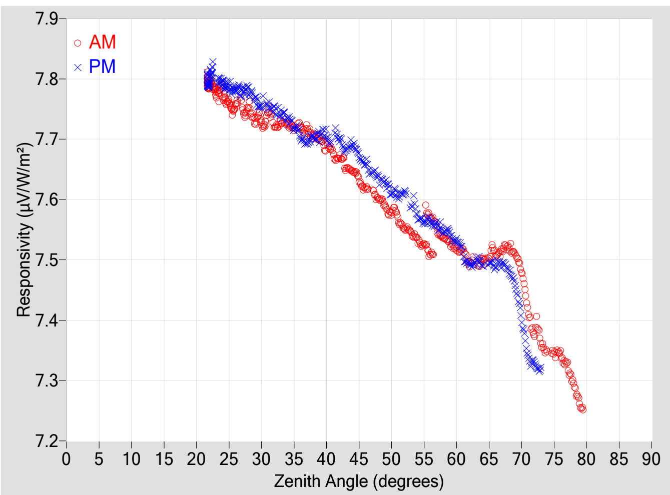


Figure 2. Responsivity vs Local Standard Time

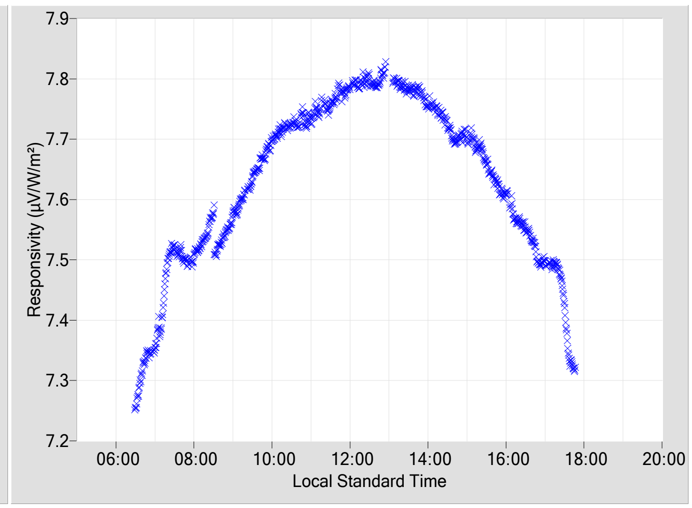


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6190	0.42	105.74	7.6601	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6012	0.41	103.72	7.6348	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5784	0.44	101.82	7.6092	0.41	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5516	0.45	100.00	7.6108	0.44	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5335	0.44	98.25	7.5711	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5392	0.44	95.11	7.5640	0.47	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5365	0.45	92.07	7.5463	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5178	0.47	90.56	7.5309	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4951	0.49	89.09	7.4944	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5017	0.51	87.63	7.4903	0.55	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5104	0.57	86.19	7.4898	0.59	271.30
22	7.7918	0.36	170.31	7.7955	0.37	189.83	68	7.5203	0.57	84.78	7.4820	N/A	272.76
24	7.7783	0.35	151.40	7.7940	0.35	208.51	70	7.4808	N/A	83.38	7.4027	N/A	274.19
26	7.7555	0.39	142.29	7.7827	0.38	217.74	72	7.3848	N/A	81.94	7.3290	N/A	275.63
28	7.7539	0.35	135.52	7.7811	0.41	224.58	74	7.3496	N/A	80.65	N/A	N/A	N/A
30	7.7281	0.41	130.17	7.7570	0.38	229.98	76	7.3433	N/A	79.12	N/A	N/A	N/A
32	7.7224	0.39	125.58	7.7490	0.40	234.48	78	7.2944	N/A	77.69	N/A	N/A	N/A
34	7.7237	0.40	121.72	7.7323	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.7207	0.38	118.45	7.7038	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.7055	0.39	115.45	7.7039	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6867	0.38	112.78	7.7054	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6689	0.38	110.18	7.6998	0.41	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6464	0.41	107.89	7.6917	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

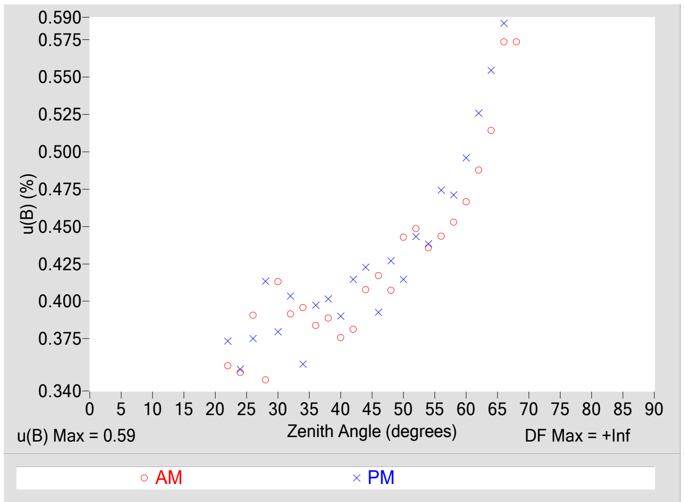


Figure 4. Residuals from Spline Interpolation

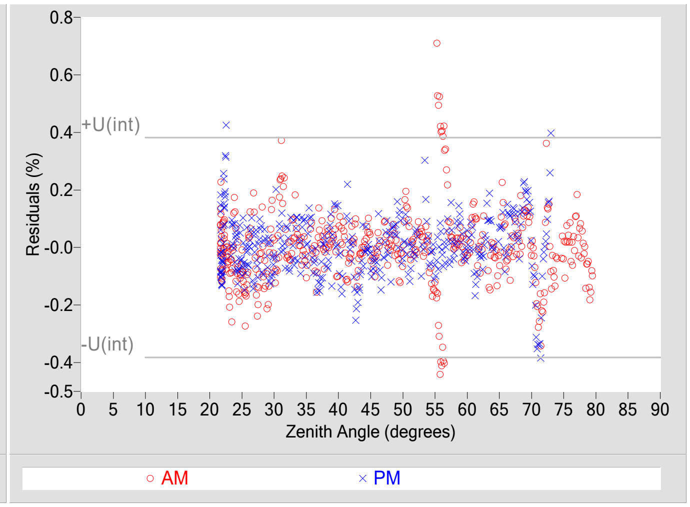


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	86548
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

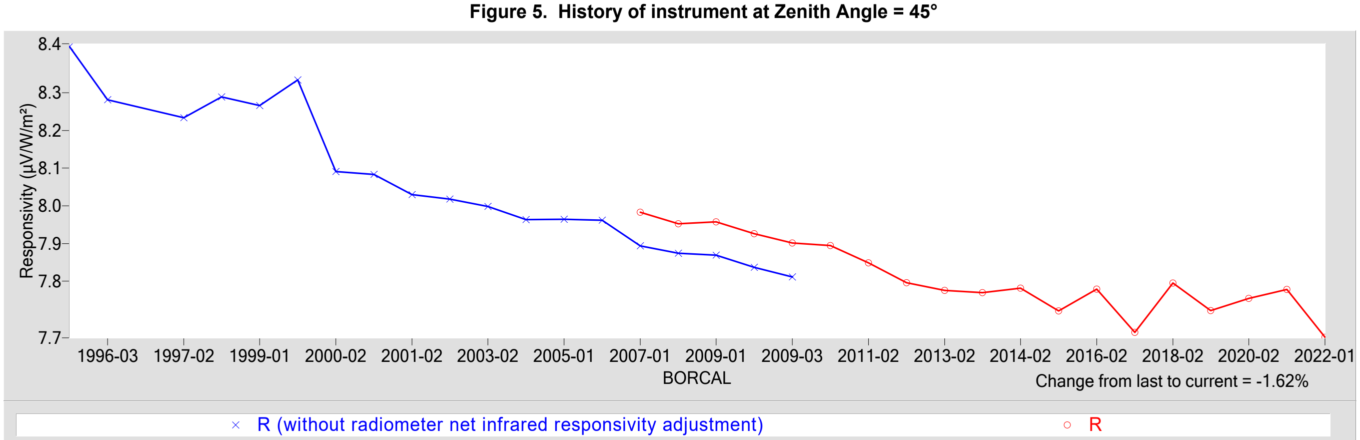
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6520	0.53200

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.4 / -1.8
Expanded Uncertainty, U (%)	+2.3 / -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	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31157F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	Calibration System	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

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 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

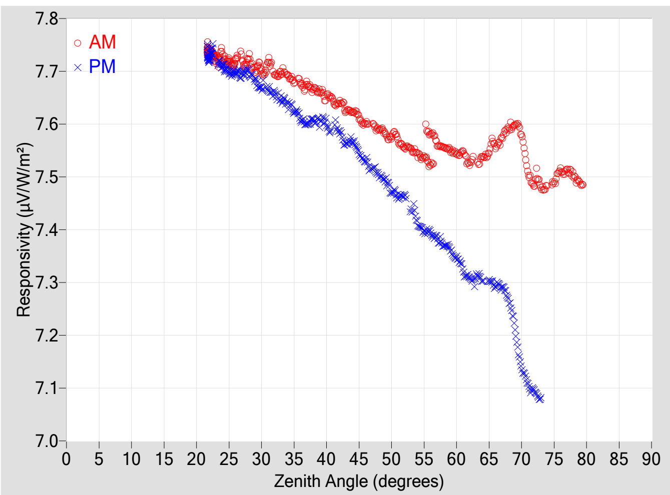


Figure 2. Responsivity vs Local Standard Time

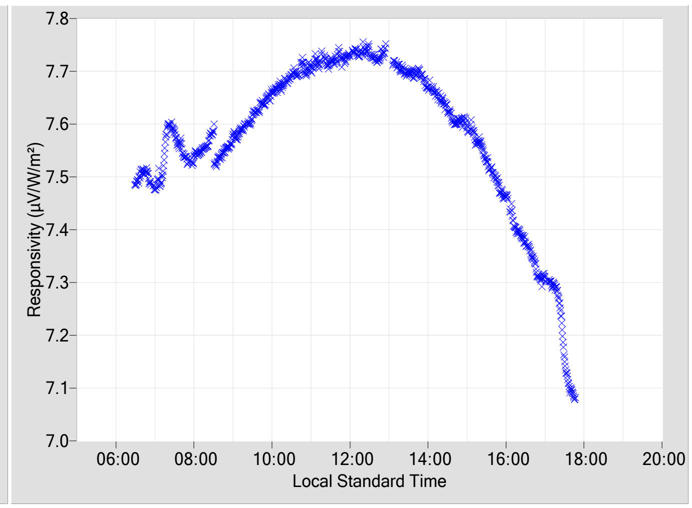


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6016	0.42	105.74	7.5306	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5901	0.41	103.72	7.5044	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5762	0.44	101.82	7.4699	0.41	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5556	0.45	100.00	7.4628	0.44	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5434	0.43	98.25	7.4121	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5519	0.44	95.11	7.3936	0.47	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5564	0.45	92.07	7.3702	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.5447	0.47	90.56	7.3460	0.49	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5262	0.49	89.09	7.3096	0.52	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5381	0.51	87.63	7.3024	0.55	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.5597	0.57	86.19	7.2930	0.58	271.30
22	7.7354	0.36	170.31	7.7268	0.37	189.83	68	7.5914	0.57	84.78	7.2659	N/A	272.76
24	7.7292	0.35	151.40	7.7110	0.35	208.51	70	7.5793	N/A	83.38	7.1386	N/A	274.19
26	7.7202	0.39	142.29	7.6972	0.37	217.74	72	7.4926	N/A	81.94	7.0945	N/A	275.63
28	7.7252	0.35	135.52	7.6978	0.41	224.58	74	7.4832	N/A	80.65	N/A	N/A	N/A
30	7.7013	0.41	130.17	7.6704	0.38	229.98	76	7.5111	N/A	79.12	N/A	N/A	N/A
32	7.6948	0.39	125.58	7.6572	0.40	234.48	78	7.5024	N/A	77.69	N/A	N/A	N/A
34	7.6913	0.40	121.72	7.6373	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6782	0.38	118.45	7.6096	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6658	0.39	115.45	7.6073	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6505	0.38	112.78	7.5997	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6403	0.38	110.18	7.5851	0.41	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6225	0.41	107.89	7.5677	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

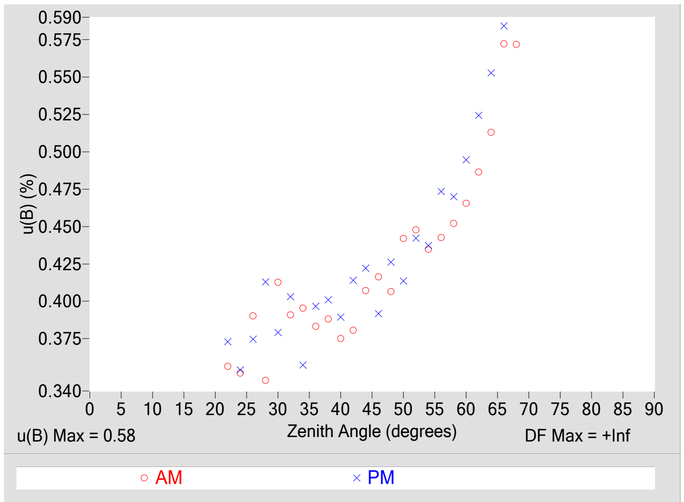


Figure 4. Residuals from Spline Interpolation

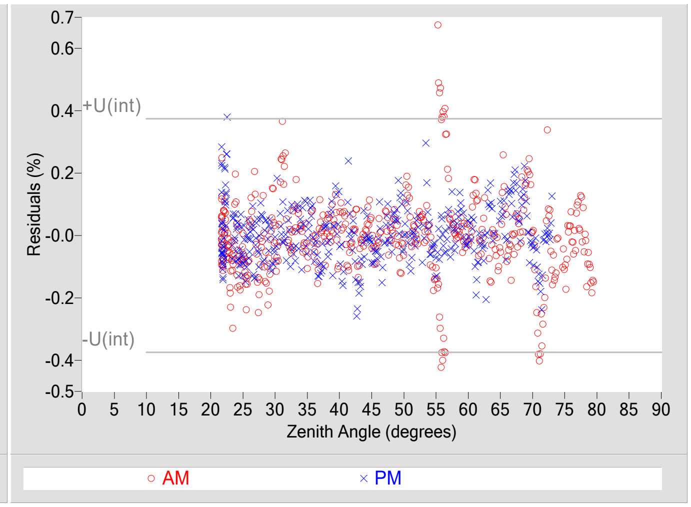


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	91971
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

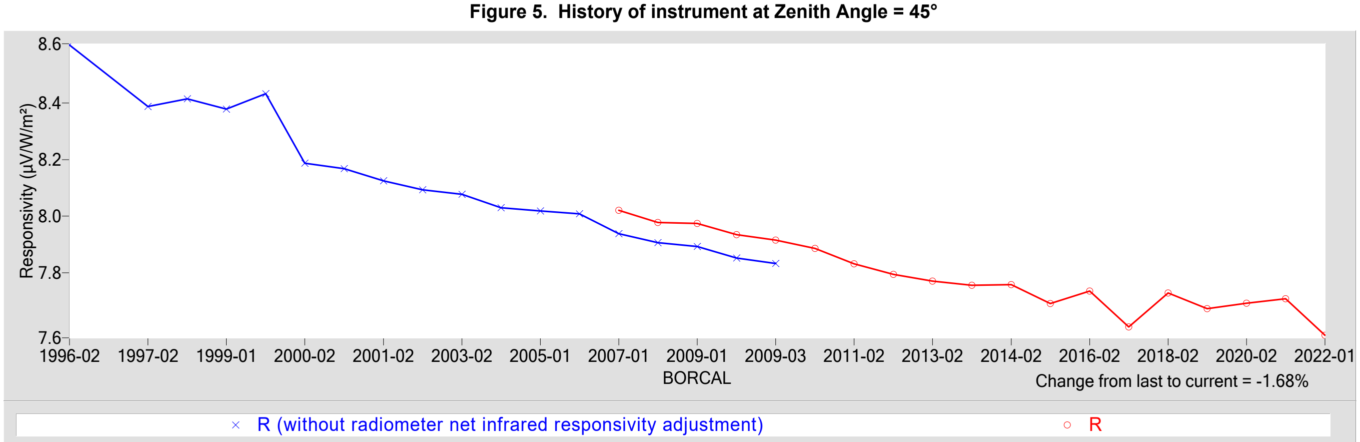
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5785	0.49000

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.6 / -3.1
Expanded Uncertainty, U (%)	+2.6 / -4.0
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:**	31275F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

31275F3 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

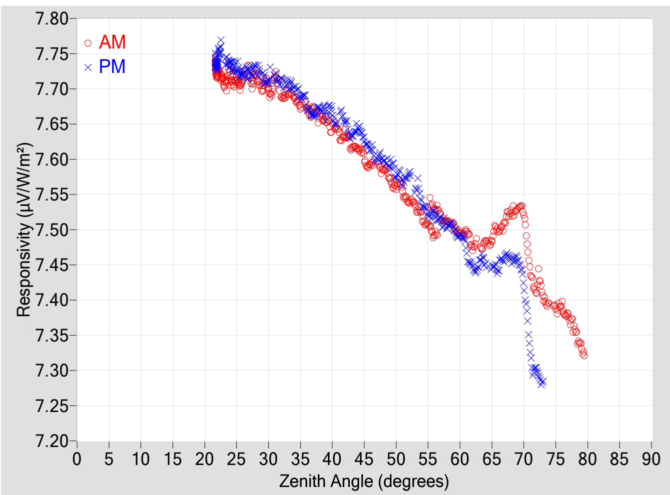


Figure 2. Responsivity vs Local Standard Time

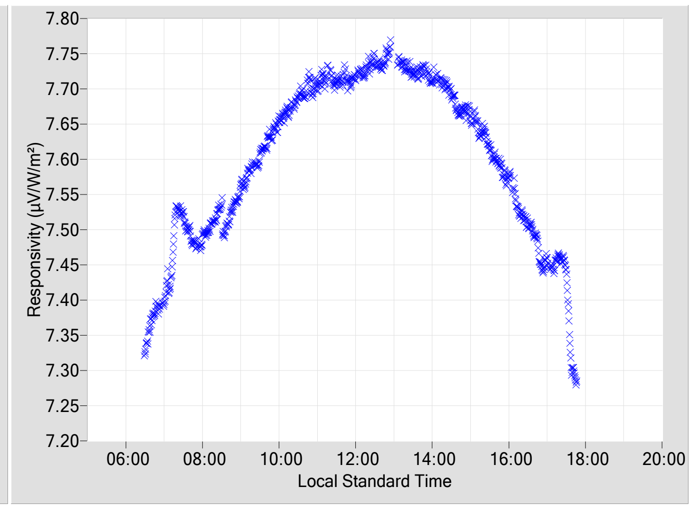


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5928	0.42	105.74	7.6149	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5846	0.41	103.72	7.5982	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5621	0.44	101.82	7.5758	0.42	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5395	0.45	100.00	7.5784	0.45	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5200	0.44	98.25	7.5377	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.5108	0.44	95.11	7.5215	0.48	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5121	0.45	92.07	7.5051	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4957	0.47	90.56	7.4920	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4754	0.49	89.09	7.4475	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4837	0.52	87.63	7.4493	0.56	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4991	0.58	86.19	7.4445	0.59	271.30
22	7.7252	0.36	170.50	7.7383	0.37	189.83	68	7.5235	0.58	84.78	7.4572	N/A	272.76
24	7.7183	0.35	151.40	7.7356	0.36	208.51	70	7.5205	N/A	83.38	7.4188	N/A	274.19
26	7.7156	0.39	142.29	7.7220	0.38	217.74	72	7.4204	N/A	81.94	7.3009	N/A	275.63
28	7.7220	0.35	135.52	7.7281	0.41	224.58	74	7.3958	N/A	80.65	N/A	N/A	N/A
30	7.6994	0.41	130.17	7.7140	0.38	229.98	76	7.3892	N/A	79.12	N/A	N/A	N/A
32	7.6902	0.39	125.58	7.7111	0.40	234.48	78	7.3571	N/A	77.69	N/A	N/A	N/A
34	7.6867	0.40	121.72	7.6997	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6735	0.38	118.45	7.6761	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6602	0.39	115.45	7.6717	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6448	0.38	112.78	7.6645	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6339	0.38	110.18	7.6535	0.42	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6142	0.41	107.89	7.6450	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

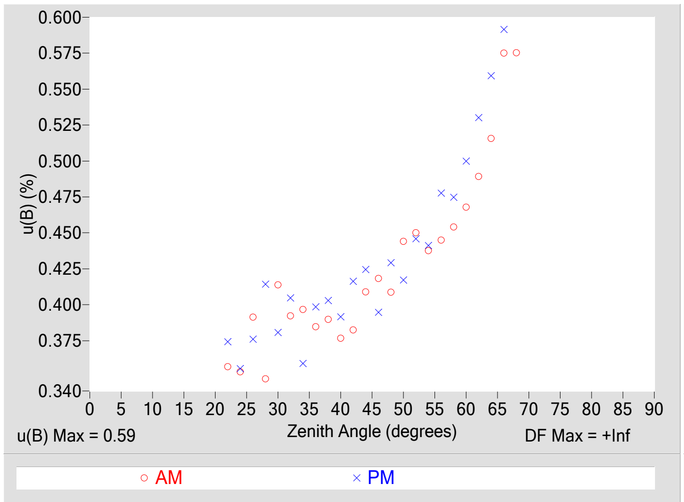


Figure 4. Residuals from Spline Interpolation

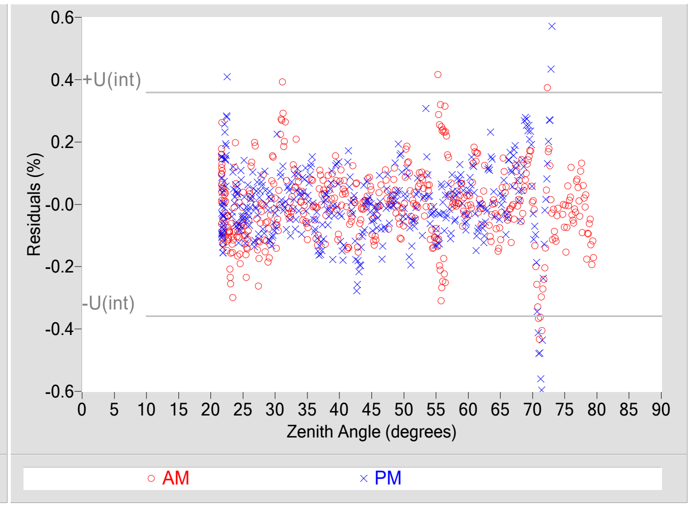


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	112903
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

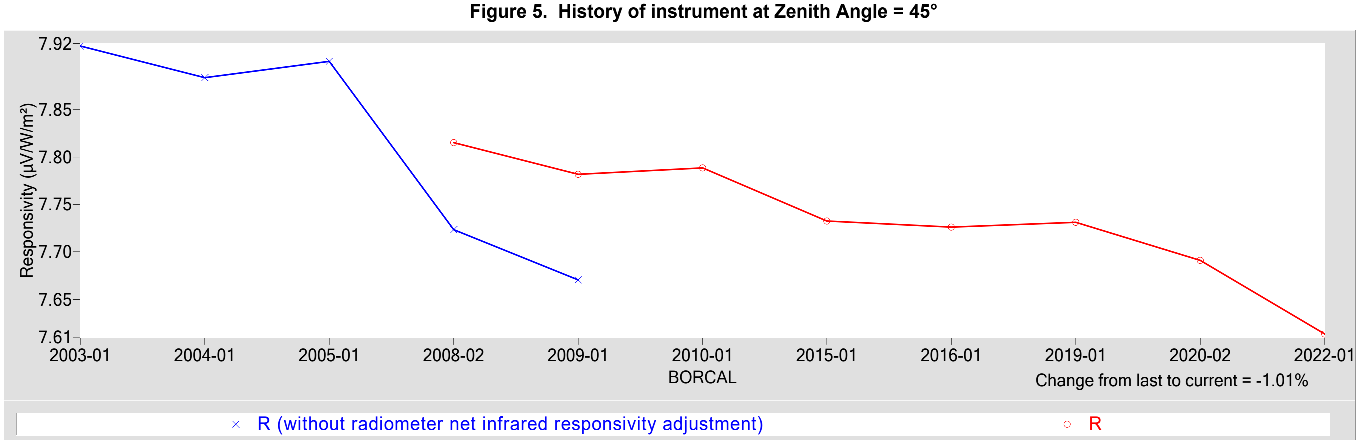
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.6135	0.59150

† Rnet determination date: 07/03/2008

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.3 / -1.6
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:**	31277F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

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

Number of pages of certificate: 4

Calibration Procedure: SGP BORCAL Calibration Procedure

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

Calibrated by: Craig Webb

______________________________ ________________

Peter Gotseff, Technical Manager Date

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

Calibration Results
31277F3 Eppley PSP

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

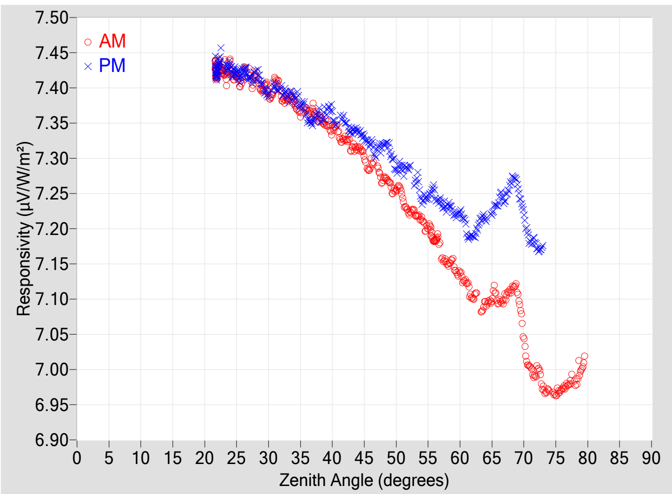


Figure 2. Responsivity vs Local Standard Time

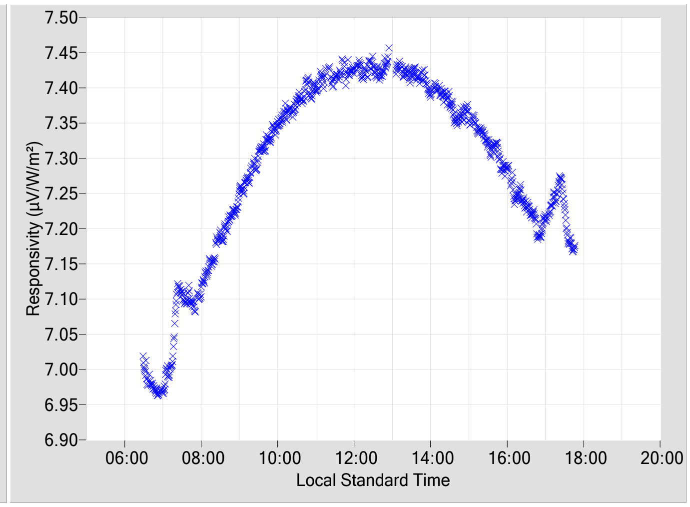


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (μV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (μV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	7.2888	0.44	105.82	7.3210	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.2699	0.41	103.74	7.3196	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.2557	0.44	101.84	7.2829	0.43	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.2233	0.43	100.03	7.2868	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.2126	0.44	98.27	7.2403	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.1836	0.44	94.94	7.2515	0.45	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.1498	0.45	92.09	7.2310	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.1359	0.47	90.58	7.2237	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.1009	0.52	89.11	7.1897	0.52	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.0929	0.55	87.65	7.2136	0.55	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.0962	0.54	86.21	7.2396	0.58	271.32
22	7.4249	0.37	170.40	7.4237	0.36	189.51	68	7.1124	0.57	84.80	7.2682	N/A	272.77
24	7.4299	0.38	151.10	7.4283	0.36	208.57	70	7.0416	N/A	83.35	7.2178	N/A	274.21
26	7.4172	0.37	142.46	7.4219	0.40	217.79	72	6.9965	N/A	81.96	7.1740	N/A	275.65
28	7.4185	0.36	135.81	7.4171	0.35	224.59	74	6.9704	N/A	80.61	N/A	N/A	N/A
30	7.3921	0.35	130.21	7.3912	0.37	229.82	76	6.9721	N/A	79.14	N/A	N/A	N/A
32	7.3863	0.42	125.57	7.3968	0.41	234.52	78	6.9827	N/A	77.66	N/A	N/A	N/A
34	7.3796	0.41	121.86	7.3838	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.3684	0.38	118.49	7.3594	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.3563	0.39	115.39	7.3587	0.37	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.3385	0.38	112.73	7.3636	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.3273	0.40	110.28	7.3527	0.40	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.3140	0.41	107.99	7.3391	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

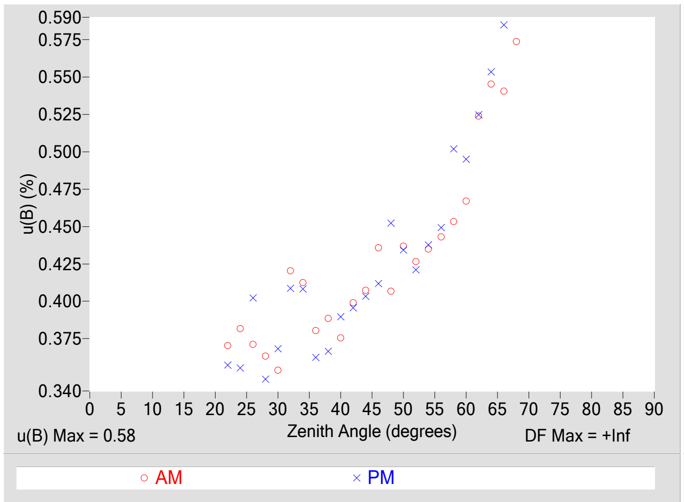


Figure 4. Residuals from Spline Interpolation

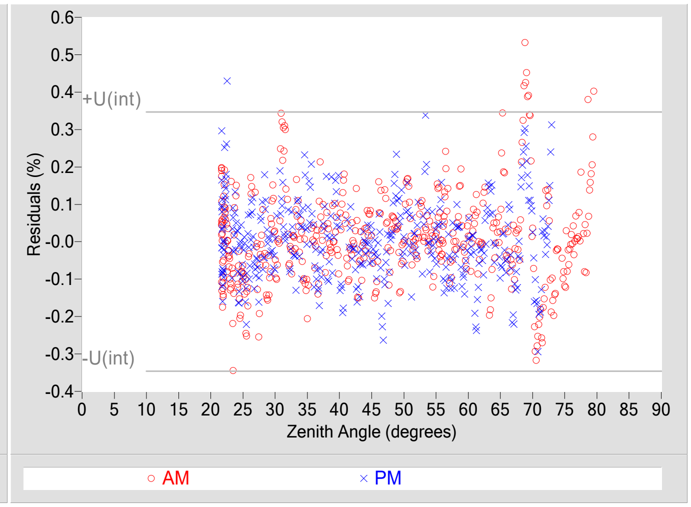


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	120989
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

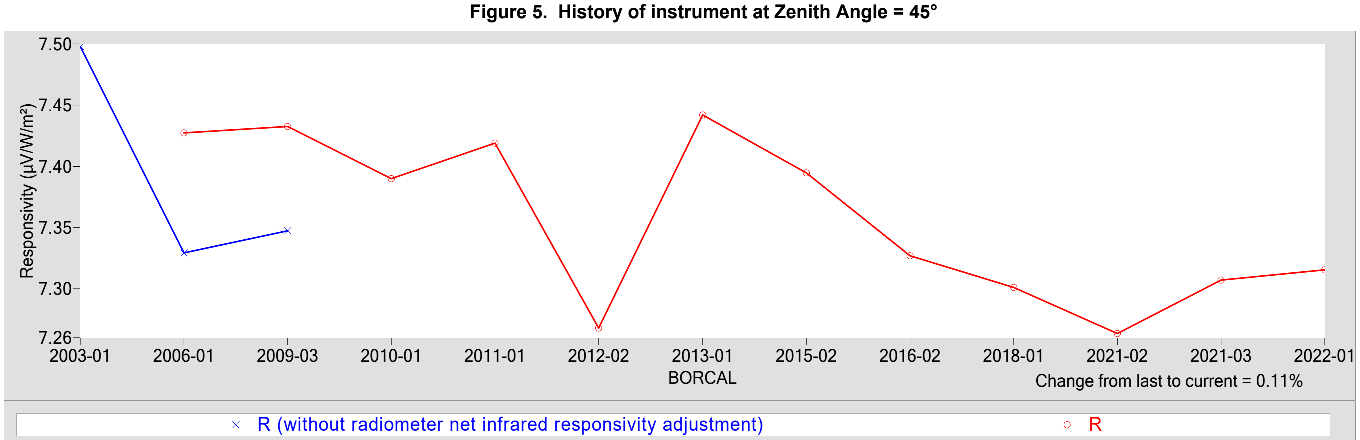
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.3153	0.50400

† Rnet determination date: 04/03/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.1 / -2.5
Expanded Uncertainty, U (%)	+2.1 / -3.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31280F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

31280F3 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

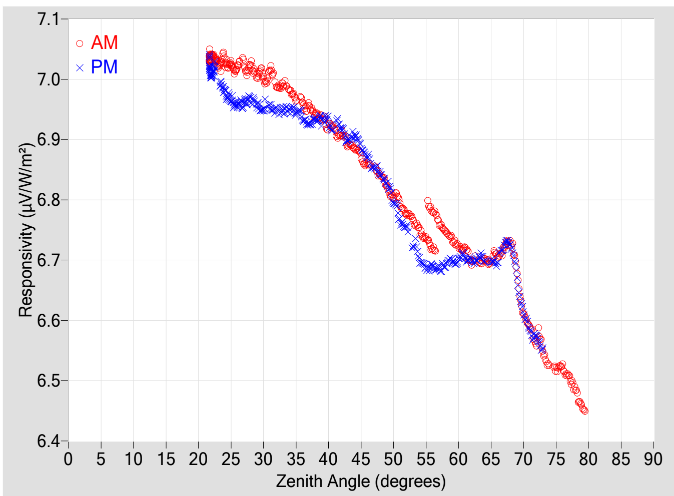


Figure 2. Responsivity vs Local Standard Time

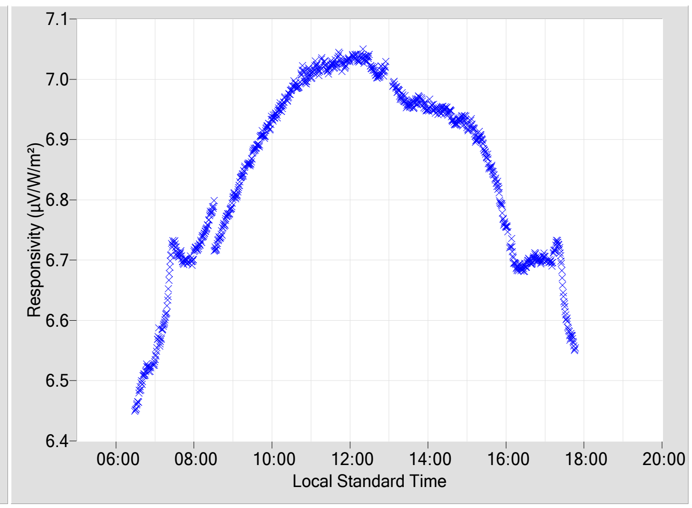


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	6.8594	0.42	105.74	6.8716	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	6.8403	0.41	103.72	6.8429	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	6.8054	0.44	101.82	6.7949	0.42	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	6.7763	0.45	100.00	6.7535	0.44	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	6.7496	0.44	98.25	6.7002	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	6.7492	0.44	95.11	6.6888	0.48	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	6.7474	0.45	92.07	6.6912	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	6.7232	0.47	90.56	6.7009	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	6.6974	0.49	89.09	6.7014	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	6.7014	0.51	87.63	6.6980	0.56	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	6.7076	0.57	86.19	6.6982	0.59	271.30
22	7.0353	0.36	170.31	7.0117	0.37	189.83	68	6.7271	0.57	84.78	6.7224	N/A	272.76
24	7.0325	0.35	151.40	6.9811	0.35	208.51	70	6.6128	N/A	83.38	6.6117	N/A	274.19
26	7.0209	0.39	142.29	6.9575	0.38	217.74	72	6.5685	N/A	81.94	6.5735	N/A	275.63
28	7.0249	0.35	135.52	6.9665	0.41	224.58	74	6.5271	N/A	80.65	N/A	N/A	N/A
30	7.0030	0.41	130.17	6.9524	0.38	229.98	76	6.5213	N/A	79.12	N/A	N/A	N/A
32	6.9893	0.39	125.58	6.9495	0.40	234.48	78	6.4846	N/A	77.69	N/A	N/A	N/A
34	6.9809	0.40	121.72	6.9494	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	6.9620	0.38	118.45	6.9358	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	6.9414	0.39	115.45	6.9335	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	6.9217	0.38	112.78	6.9286	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	6.9084	0.38	110.18	6.9179	0.42	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	6.8848	0.41	107.89	6.9072	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

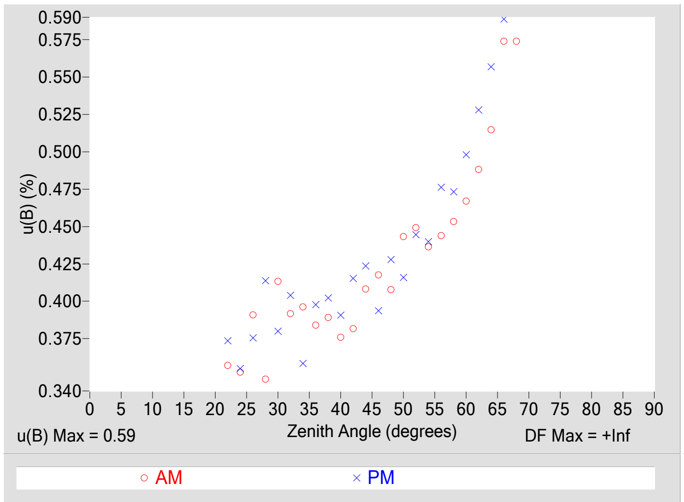


Figure 4. Residuals from Spline Interpolation

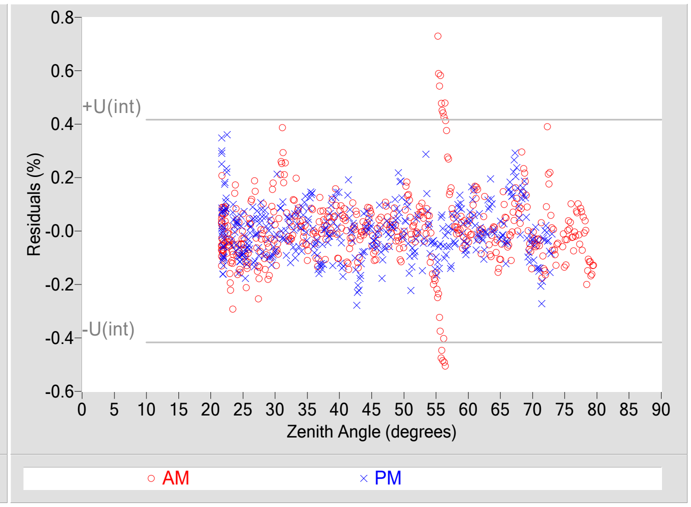


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.21
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	64596
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

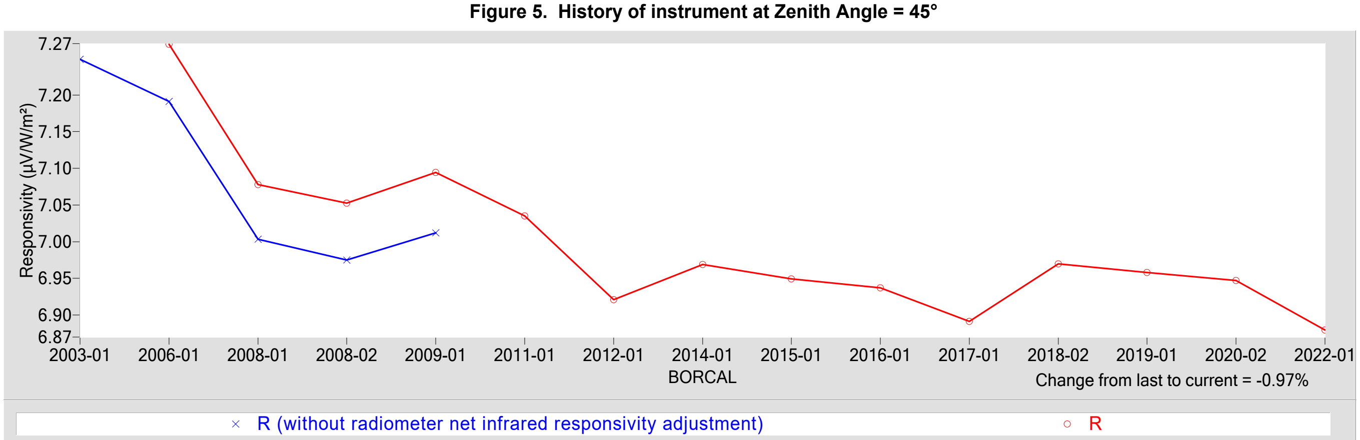
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
6.8794	0.49700

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.8 / -2.8
Expanded Uncertainty, U (%)	+2.8 / -3.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	31281F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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:

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

where,

V = radiometer output voltage (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

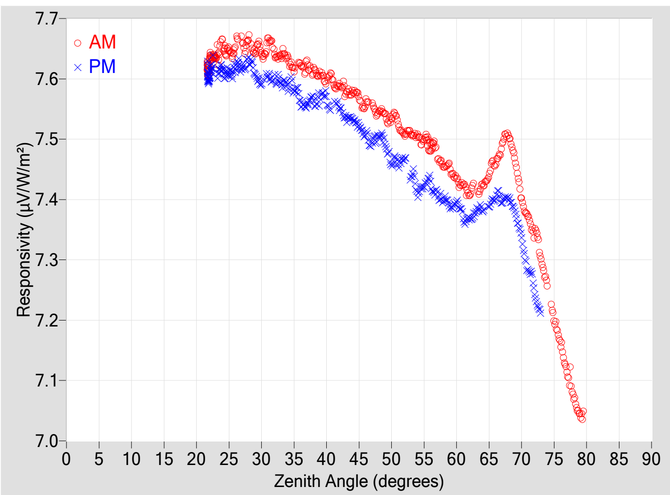


Figure 2. Responsivity vs Local Standard Time

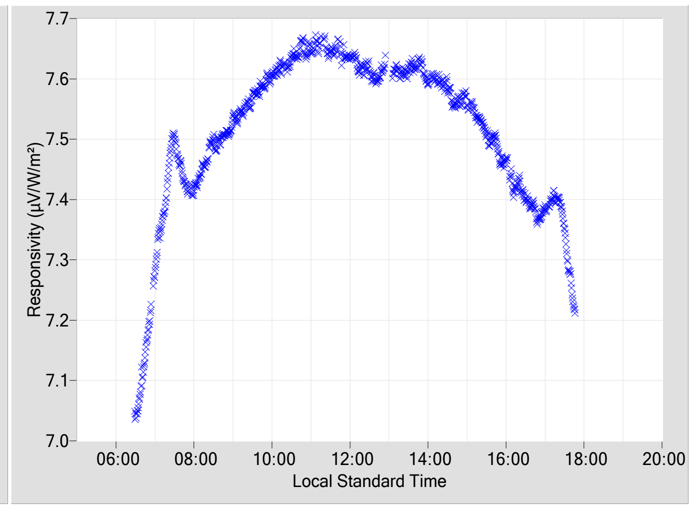


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5571	0.44	105.82	7.5079	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5439	0.41	103.74	7.5049	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5349	0.44	101.84	7.4587	0.43	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5077	0.43	100.03	7.4669	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.5048	0.44	98.27	7.4115	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4888	0.44	94.94	7.4274	0.45	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4550	0.45	92.09	7.3993	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4349	0.47	90.58	7.3953	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4085	0.52	89.11	7.3685	0.53	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4227	0.55	87.65	7.3828	0.55	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4596	0.54	86.21	7.4040	0.59	271.32
22	7.6236	0.37	170.40	7.6033	0.36	189.51	68	7.5044	0.57	84.80	7.4006	N/A	272.77
24	7.6566	0.38	151.10	7.6146	0.36	208.57	70	7.4011	N/A	83.35	7.3346	N/A	274.21
26	7.6553	0.37	142.46	7.6187	0.40	217.79	72	7.3460	N/A	81.96	7.2449	N/A	275.65
28	7.6649	0.36	135.81	7.6287	0.35	224.59	74	7.2616	N/A	80.61	N/A	N/A	N/A
30	7.6422	0.35	130.21	7.5926	0.37	229.82	76	7.1635	N/A	79.14	N/A	N/A	N/A
32	7.6400	0.42	125.57	7.5990	0.41	234.52	78	7.0748	N/A	77.71	N/A	N/A	N/A
34	7.6341	0.41	121.86	7.5872	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6236	0.38	118.49	7.5621	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6126	0.39	115.39	7.5612	0.37	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5966	0.38	112.73	7.5667	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5885	0.40	110.28	7.5531	0.40	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5762	0.41	107.99	7.5332	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

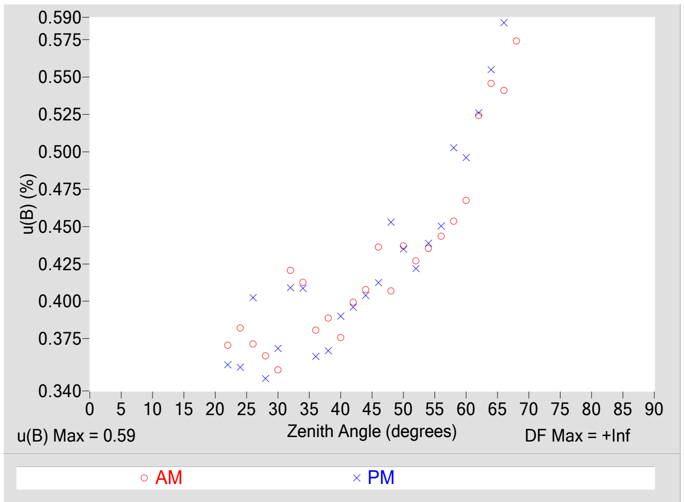


Figure 4. Residuals from Spline Interpolation

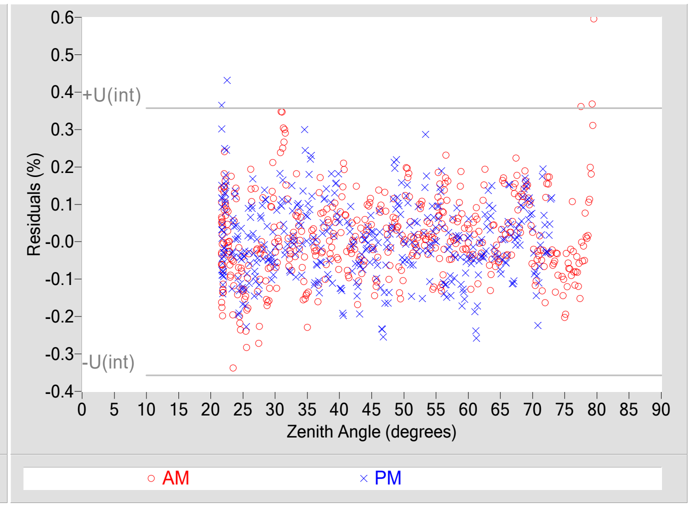


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	109014
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

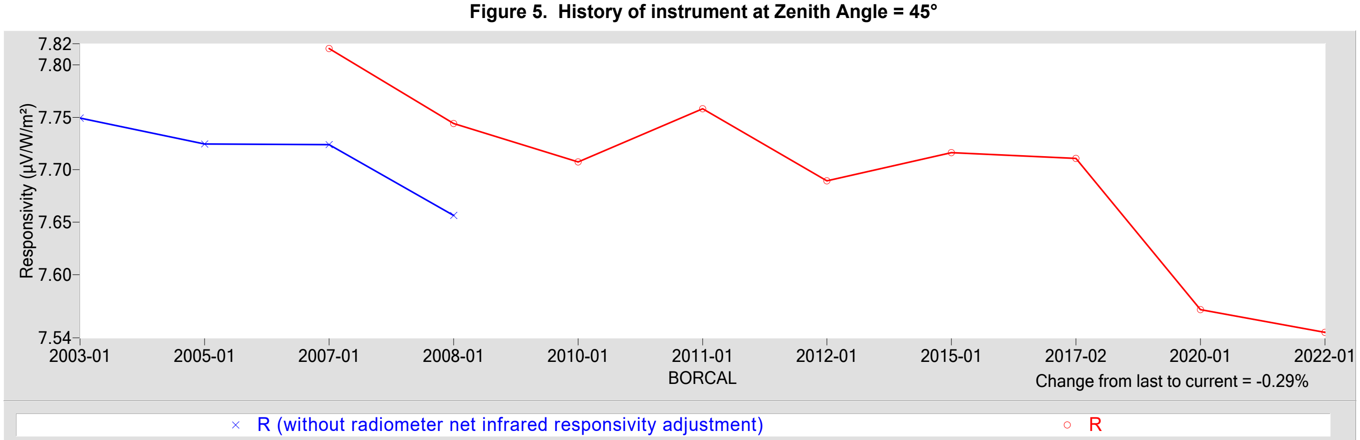
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.5452	0.54100

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.3 / -2.0
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:**	31287F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

31287F3 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

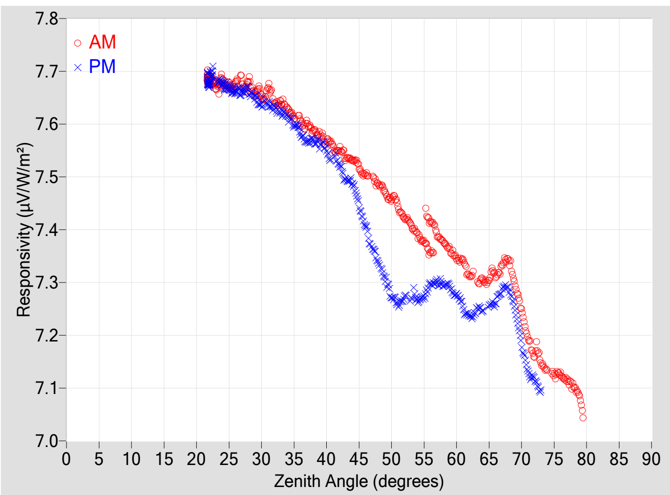


Figure 2. Responsivity vs Local Standard Time

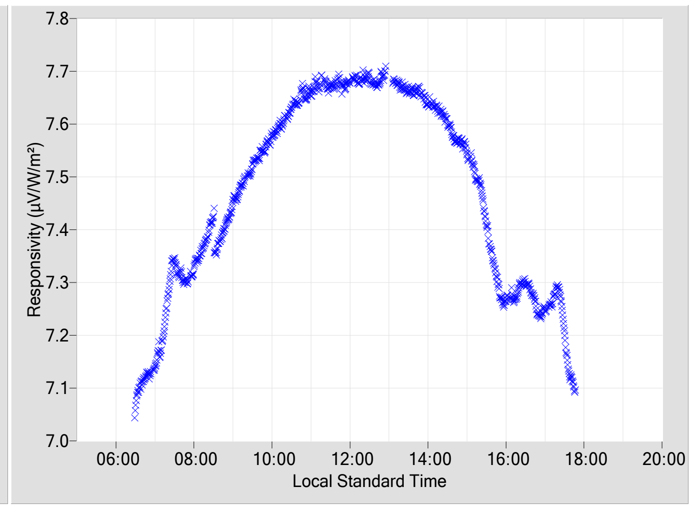


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5049	0.42	105.74	7.4070	0.40	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.4854	0.41	103.72	7.3378	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.4585	0.45	101.82	7.2707	0.42	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.4216	0.45	100.00	7.2719	0.45	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.3906	0.44	98.25	7.2653	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.3850	0.45	95.11	7.2968	0.48	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.3765	0.46	92.07	7.2948	0.48	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.3463	0.47	90.56	7.2761	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.3131	0.49	89.09	7.2379	0.53	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.3057	0.52	87.63	7.2458	0.56	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.3143	0.58	86.19	7.2618	0.60	271.30
22	7.6842	0.36	170.31	7.6806	0.37	189.83	68	7.3409	0.58	84.78	7.2874	N/A	272.76
24	7.6806	0.35	151.40	7.6770	0.36	208.51	70	7.2487	N/A	83.38	7.1835	N/A	274.19
26	7.6764	0.39	142.29	7.6627	0.38	217.74	72	7.1683	N/A	81.94	7.1170	N/A	275.63
28	7.6821	0.35	135.52	7.6638	0.41	224.58	74	7.1352	N/A	80.65	N/A	N/A	N/A
30	7.6533	0.41	130.17	7.6385	0.38	229.98	76	7.1257	N/A	79.12	N/A	N/A	N/A
32	7.6421	0.39	125.58	7.6300	0.41	234.48	78	7.1022	N/A	77.69	N/A	N/A	N/A
34	7.6284	0.40	121.72	7.6125	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6076	0.39	118.45	7.5818	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.5874	0.39	115.45	7.5692	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.5662	0.38	112.78	7.5504	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.5506	0.38	110.18	7.5217	0.42	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.5313	0.41	107.89	7.4877	0.43	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

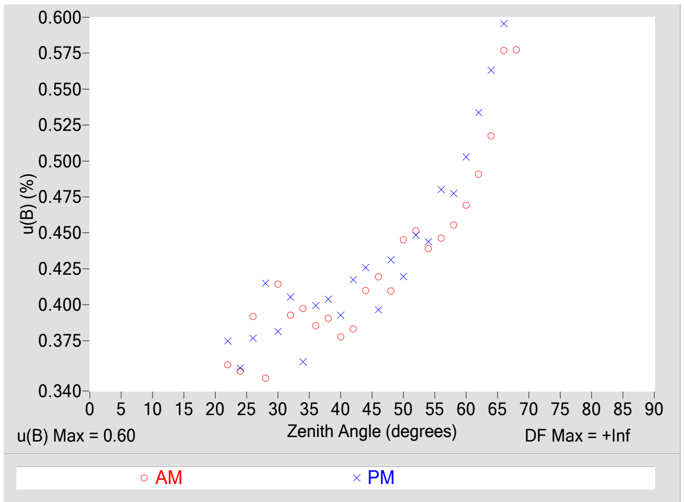


Figure 4. Residuals from Spline Interpolation

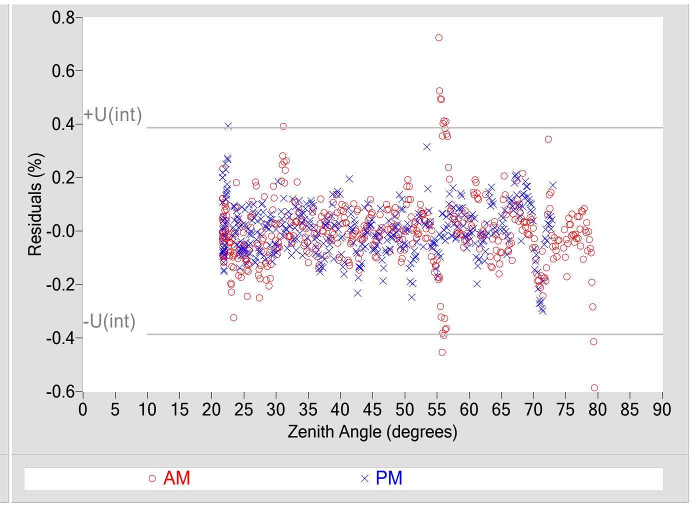


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.60
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.63
Effective degrees of freedom, DF(c)	87768
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

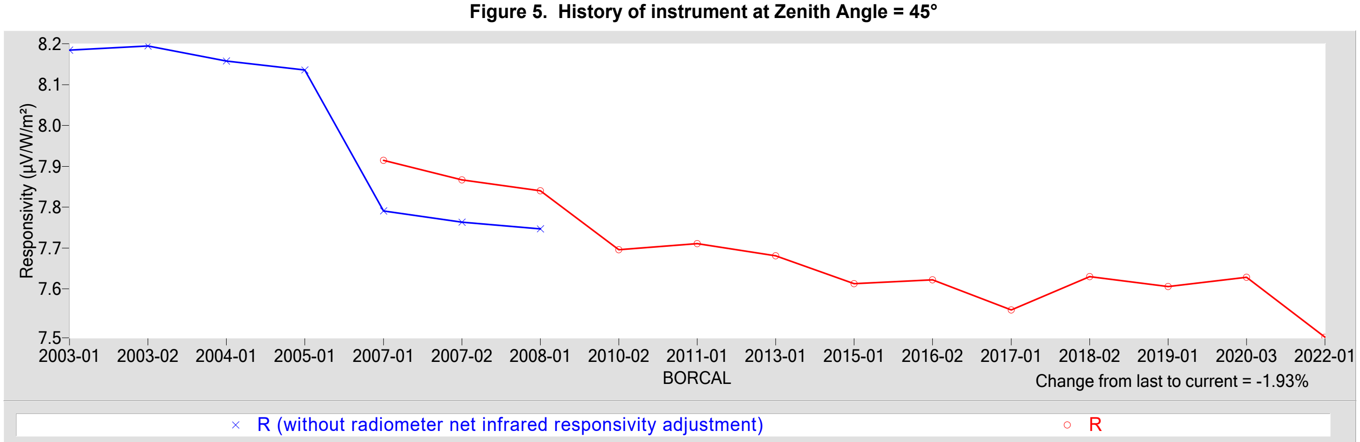
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.4814	0.62407

† Rnet determination date: 04/26/2007

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+2.3 / -2.9
Expanded Uncertainty, U (%)	+3.3 / -3.9
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.

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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:**	31288F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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2. The Expanded Uncertainty of using Spline Interpolating Functions for the responsivity versus zenith angle.

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

31288F3 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

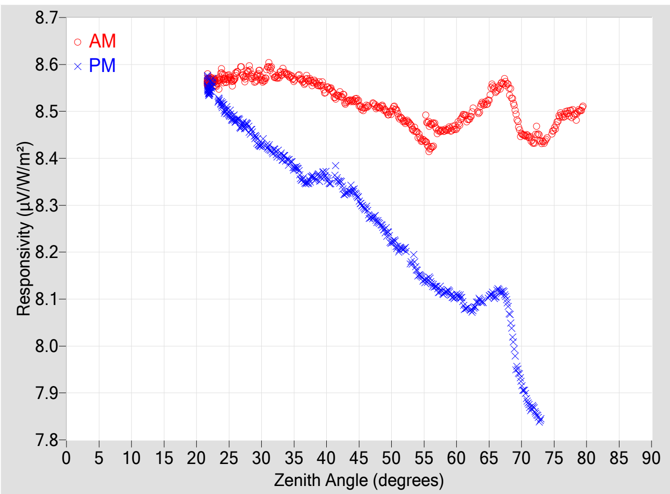


Figure 2. Responsivity vs Local Standard Time

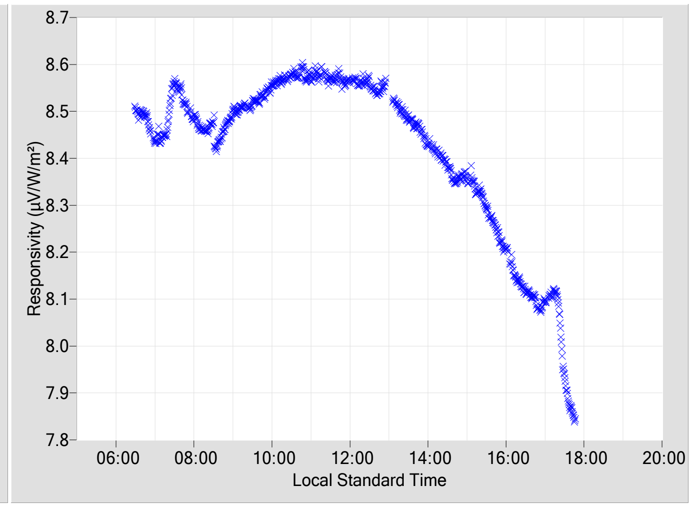


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5089	0.42	105.74	8.2933	0.39	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5083	0.41	103.72	8.2635	0.43	256.32
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4998	0.44	101.82	8.2208	0.41	258.33
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4781	0.45	100.00	8.2062	0.44	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4520	0.44	98.25	8.1560	0.44	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4460	0.44	95.11	8.1374	0.47	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4596	0.45	92.07	8.1130	0.47	265.18
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4685	0.47	90.56	8.1066	0.50	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4854	0.49	89.09	8.0791	0.53	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5161	0.51	87.63	8.0935	0.56	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5454	0.57	86.19	8.1075	0.59	271.30
22	8.5627	0.36	170.31	8.5457	0.37	189.83	68	8.5502	0.57	84.78	8.0781	N/A	272.76
24	8.5747	0.35	151.40	8.5129	0.35	208.51	70	8.4523	N/A	83.38	7.9195	N/A	274.19
26	8.5756	0.39	142.29	8.4819	0.38	217.74	72	8.4372	N/A	81.99	7.8638	N/A	275.63
28	8.5882	0.35	135.52	8.4643	0.41	224.58	74	8.4419	N/A	80.65	N/A	N/A	N/A
30	8.5708	0.41	130.17	8.4297	0.38	229.98	76	8.4913	N/A	79.12	N/A	N/A	N/A
32	8.5745	0.39	125.58	8.4139	0.40	234.48	78	8.4938	N/A	77.69	N/A	N/A	N/A
34	8.5775	0.40	121.72	8.3944	0.36	238.40	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5701	0.38	118.45	8.3601	0.40	241.60	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5611	0.39	115.45	8.3593	0.40	244.61	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5456	0.38	112.78	8.3605	0.39	247.40	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5340	0.38	110.18	8.3500	0.41	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5224	0.41	107.89	8.3337	0.42	252.21	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

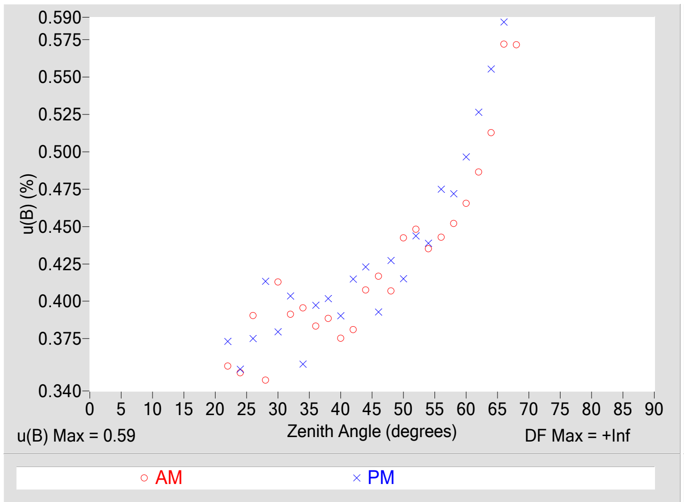


Figure 4. Residuals from Spline Interpolation

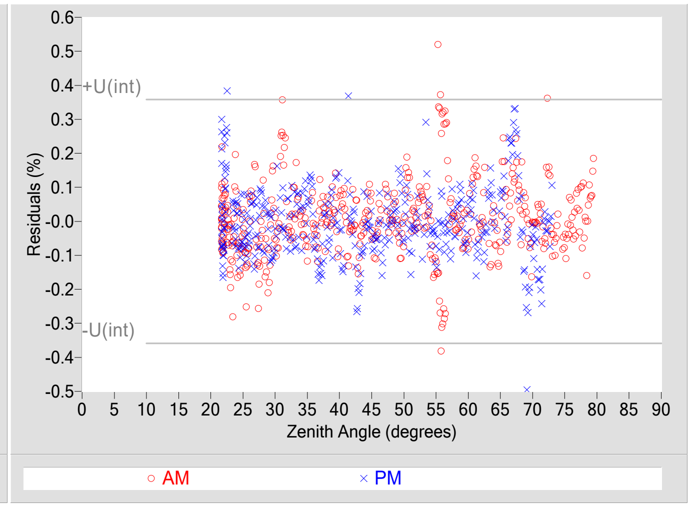


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	109436
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

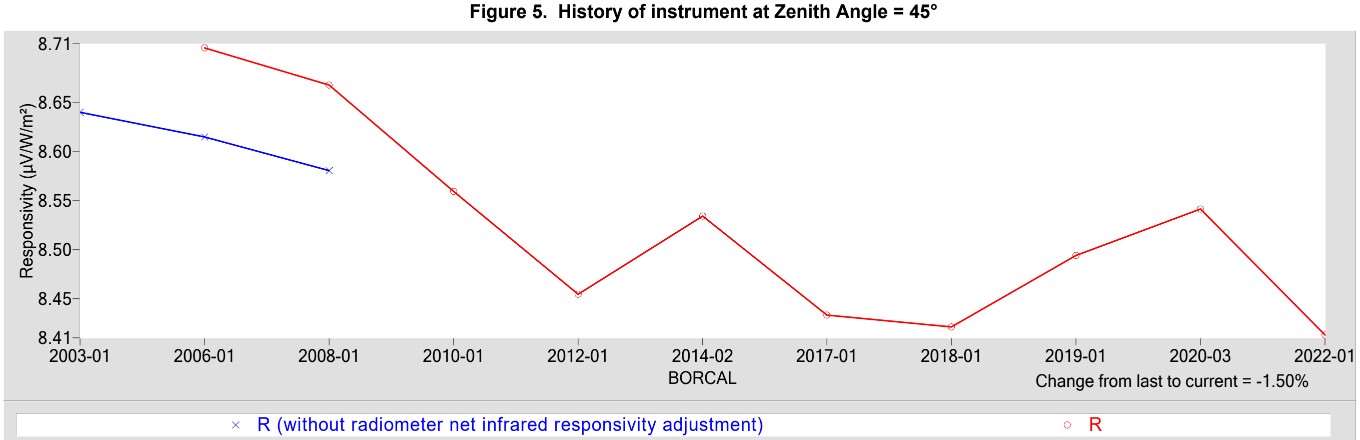
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4128	0.57800

† Rnet determination date: 03/30/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+2.0 / -3.6
Expanded Uncertainty, U (%)	+2.9 / -4.6
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:**	31344E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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
31344E6 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

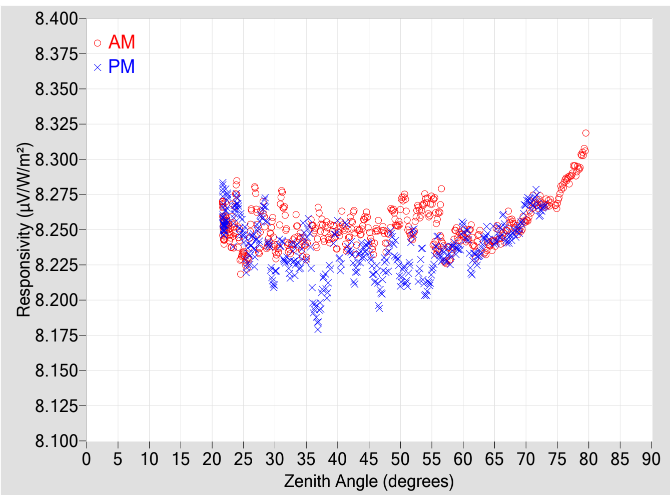


Figure 2. Responsivity vs Local Standard Time

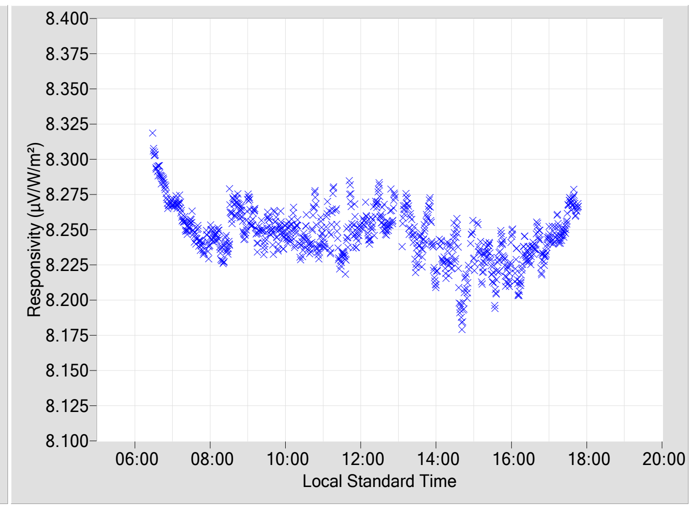


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2444	0.29	105.79	8.2177	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2423	0.29	103.83	8.2315	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2637	0.29	101.81	8.2162	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2460	0.29	100.05	8.2482	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2716	0.29	98.24	8.2057	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2485	0.30	95.29	8.2389	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2315	0.29	92.06	8.2319	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2473	0.31	90.60	8.2510	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2358	0.29	89.08	8.2298	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2387	0.30	87.62	8.2460	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2434	0.30	86.18	8.2494	0.30	271.29
22	8.2523	0.30	170.42	8.2556	0.30	189.39	68	8.2541	0.30	84.77	8.2474	N/A	272.75
24	8.2629	0.28	151.74	8.2675	0.29	208.60	70	8.2562	N/A	83.37	8.2693	N/A	274.18
26	8.2463	0.29	142.26	8.2361	0.29	217.92	72	8.2691	N/A	81.97	8.2658	N/A	275.62
28	8.2636	0.31	135.26	8.2631	0.29	224.68	74	8.2691	N/A	80.64	N/A	N/A	N/A
30	8.2363	0.29	130.14	8.2163	0.29	229.96	76	8.2826	N/A	79.11	N/A	N/A	N/A
32	8.2424	0.28	125.73	8.2247	0.31	234.66	78	8.2923	N/A	77.68	N/A	N/A	N/A
34	8.2417	0.31	121.80	8.2277	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2528	0.31	118.52	8.2027	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2484	0.31	115.51	8.2112	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2429	0.28	112.68	8.2411	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2509	0.30	110.23	8.2371	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2529	0.30	107.94	8.2347	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

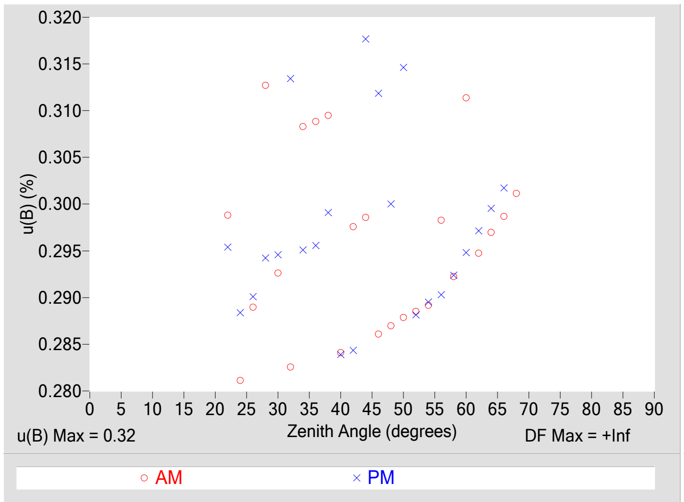


Figure 4. Residuals from Spline Interpolation

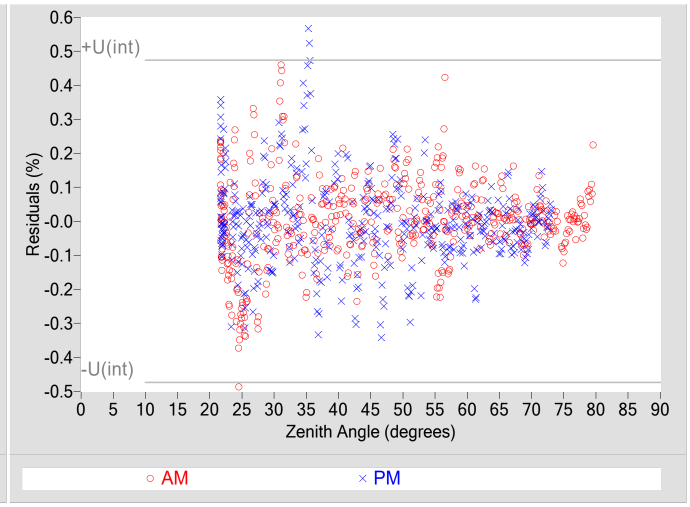


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	6254
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

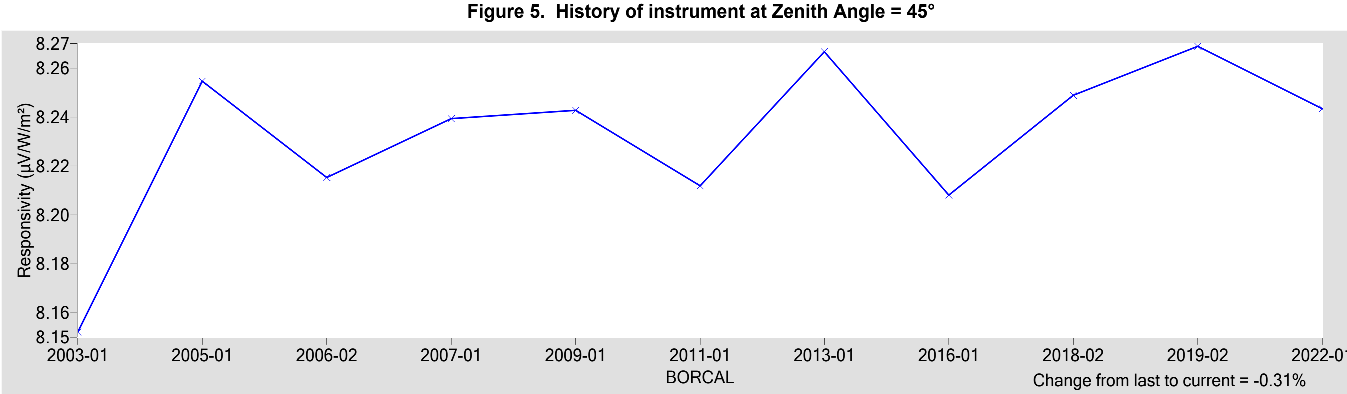
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.2434	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.34 / -0.49
Expanded Uncertainty, U (%)	+0.96 / -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:**	31627F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

31627F3 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

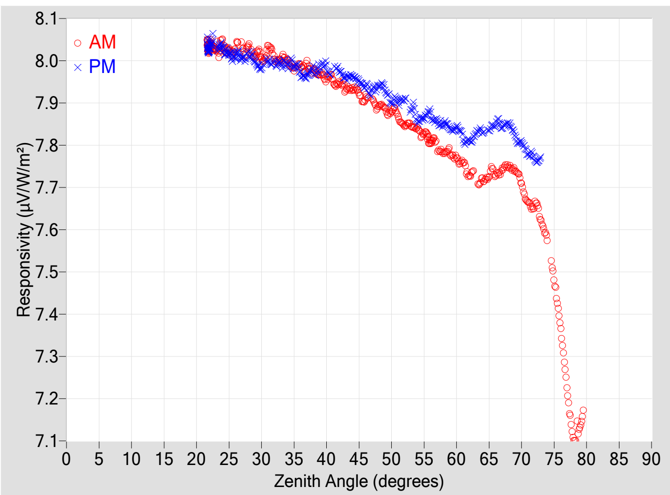


Figure 2. Responsivity vs Local Standard Time

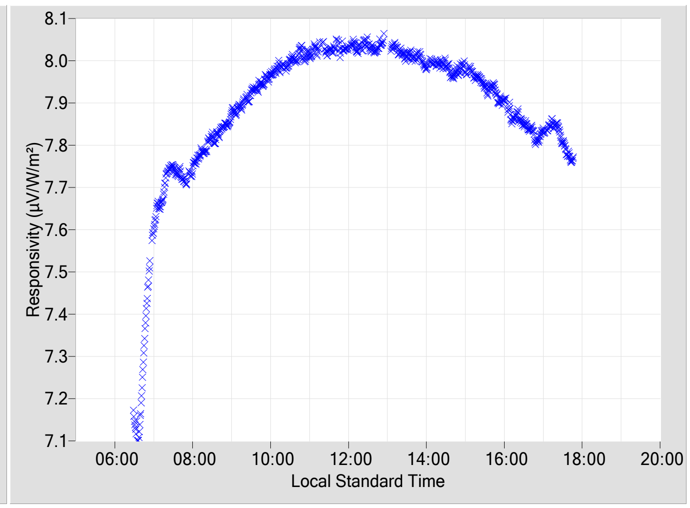


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	7.9093	0.44	105.82	7.9400	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8911	0.41	103.74	7.9404	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8798	0.44	101.84	7.9001	0.44	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8467	0.43	100.03	7.9082	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8384	0.44	98.27	7.8567	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8096	0.44	94.94	7.8728	0.45	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.7824	0.46	92.09	7.8505	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.7689	0.47	90.58	7.8436	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.7270	0.53	89.11	7.8111	0.53	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.7168	0.55	87.65	7.8311	0.56	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.7301	0.54	86.21	7.8504	0.59	271.32
22	8.0332	0.37	170.40	8.0297	0.36	189.51	68	7.7495	0.58	84.80	7.8498	N/A	272.77
24	8.0392	0.38	151.10	8.0315	0.36	208.57	70	7.7068	N/A	83.35	7.8050	N/A	274.21
26	8.0308	0.37	142.46	8.0130	0.40	217.79	72	7.6574	N/A	81.96	7.7666	N/A	275.65
28	8.0348	0.36	135.81	8.0132	0.35	224.59	74	7.5807	N/A	80.61	N/A	N/A	N/A
30	8.0068	0.35	130.21	7.9833	0.37	229.82	76	7.3711	N/A	79.14	N/A	N/A	N/A
32	8.0030	0.42	125.57	7.9957	0.41	234.52	78	7.1081	N/A	77.71	N/A	N/A	N/A
34	7.9993	0.41	121.86	7.9888	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9886	0.38	118.49	7.9698	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9760	0.39	115.39	7.9745	0.37	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9559	0.38	112.73	7.9853	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9460	0.40	110.28	7.9767	0.40	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9321	0.41	107.99	7.9632	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

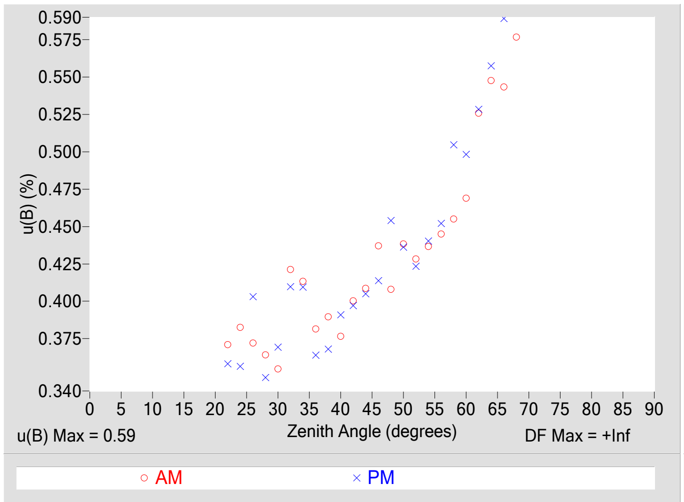


Figure 4. Residuals from Spline Interpolation

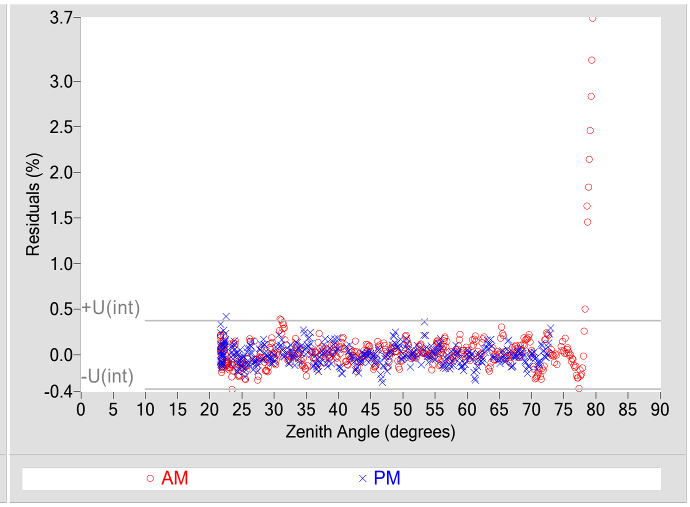


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	92361
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

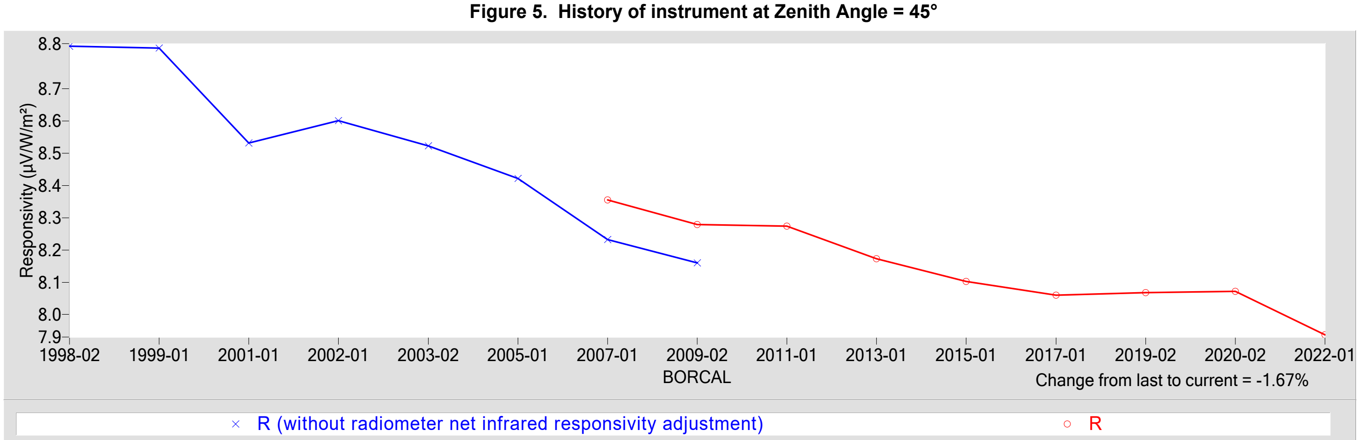
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.9367	0.61800

† Rnet determination date: 06/29/2005

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+0.88 / -2.1
Expanded Uncertainty, U (%)	+1.9 / -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:**	31632F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

31632F3 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

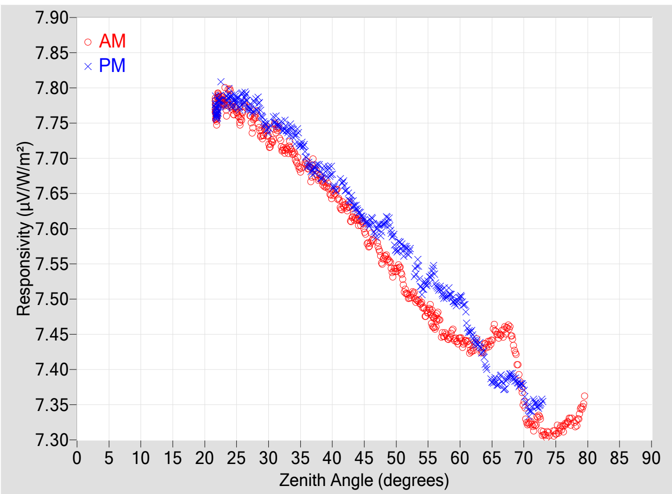


Figure 2. Responsivity vs Local Standard Time

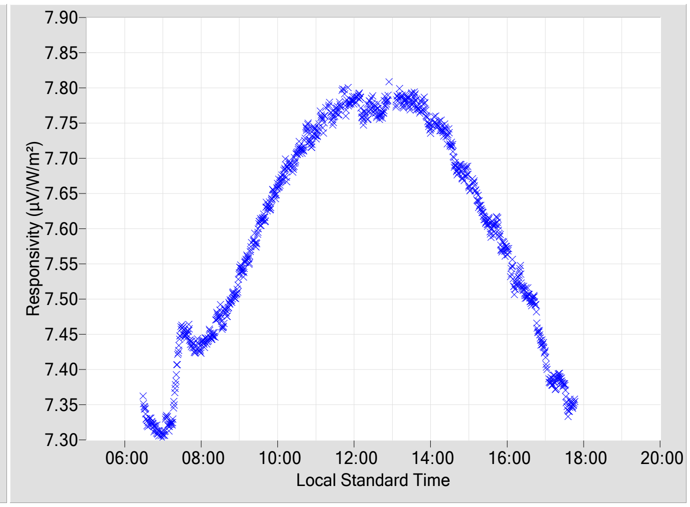


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.5810	0.45	105.82	7.6104	0.44	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.5565	0.43	103.74	7.6063	0.48	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.5419	0.46	101.84	7.5705	0.46	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.5036	0.45	100.03	7.5666	0.45	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.4916	0.46	98.27	7.5140	0.47	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.4673	0.47	94.94	7.5337	0.49	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.4459	0.48	92.09	7.5064	0.54	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.4422	0.50	90.58	7.5033	0.54	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.4273	0.55	89.11	7.4475	0.58	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.4339	0.58	87.65	7.4070	0.61	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.4485	0.58	86.21	7.3824	0.65	271.32
22	7.7711	0.38	170.40	7.7679	0.37	189.51	68	7.4514	0.62	84.80	7.3922	N/A	272.77
24	7.7855	0.39	151.10	7.7863	0.37	208.57	70	7.3493	N/A	83.35	7.3683	N/A	274.21
26	7.7663	0.38	142.46	7.7841	0.41	217.79	72	7.3266	N/A	81.96	7.3489	N/A	275.65
28	7.7604	0.38	135.81	7.7751	0.36	224.59	74	7.3084	N/A	80.61	N/A	N/A	N/A
30	7.7258	0.37	130.21	7.7414	0.38	229.82	76	7.3163	N/A	79.14	N/A	N/A	N/A
32	7.7161	0.43	125.57	7.7457	0.42	234.52	78	7.3233	N/A	77.66	N/A	N/A	N/A
34	7.7050	0.42	121.86	7.7316	0.42	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6906	0.39	118.49	7.6974	0.38	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6715	0.40	115.39	7.6786	0.39	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6475	0.39	112.73	7.6722	0.41	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6318	0.42	110.28	7.6583	0.42	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6113	0.43	107.99	7.6267	0.43	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

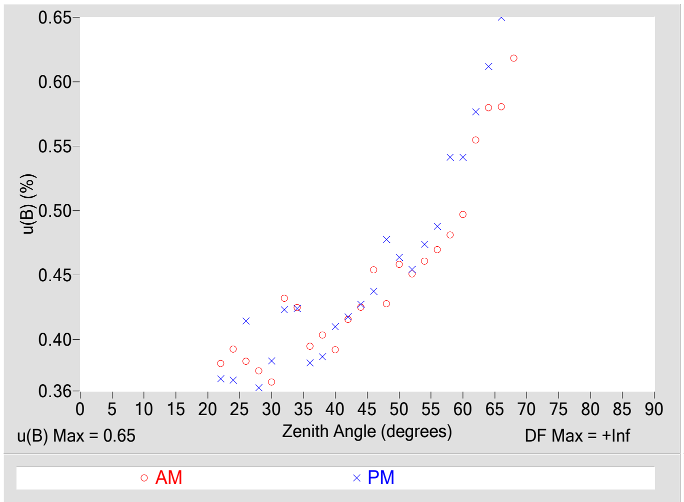


Figure 4. Residuals from Spline Interpolation

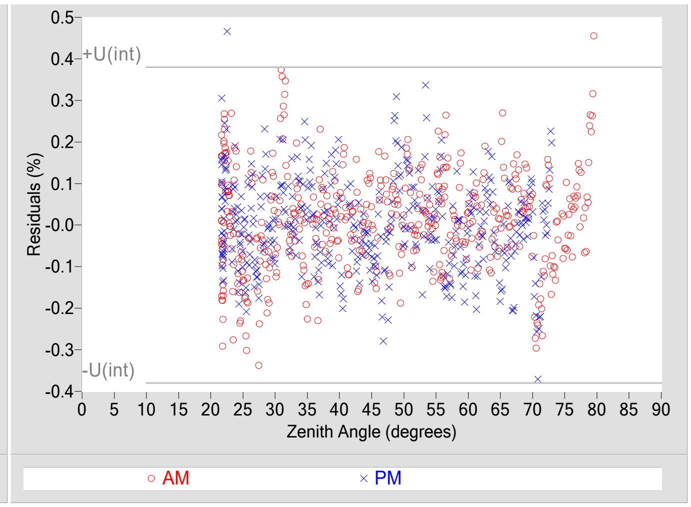


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.65
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.68
Effective degrees of freedom, DF(c)	127318
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

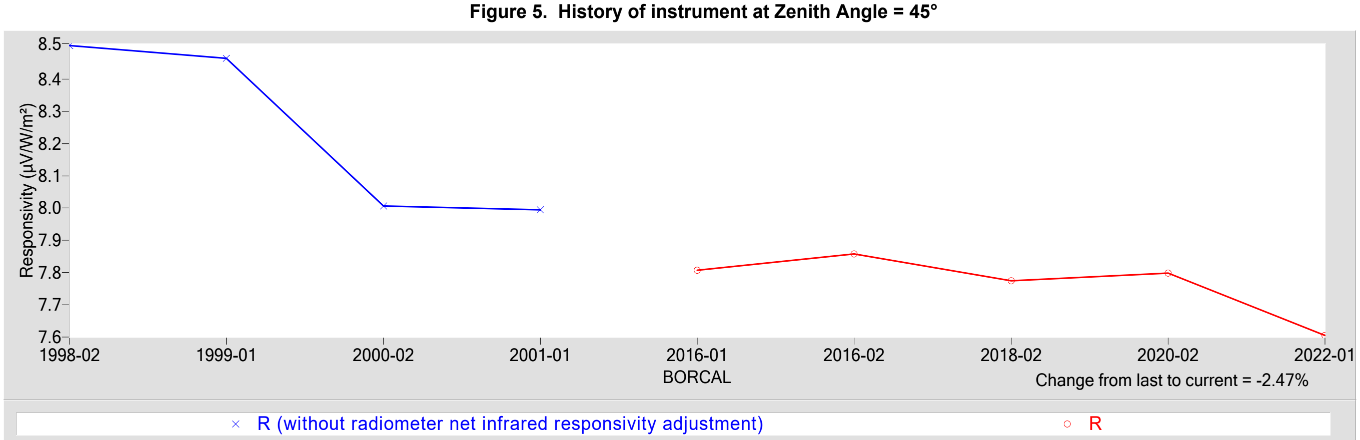
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6052	0.60000

† Rnet determination date: 06/24/2013

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.1
Offset Uncertainty, U(off) (%)	+1.8 / -2.1
Expanded Uncertainty, U (%)	+2.9 / -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:**	31635F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

31635F3 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

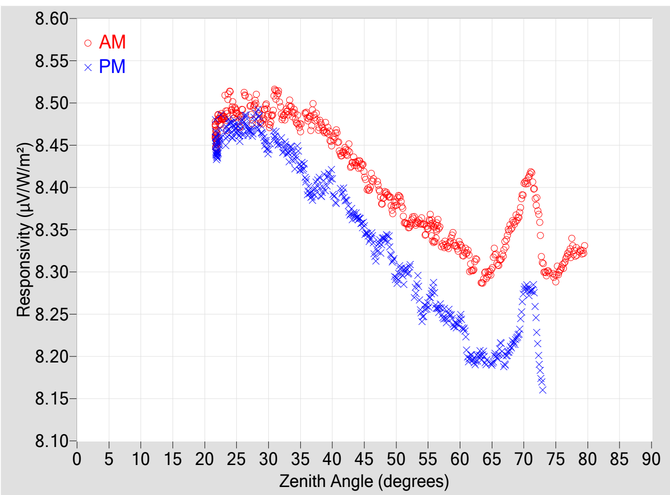


Figure 2. Responsivity vs Local Standard Time

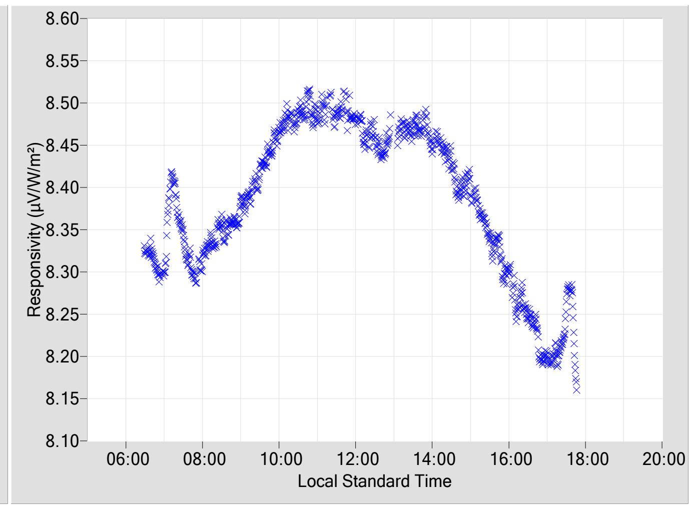


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4038	0.44	105.82	8.3407	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3876	0.41	103.74	8.3395	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3822	0.44	101.84	8.2913	0.44	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3548	0.43	100.03	8.3029	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3582	0.44	98.27	8.2485	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3464	0.44	94.94	8.2724	0.45	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3302	0.45	92.09	8.2477	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3306	0.47	90.58	8.2456	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3017	0.52	89.11	8.1965	0.53	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2954	0.55	87.65	8.1947	0.56	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3101	0.54	86.21	8.2046	0.59	271.32
22	8.4660	0.37	170.40	8.4452	0.36	189.51	68	8.3534	0.57	84.80	8.2126	N/A	272.77
24	8.5027	0.38	151.10	8.4724	0.36	208.57	70	8.3997	N/A	83.35	8.2762	N/A	274.21
26	8.4953	0.37	142.46	8.4725	0.40	217.79	72	8.3814	N/A	81.96	8.2300	N/A	275.65
28	8.5016	0.36	135.81	8.4770	0.35	224.59	74	8.3000	N/A	80.61	N/A	N/A	N/A
30	8.4804	0.35	130.21	8.4453	0.37	229.82	76	8.3054	N/A	79.14	N/A	N/A	N/A
32	8.4863	0.42	125.57	8.4502	0.41	234.52	78	8.3234	N/A	77.71	N/A	N/A	N/A
34	8.4866	0.41	121.86	8.4334	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4846	0.38	118.49	8.4026	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4737	0.39	115.39	8.3978	0.37	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4551	0.38	112.73	8.4047	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4429	0.40	110.28	8.3882	0.40	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4281	0.41	107.99	8.3649	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

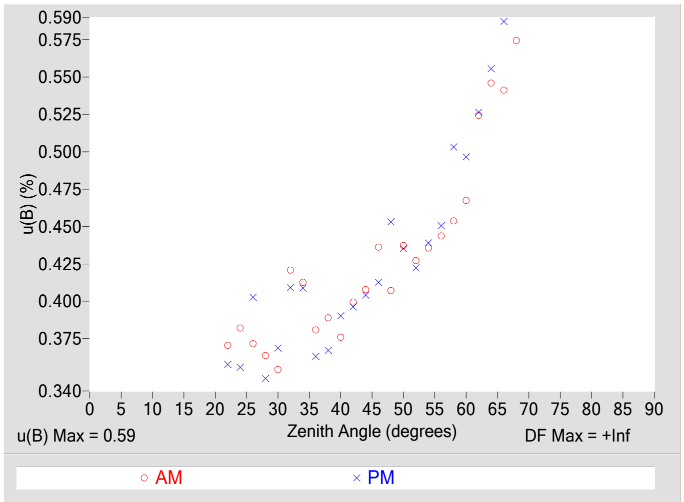


Figure 4. Residuals from Spline Interpolation

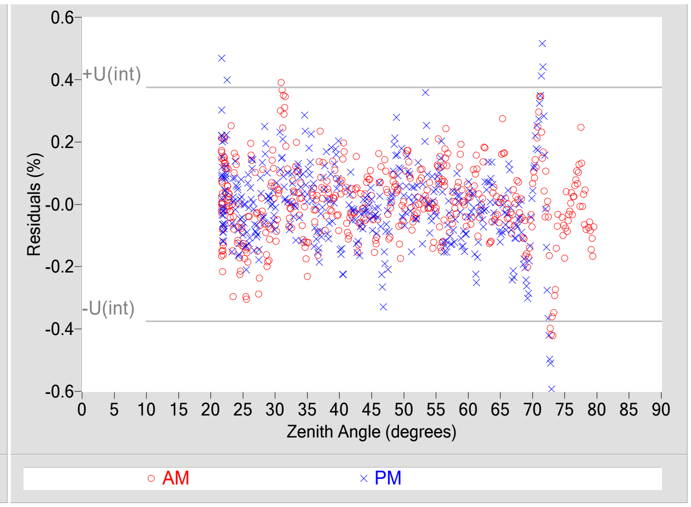


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	91939
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

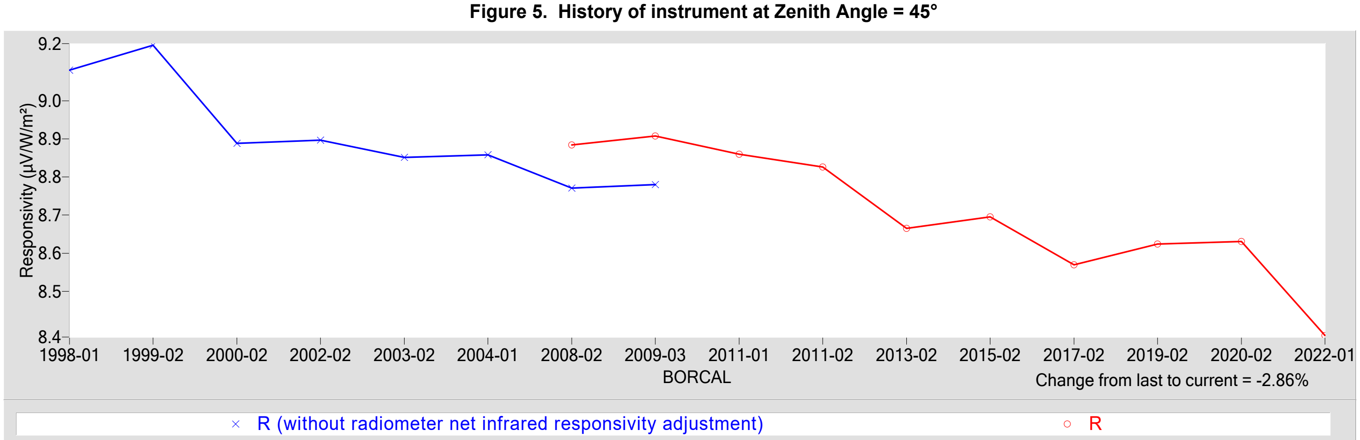
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3841	0.61365

† Rnet determination date: 06/06/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.99
Offset Uncertainty, U(off) (%)	+1.2 / -1.7
Expanded Uncertainty, U (%)	+2.2 / -2.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31746E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

31746E6 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

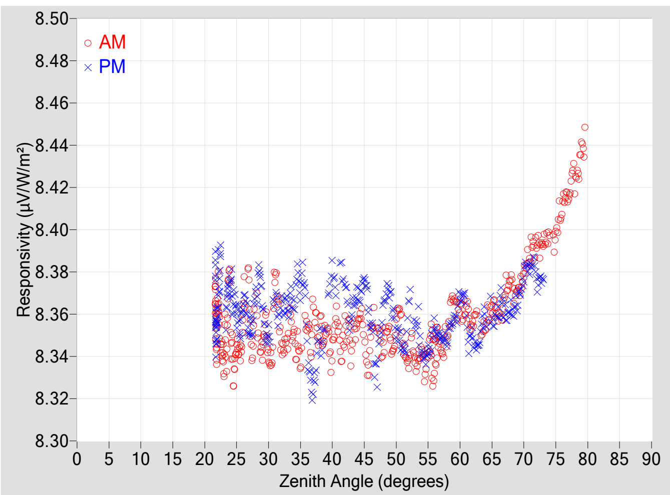


Figure 2. Responsivity vs Local Standard Time

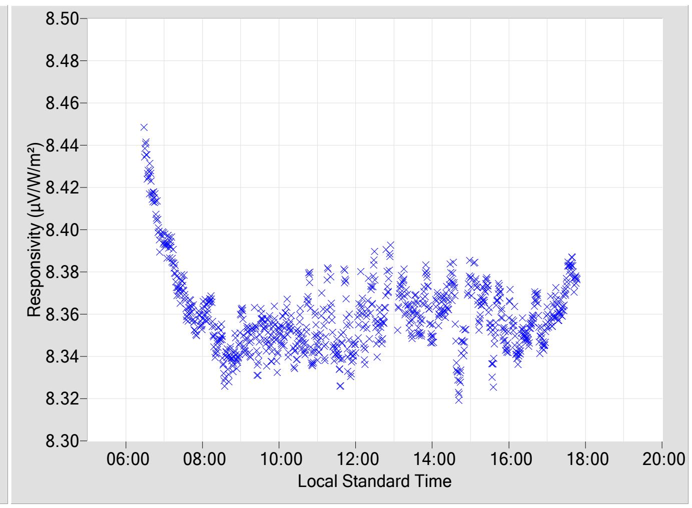


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3463	0.29	105.79	8.3564	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3420	0.29	103.83	8.3639	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3554	0.29	101.81	8.3521	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3379	0.29	100.05	8.3655	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3415	0.29	98.24	8.3426	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3389	0.30	95.29	8.3543	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3500	0.29	92.06	8.3481	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3631	0.31	90.60	8.3679	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3563	0.29	89.08	8.3485	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3564	0.30	87.62	8.3584	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3599	0.30	86.18	8.3616	0.30	271.29
22	8.3570	0.30	170.42	8.3591	0.30	189.39	68	8.3758	0.30	84.77	8.3619	N/A	272.75
24	8.3636	0.28	151.74	8.3740	0.29	208.60	70	8.3793	N/A	83.37	8.3786	N/A	274.18
26	8.3577	0.29	142.26	8.3651	0.29	217.92	72	8.3928	N/A	81.97	8.3768	N/A	275.62
28	8.3601	0.31	135.26	8.3688	0.29	224.68	74	8.3965	N/A	80.64	N/A	N/A	N/A
30	8.3407	0.29	130.14	8.3494	0.29	229.96	76	8.4108	N/A	79.11	N/A	N/A	N/A
32	8.3469	0.28	125.73	8.3648	0.31	234.66	78	8.4245	N/A	77.68	N/A	N/A	N/A
34	8.3477	0.31	121.80	8.3657	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3548	0.31	118.52	8.3484	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3524	0.31	115.51	8.3470	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3430	0.28	112.68	8.3795	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3501	0.30	110.23	8.3731	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3563	0.30	107.94	8.3697	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

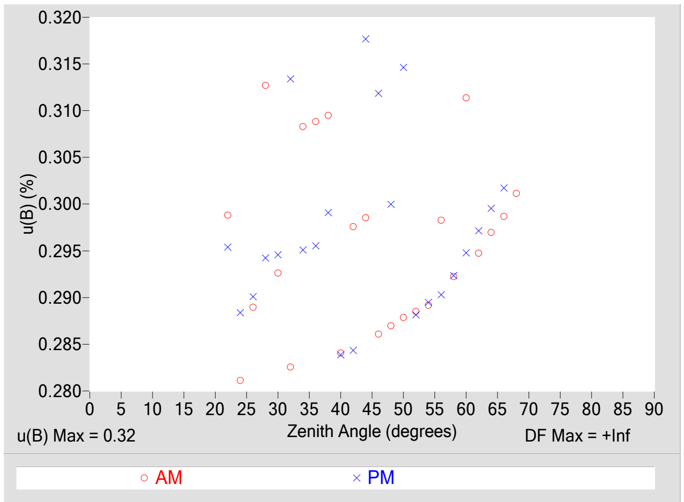


Figure 4. Residuals from Spline Interpolation

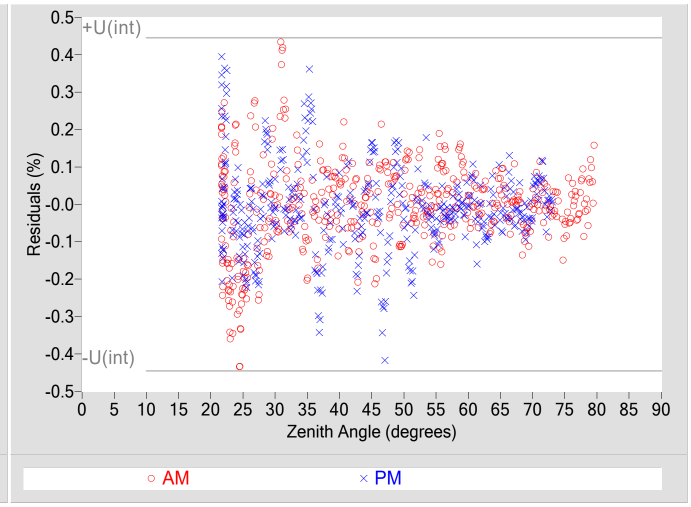


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	7368
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.76
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

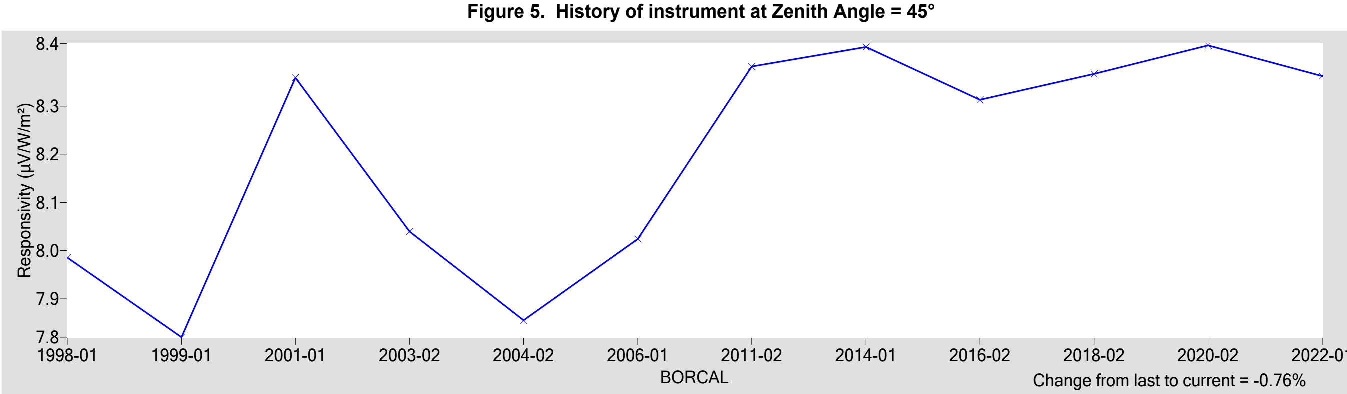
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3620	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.21 / -0.29
Expanded Uncertainty, U (%)	+0.83 / -0.91
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	31759E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

31759E6 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

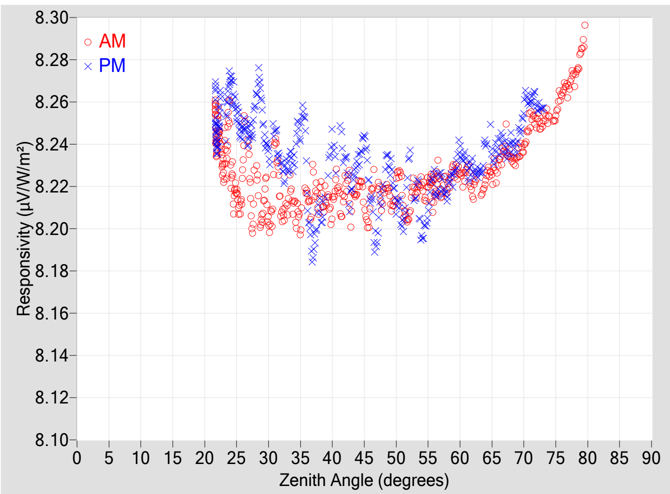


Figure 2. Responsivity vs Local Standard Time

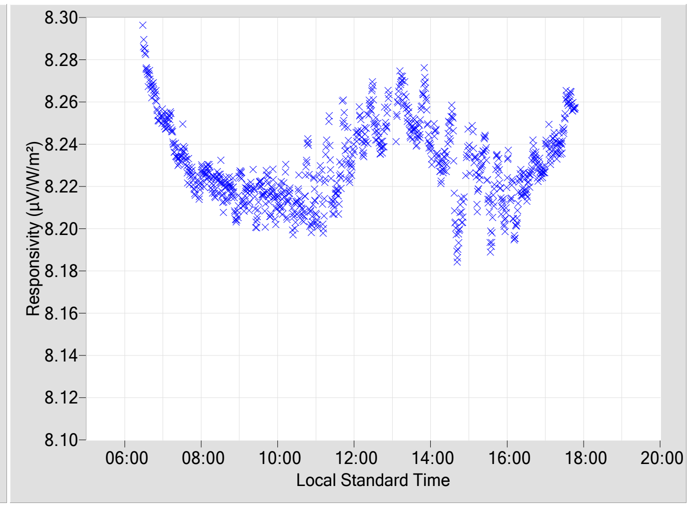


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2126	0.29	105.79	8.2157	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.2140	0.29	103.83	8.2226	0.31	256.38
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.2208	0.29	101.81	8.2130	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2056	0.29	100.05	8.2319	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2210	0.29	98.24	8.1974	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2176	0.30	95.29	8.2217	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2200	0.29	92.06	8.2168	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2266	0.31	90.60	8.2368	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2171	0.29	89.08	8.2280	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2231	0.30	87.62	8.2404	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2304	0.30	86.18	8.2391	0.30	271.29
22	8.2445	0.30	170.42	8.2437	0.30	189.39	68	8.2341	0.30	84.77	8.2407	N/A	272.75
24	8.2419	0.28	151.74	8.2694	0.29	208.60	70	8.2381	N/A	83.37	8.2571	N/A	274.18
26	8.2317	0.29	142.26	8.2471	0.29	217.92	72	8.2512	N/A	81.97	8.2587	N/A	275.62
28	8.2265	0.31	135.26	8.2614	0.29	224.68	74	8.2521	N/A	80.64	N/A	N/A	N/A
30	8.2037	0.29	130.14	8.2356	0.29	229.96	76	8.2641	N/A	79.11	N/A	N/A	N/A
32	8.2095	0.28	125.73	8.2290	0.31	234.66	78	8.2720	N/A	77.68	N/A	N/A	N/A
34	8.2096	0.31	121.80	8.2327	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2167	0.31	118.52	8.2213	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2146	0.31	115.51	8.2091	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2101	0.28	112.68	8.2406	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2184	0.30	110.23	8.2338	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2190	0.30	107.94	8.2318	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

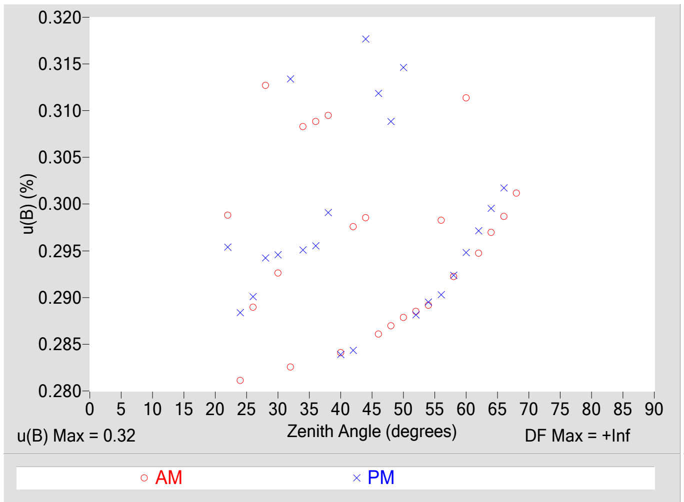


Figure 4. Residuals from Spline Interpolation

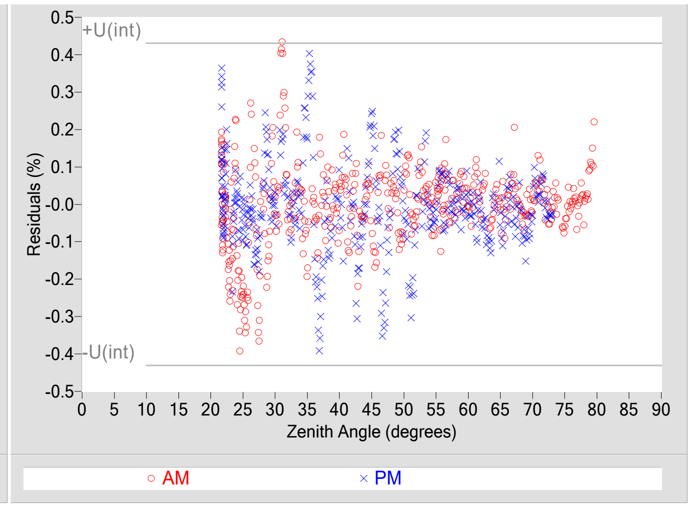


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	8044
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

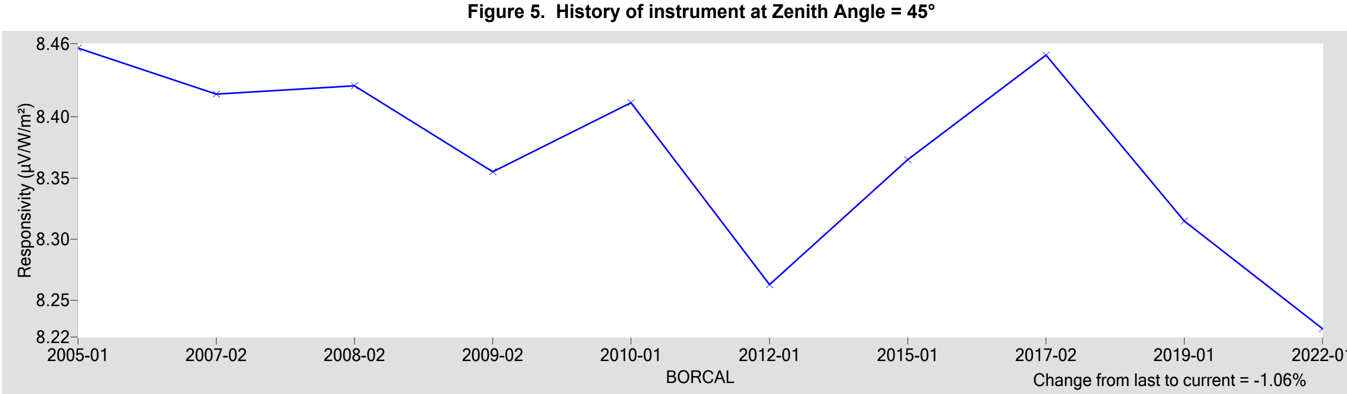
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.2269	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.17 / -0.36
Expanded Uncertainty, U (%)	+0.79 / -0.98
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the 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: 5/7/2022
Due Date: 5/7/2023
Customer: TWP
Environmental Conditions: see page 4
Test Dates: 4/30, 5/7

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

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

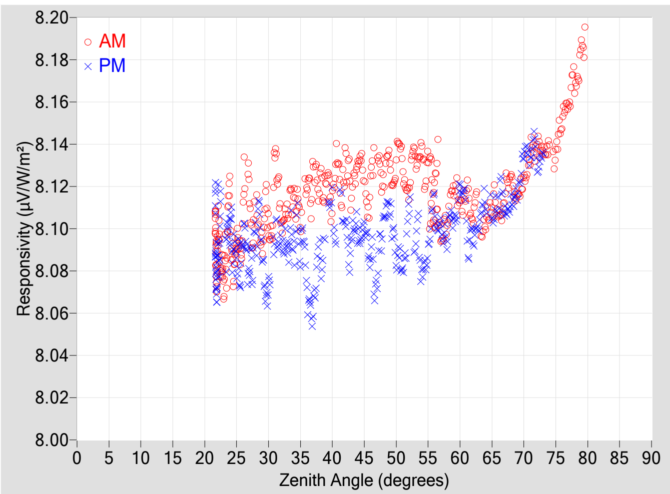


Figure 2. Responsivity vs Local Standard Time

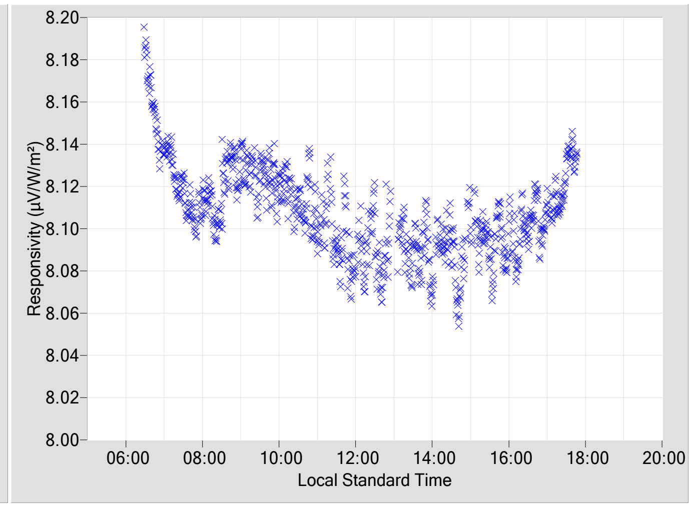


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1212	0.29	105.79	8.0883	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1207	0.29	103.83	8.1034	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1322	0.29	101.81	8.0870	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1184	0.29	100.05	8.1093	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1359	0.29	98.24	8.0797	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1130	0.30	95.29	8.1104	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1030	0.29	92.06	8.0965	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1132	0.31	90.60	8.1185	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1056	0.29	89.08	8.0963	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1042	0.30	87.62	8.1119	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1075	0.30	86.18	8.1125	0.30	271.29
22	8.0888	0.30	170.42	8.0817	0.30	189.39	68	8.1237	0.30	84.77	8.1119	N/A	272.75
24	8.1058	0.28	151.74	8.1010	0.29	208.60	70	8.1227	N/A	83.37	8.1354	N/A	274.18
26	8.1064	0.29	142.26	8.0963	0.29	217.92	72	8.1381	N/A	81.97	8.1337	N/A	275.62
28	8.1091	0.31	135.26	8.0956	0.29	224.68	74	8.1388	N/A	80.64	N/A	N/A	N/A
30	8.1006	0.29	130.14	8.0717	0.29	229.96	76	8.1512	N/A	79.11	N/A	N/A	N/A
32	8.1048	0.28	125.73	8.0956	0.31	234.66	78	8.1693	N/A	77.68	N/A	N/A	N/A
34	8.1127	0.31	121.80	8.0911	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1201	0.31	118.52	8.0711	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1207	0.31	115.51	8.0871	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1138	0.28	112.68	8.1075	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1276	0.30	110.23	8.1028	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1305	0.30	107.94	8.0988	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

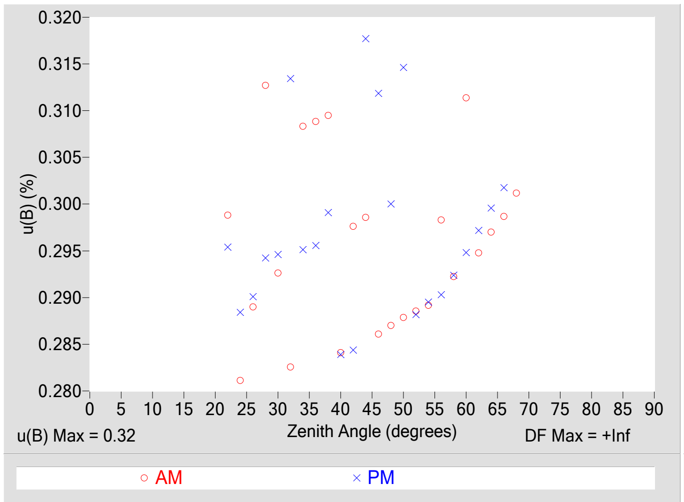


Figure 4. Residuals from Spline Interpolation

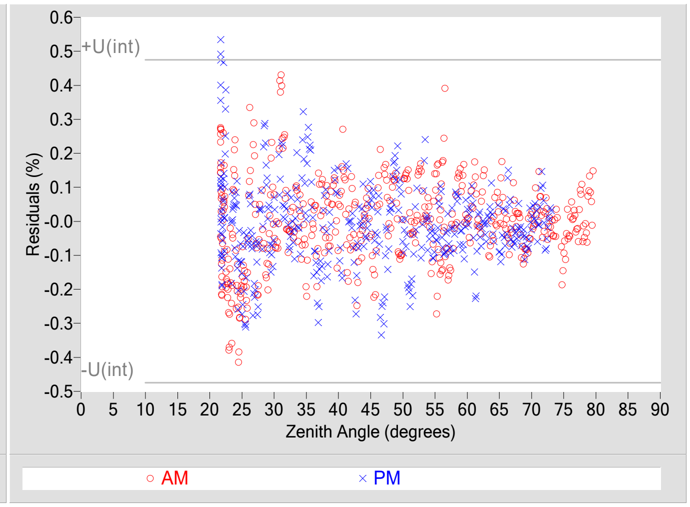


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	6223
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

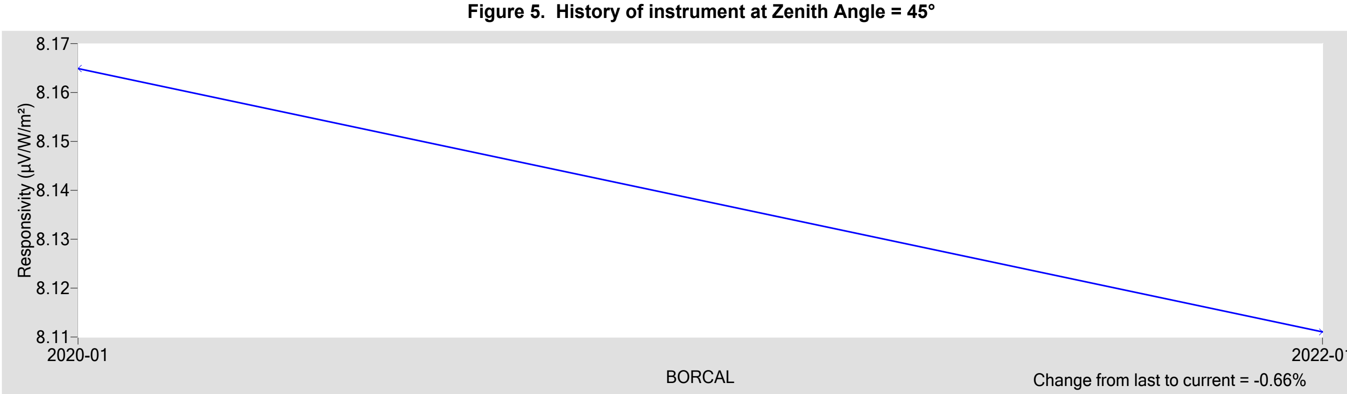
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1110	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.31 / -0.49
Expanded Uncertainty, U (%)	+0.93 / -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:**	32015F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

32015F3 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

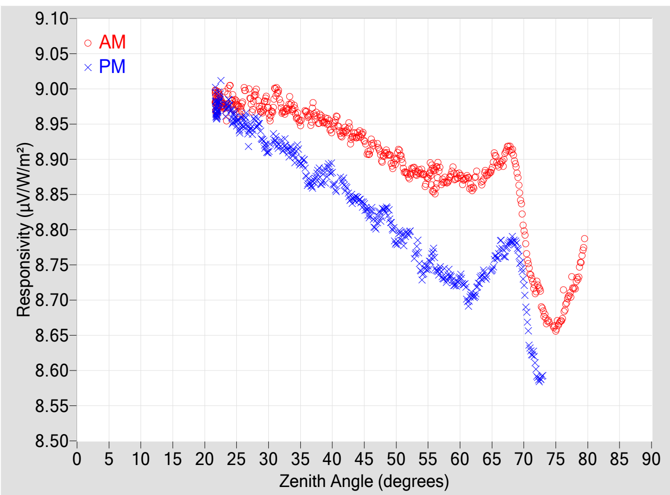


Figure 2. Responsivity vs Local Standard Time

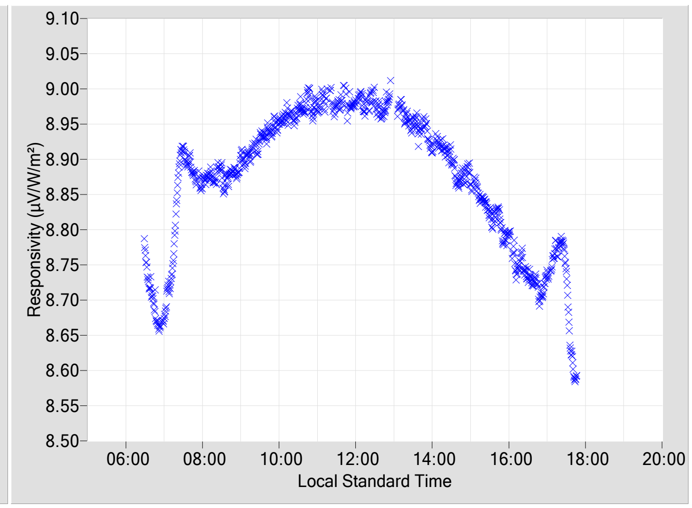


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.9156	0.43	105.82	8.8243	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.9037	0.40	103.74	8.8286	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.9007	0.43	101.84	8.7814	0.43	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8762	0.42	100.03	8.7955	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8808	0.43	98.27	8.7373	0.43	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8724	0.44	94.94	8.7581	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8678	0.45	92.09	8.7333	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8762	0.46	90.58	8.7329	0.49	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8585	0.52	89.11	8.7068	0.52	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8783	0.54	87.65	8.7340	0.55	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8934	0.53	86.21	8.7685	0.58	271.32
22	8.9806	0.37	170.40	8.9708	0.36	189.51	68	8.9132	0.57	84.80	8.7847	N/A	272.77
24	8.9929	0.38	151.10	8.9714	0.35	208.57	70	8.7998	N/A	83.35	8.7176	N/A	274.21
26	8.9838	0.37	142.46	8.9526	0.40	217.79	72	8.7172	N/A	81.96	8.5961	N/A	275.65
28	8.9936	0.36	135.81	8.9524	0.35	224.59	74	8.6701	N/A	80.61	N/A	N/A	N/A
30	8.9678	0.35	130.21	8.9125	0.37	229.82	76	8.6823	N/A	79.14	N/A	N/A	N/A
32	8.9715	0.42	125.57	8.9194	0.41	234.52	78	8.7190	N/A	77.71	N/A	N/A	N/A
34	8.9705	0.41	121.86	8.9041	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9645	0.38	118.49	8.8735	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.9574	0.39	115.39	8.8727	0.36	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.9444	0.37	112.73	8.8768	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.9406	0.40	110.28	8.8625	0.39	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.9331	0.40	107.99	8.8445	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

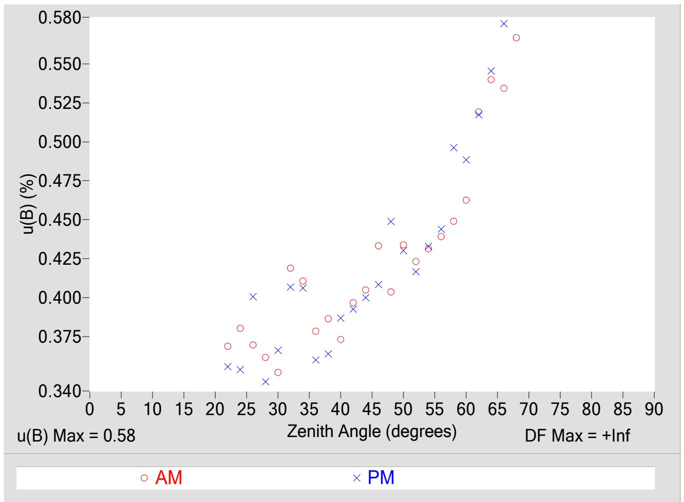


Figure 4. Residuals from Spline Interpolation

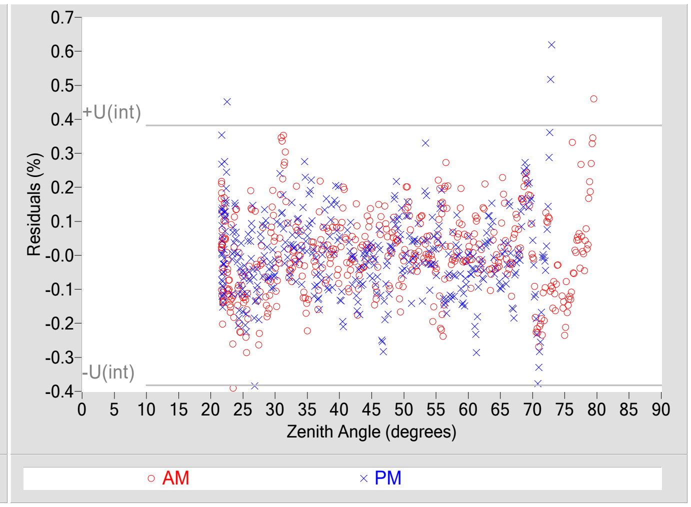


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	79872
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

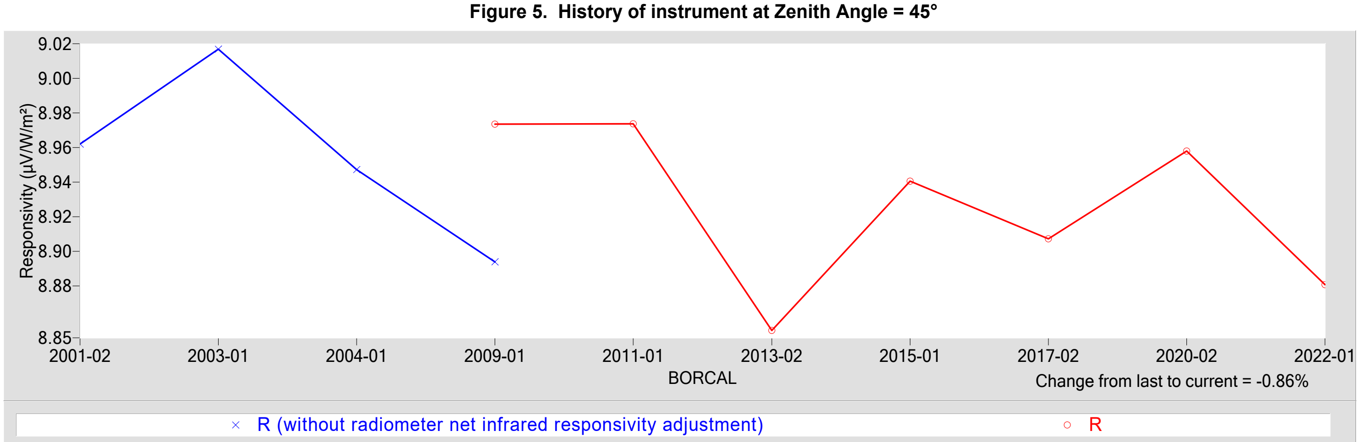
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8807	0.42210

† Rnet determination date: 03/25/2009

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.97
Offset Uncertainty, U(off) (%)	+1.0 / -1.7
Expanded Uncertainty, U (%)	+2.0 / -2.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	32017F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

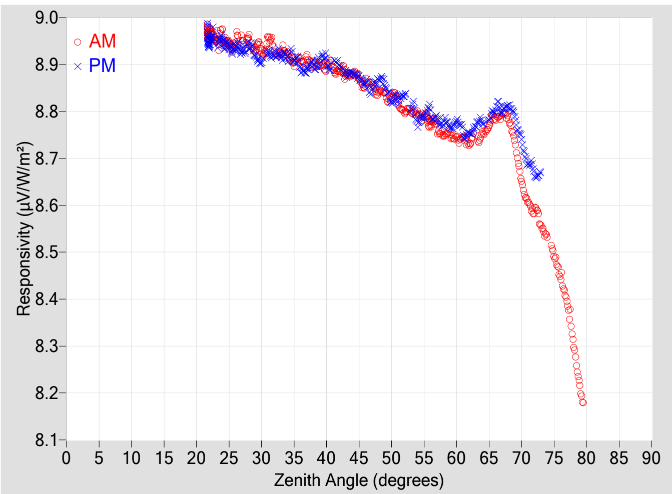


Figure 2. Responsivity vs Local Standard Time

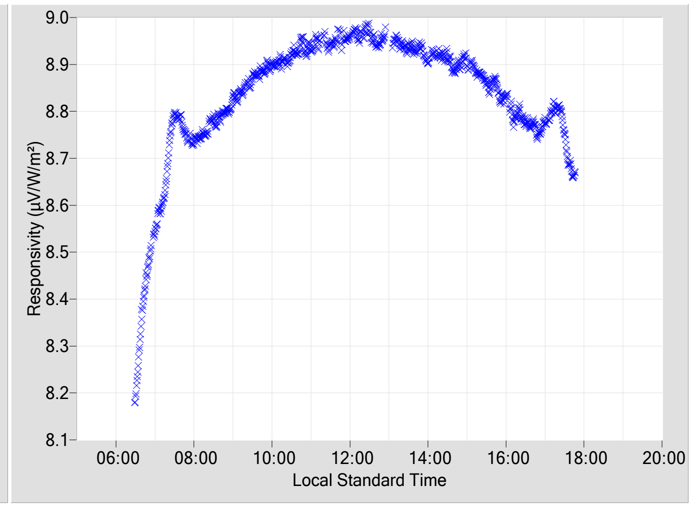


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	8.8573	0.44	105.82	8.8609	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8404	0.41	103.74	8.8674	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8303	0.44	101.84	8.8203	0.43	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7987	0.43	100.03	8.8344	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7954	0.43	98.27	8.7766	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7753	0.44	94.94	8.7997	0.45	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7483	0.45	92.09	8.7762	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7438	0.47	90.58	8.7793	0.49	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7302	0.52	89.11	8.7538	0.52	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7508	0.54	87.65	8.7754	0.55	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7843	0.54	86.21	8.8058	0.58	271.32
22	8.9644	0.37	170.40	8.9481	0.36	189.51	68	8.7814	0.57	84.80	8.8102	N/A	272.77
24	8.9628	0.38	151.10	8.9512	0.36	208.57	70	8.6510	N/A	83.35	8.7375	N/A	274.21
26	8.9500	0.37	142.46	8.9372	0.40	217.79	72	8.5885	N/A	81.96	8.6661	N/A	275.65
28	8.9571	0.36	135.81	8.9391	0.35	224.59	74	8.5349	N/A	80.61	N/A	N/A	N/A
30	8.9279	0.35	130.21	8.9050	0.37	229.82	76	8.4498	N/A	79.14	N/A	N/A	N/A
32	8.9273	0.42	125.57	8.9211	0.41	234.52	78	8.3072	N/A	77.71	N/A	N/A	N/A
34	8.9210	0.41	121.86	8.9140	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.9101	0.38	118.49	8.8919	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.9008	0.39	115.39	8.8966	0.37	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8919	0.38	112.73	8.9086	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8862	0.40	110.28	8.8982	0.40	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8774	0.41	107.99	8.8811	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

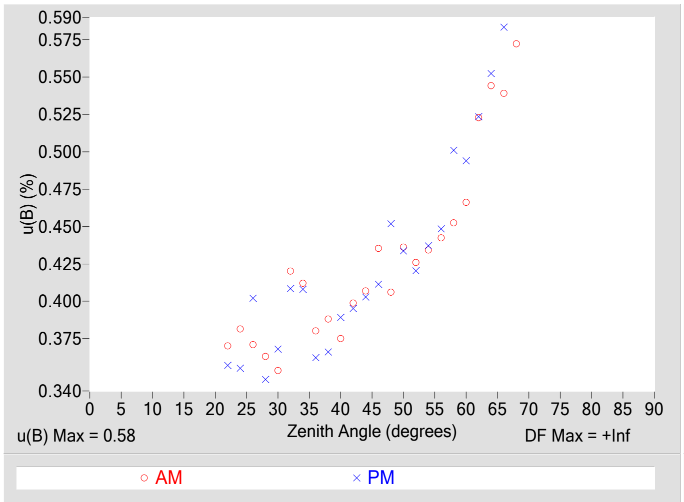


Figure 4. Residuals from Spline Interpolation

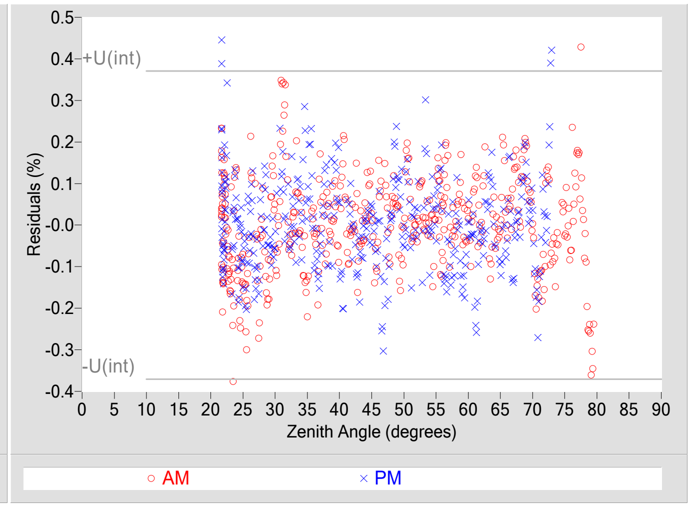


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	93471
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

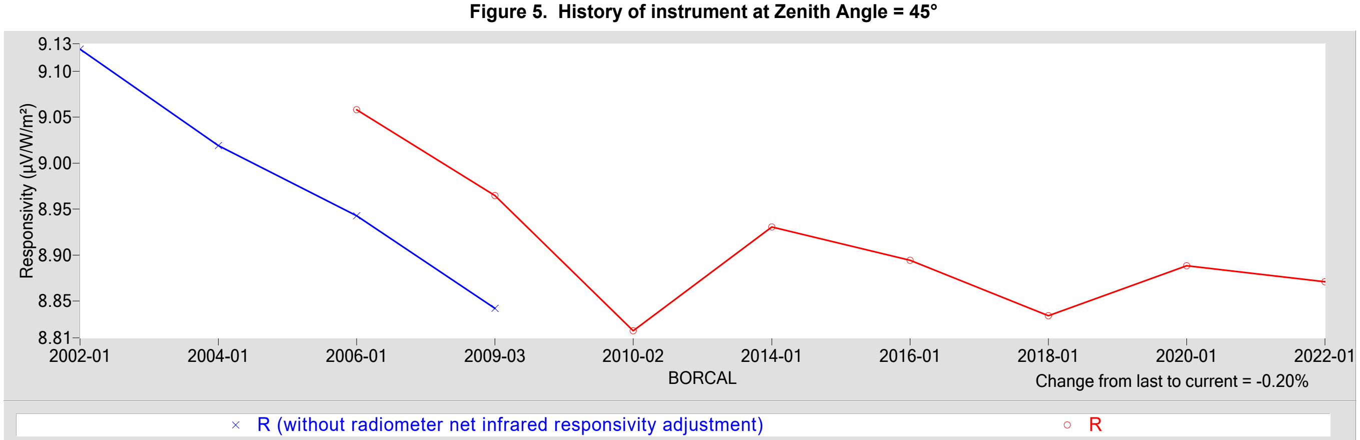
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8710	0.59100

† Rnet determination date: 04/03/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+0.64 / -1.4
Expanded Uncertainty, U (%)	+1.6 / -2.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	32018F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

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

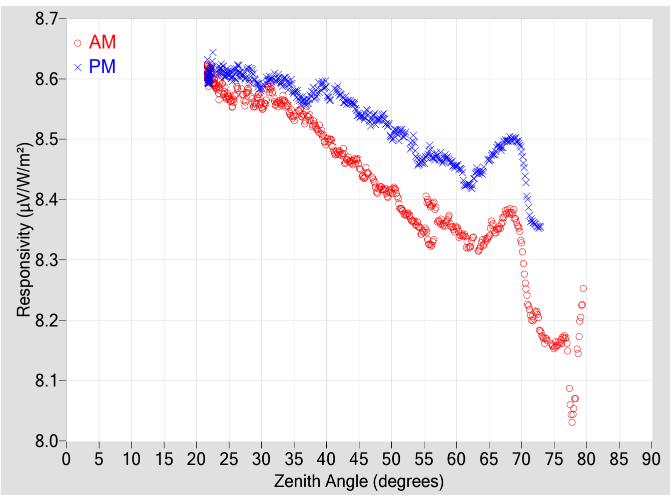


Figure 2. Responsivity vs Local Standard Time

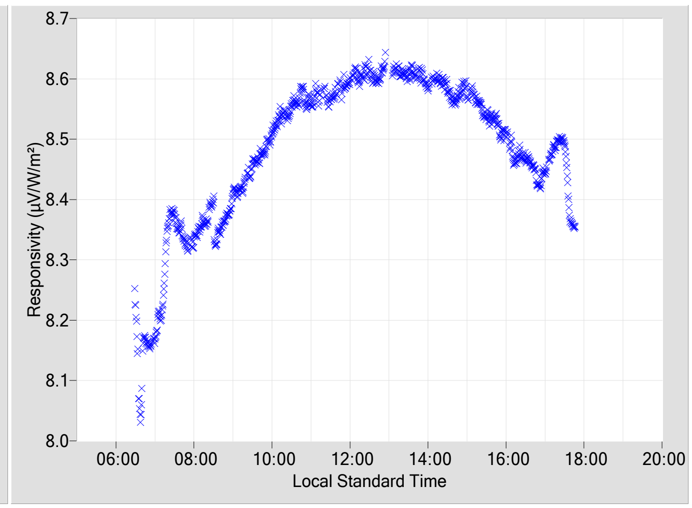


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4410	0.44	105.82	8.5415	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4171	0.41	103.74	8.5320	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4145	0.44	101.84	8.5029	0.43	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3766	0.43	100.03	8.5068	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3575	0.44	98.27	8.4630	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.3613	0.44	94.94	8.4792	0.45	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3580	0.45	92.09	8.4664	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3509	0.47	90.58	8.4562	0.50	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3209	0.52	89.11	8.4240	0.53	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3267	0.55	87.65	8.4468	0.55	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3470	0.54	86.21	8.4813	0.59	271.32
22	8.6051	0.37	170.40	8.6025	0.36	189.51	68	8.3799	0.57	84.80	8.4989	N/A	272.77
24	8.5831	0.38	151.10	8.6157	0.36	208.57	70	8.3230	N/A	83.35	8.4775	N/A	274.21
26	8.5741	0.37	142.46	8.6093	0.40	217.79	72	8.2071	N/A	81.96	8.3595	N/A	275.65
28	8.5824	0.36	135.81	8.6070	0.35	224.59	74	8.1674	N/A	80.61	N/A	N/A	N/A
30	8.5568	0.35	130.21	8.5848	0.37	229.82	76	8.1633	N/A	79.14	N/A	N/A	N/A
32	8.5611	0.42	125.57	8.6020	0.41	234.52	78	8.0496	N/A	77.71	N/A	N/A	N/A
34	8.5537	0.41	121.86	8.5911	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5435	0.38	118.49	8.5650	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5247	0.39	115.39	8.5744	0.37	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4957	0.38	112.73	8.5821	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4770	0.40	110.28	8.5773	0.40	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4623	0.41	107.99	8.5609	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

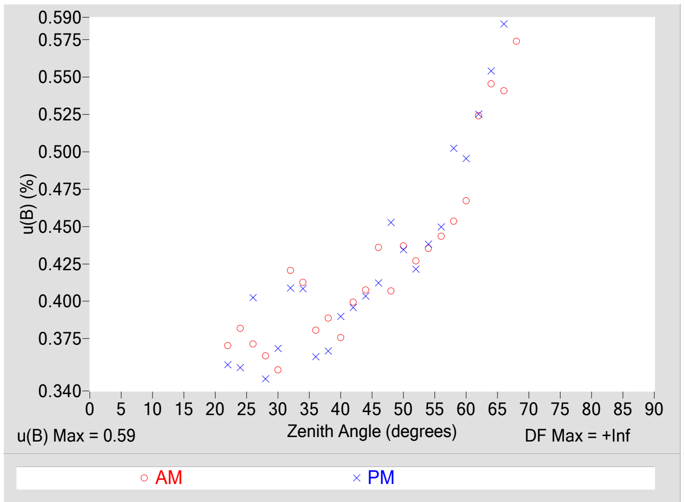


Figure 4. Residuals from Spline Interpolation

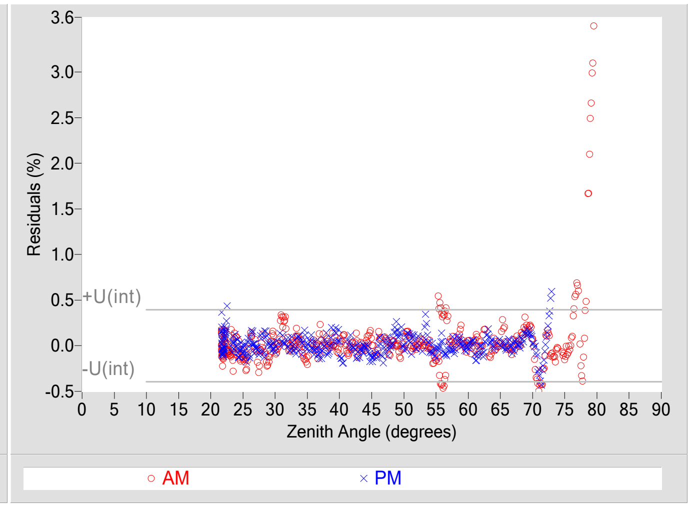


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.59
Type-A Interpolating Function, u(int) (%)	±0.20
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	75919
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

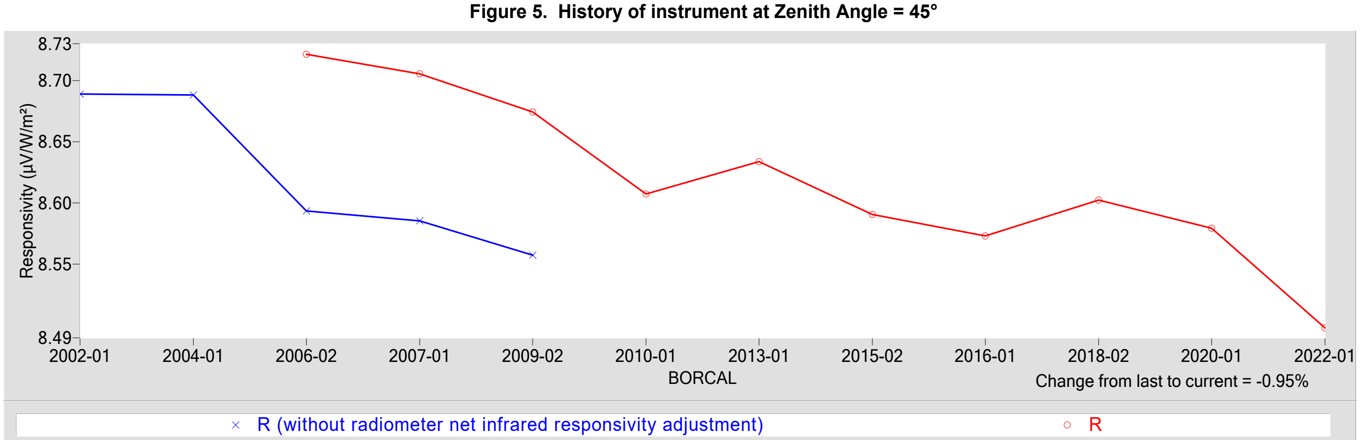
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4980	0.60555

† Rnet determination date: 06/13/2006

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+1.2 / -1.7
Expanded Uncertainty, U (%)	+2.2 / -2.7
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33237
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

33237 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

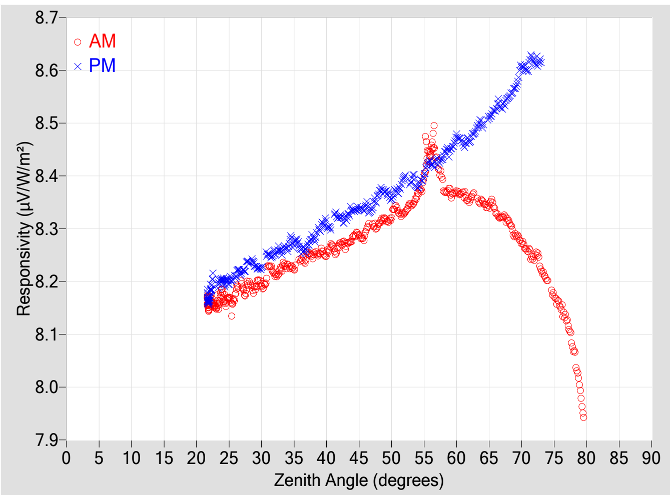


Figure 2. Responsivity vs Local Standard Time

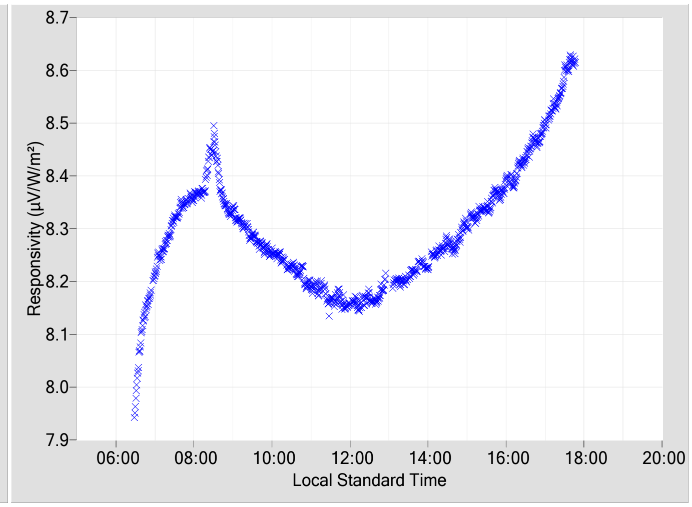


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2916	0.43	105.77	8.3430	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3071	0.42	103.75	8.3671	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3259	0.43	101.79	8.3564	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.3300	0.44	100.03	8.3978	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.3621	0.43	98.28	8.3795	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4453	0.44	95.27	8.4249	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.3801	0.47	92.09	8.4395	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.3692	0.46	90.58	8.4725	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3549	0.48	89.11	8.4681	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3523	0.50	87.65	8.4977	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3314	0.53	86.16	8.5272	0.57	271.27
22	8.1585	0.37	170.39	8.1701	0.36	189.57	68	8.3155	0.56	84.80	8.5487	N/A	272.73
24	8.1742	0.36	151.66	8.2023	0.36	208.55	70	8.2744	N/A	83.35	8.6060	N/A	274.21
26	8.1770	0.35	142.31	8.2134	0.35	218.06	72	8.2473	N/A	81.96	8.6138	N/A	275.65
28	8.1973	0.36	135.69	8.2368	0.36	224.47	74	8.2031	N/A	80.62	N/A	N/A	N/A
30	8.1922	0.36	130.10	8.2253	0.41	229.79	76	8.1542	N/A	79.14	N/A	N/A	N/A
32	8.2142	0.35	125.69	8.2539	0.37	234.35	78	8.0725	N/A	77.71	N/A	N/A	N/A
34	8.2294	0.39	121.94	8.2643	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2414	0.38	118.45	8.2607	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.2491	0.41	115.57	8.2817	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.2529	0.39	112.74	8.3082	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.2691	0.39	110.21	8.3223	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.2817	0.38	107.92	8.3341	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

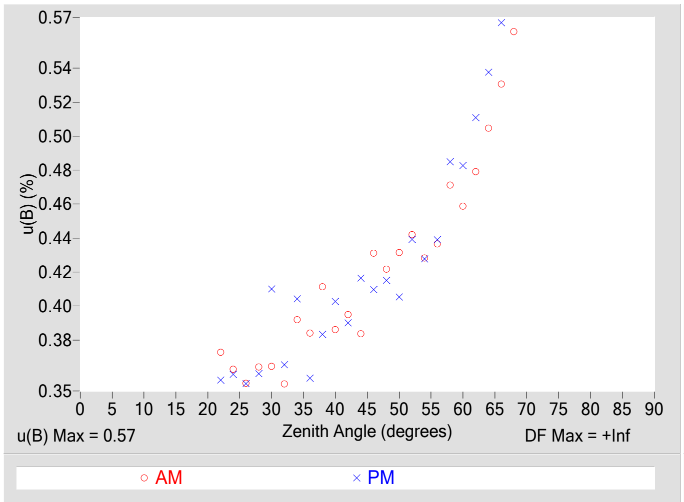


Figure 4. Residuals from Spline Interpolation

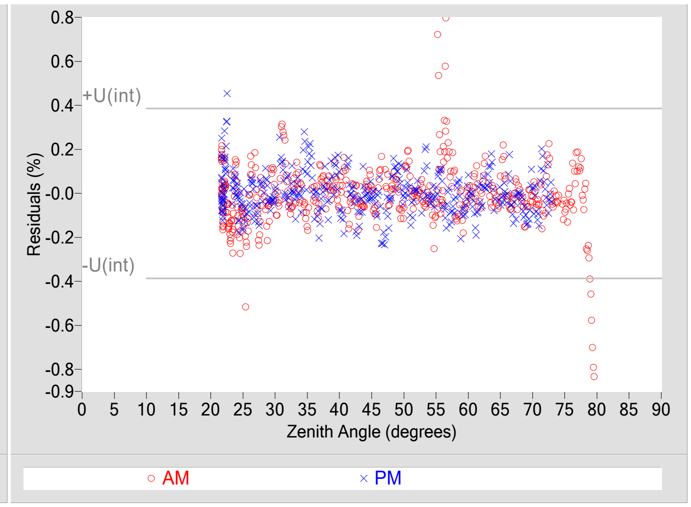


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.60
Effective degrees of freedom, DF(c)	74476
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

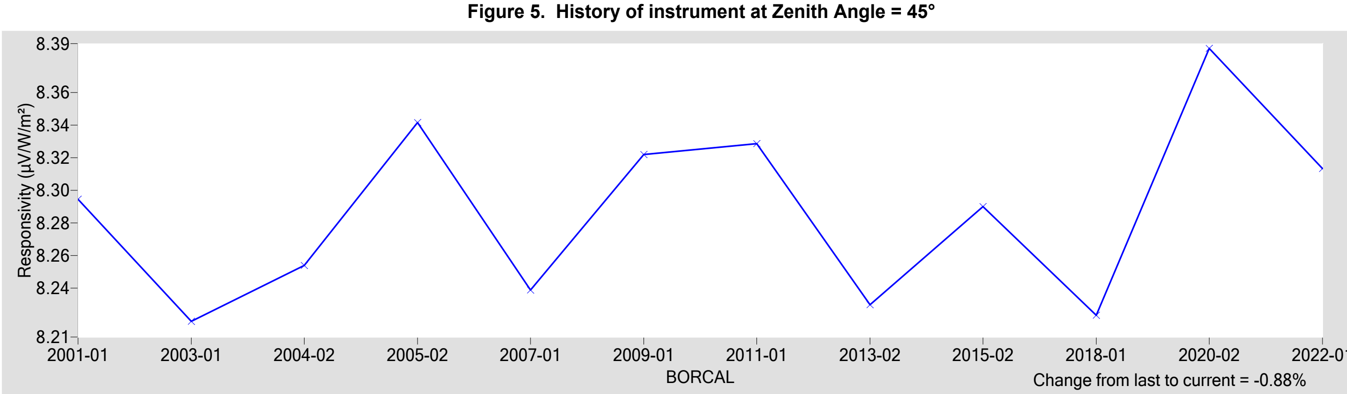
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.3133	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+1.9 / -1.5
Expanded Uncertainty, U (%)	+2.9 / -2.4
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility
National Renewable Energy Laboratory
Metrology Laboratory
Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33239
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

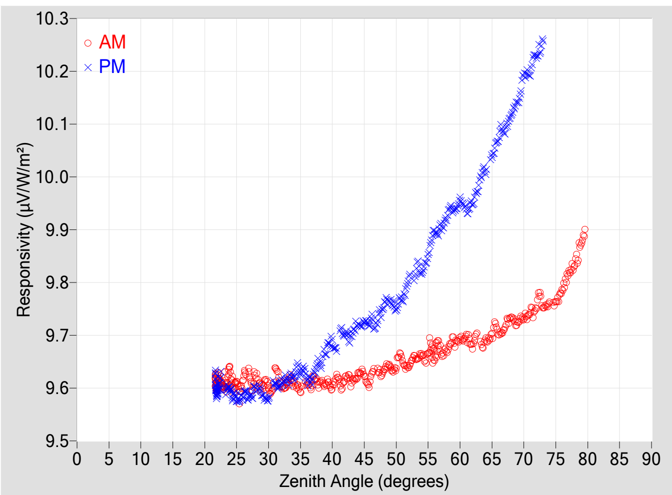


Figure 2. Responsivity vs Local Standard Time

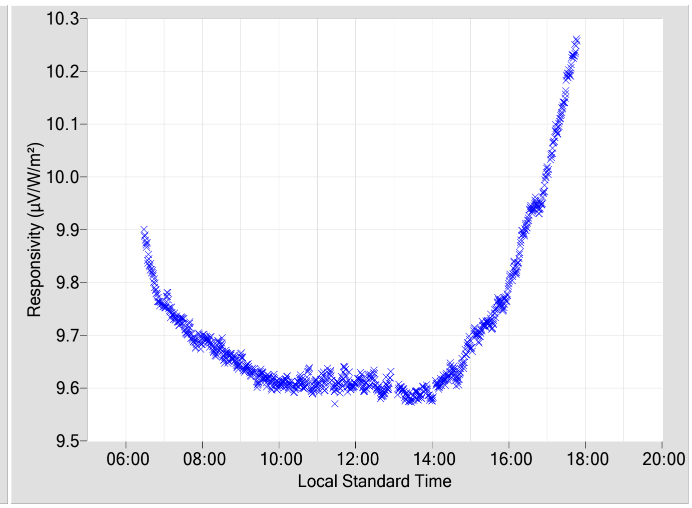


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.6185	0.43	105.77	9.7294	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.6310	0.42	103.75	9.7556	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.6449	0.43	101.79	9.7490	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.6418	0.44	100.03	9.8072	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.6624	0.43	98.28	9.8189	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6642	0.44	95.27	9.8952	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6728	0.47	92.09	9.9288	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.6934	0.46	90.58	9.9541	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6827	0.48	89.11	9.9521	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.6902	0.50	87.65	10.012	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.7051	0.53	86.16	10.072	0.57	271.27
22	9.6099	0.37	170.39	9.5961	0.36	189.57	68	9.7331	0.56	84.80	10.116	N/A	272.73
24	9.6256	0.36	151.66	9.5961	0.36	208.55	70	9.7342	N/A	83.35	10.192	N/A	274.21
26	9.6149	0.35	142.31	9.5858	0.35	218.06	72	9.7593	N/A	81.96	10.229	N/A	275.65
28	9.6253	0.36	135.69	9.5991	0.36	224.47	74	9.7591	N/A	80.62	N/A	N/A	N/A
30	9.5988	0.36	130.10	9.5789	0.41	229.79	76	9.7859	N/A	79.14	N/A	N/A	N/A
32	9.6071	0.35	125.69	9.6101	0.37	234.35	78	9.8366	N/A	77.71	N/A	N/A	N/A
34	9.6088	0.39	121.94	9.6219	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.6084	0.38	118.45	9.6164	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.6074	0.41	115.57	9.6463	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.6035	0.39	112.74	9.6838	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.6175	0.39	110.21	9.7020	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.6246	0.38	107.92	9.7192	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

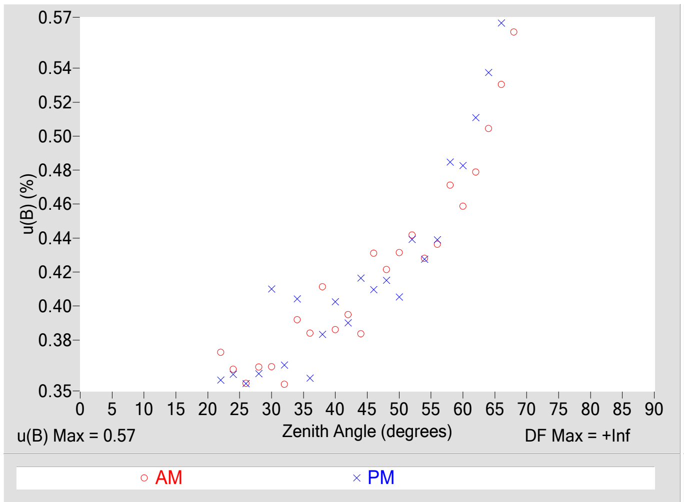


Figure 4. Residuals from Spline Interpolation

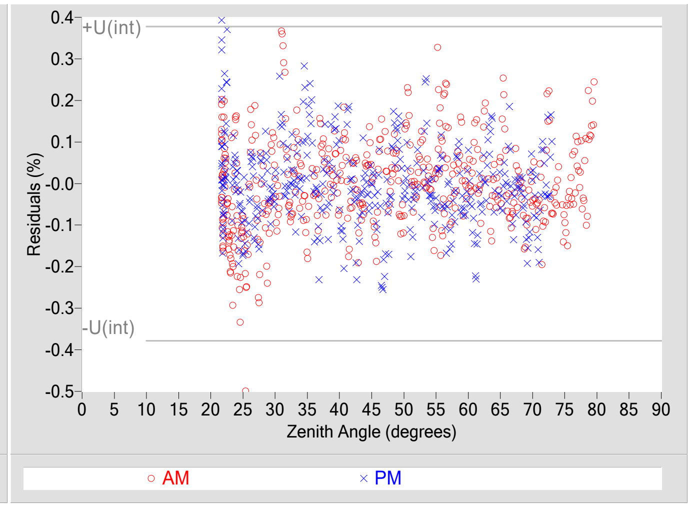


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.60
Effective degrees of freedom, DF(c)	80211
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

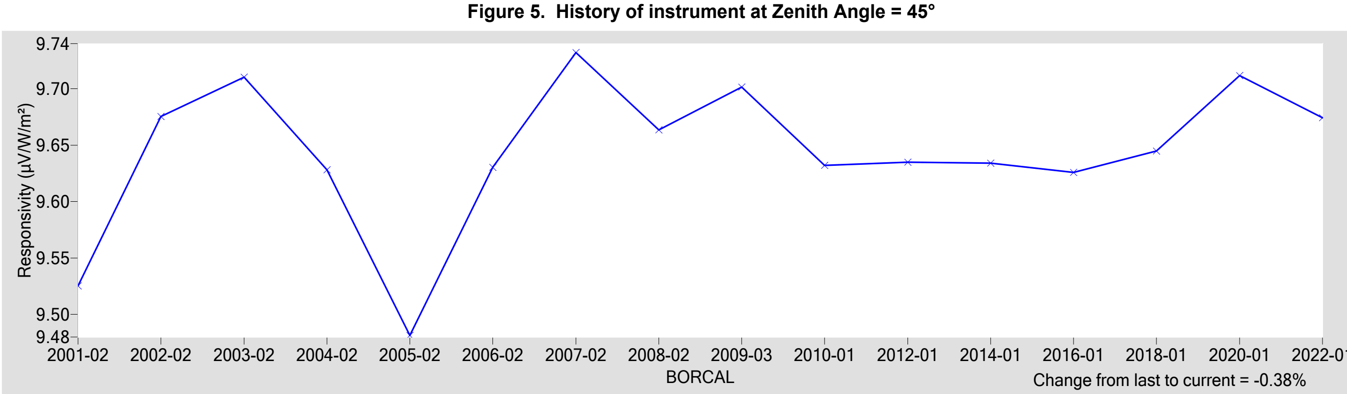
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.6744	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.9 / -0.99
Expanded Uncertainty, U (%)	+3.8 / -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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33242
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

where,

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

Figure 1. Responsivity vs Zenith Angle

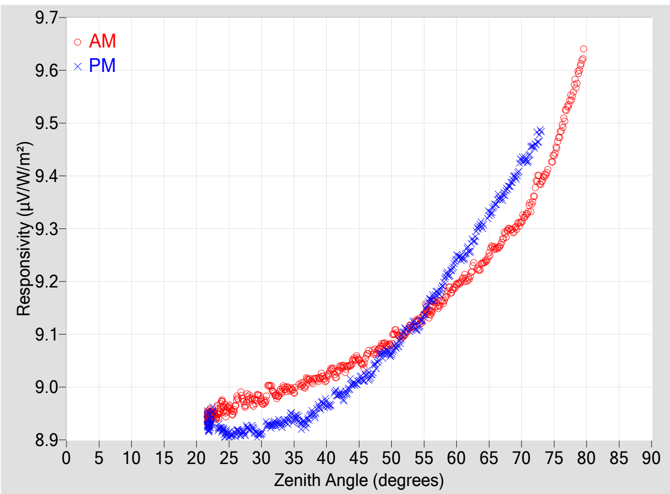


Figure 2. Responsivity vs Local Standard Time

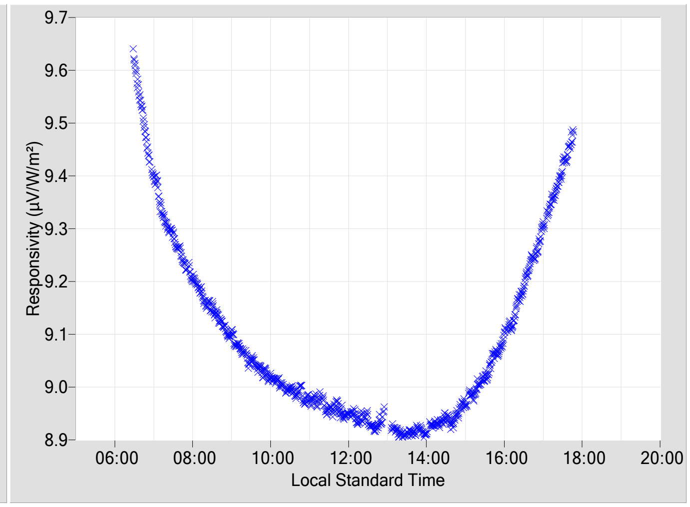


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	Angle (deg.)	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle	R (µV/W/m²)	u(B) ± (%)	Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0520	0.43	105.77	9.0223	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0704	0.42	103.75	9.0539	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0886	0.43	101.79	9.0624	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0984	0.44	100.03	9.1078	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1265	0.43	98.28	9.1107	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1433	0.44	95.27	9.1661	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1633	0.47	92.09	9.1993	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1932	0.46	90.58	9.2452	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2082	0.48	89.11	9.2616	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2345	0.50	87.65	9.3065	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2634	0.53	86.16	9.3473	0.57	271.27
22	8.9435	0.37	170.39	8.9274	0.36	189.57	68	9.2987	0.56	84.80	9.3786	N/A	272.73
24	8.9661	0.36	151.66	8.9187	0.36	208.55	70	9.3157	N/A	83.35	9.4309	N/A	274.21
26	8.9664	0.35	142.31	8.9136	0.35	218.06	72	9.3684	N/A	81.96	9.4574	N/A	275.65
28	8.9826	0.36	135.69	8.9215	0.36	224.47	74	9.4065	N/A	80.62	N/A	N/A	N/A
30	8.9733	0.36	130.10	8.9120	0.41	229.79	76	9.4822	N/A	79.14	N/A	N/A	N/A
32	8.9872	0.35	125.69	8.9304	0.37	234.35	78	9.5619	N/A	77.71	N/A	N/A	N/A
34	8.9968	0.39	121.94	8.9354	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0042	0.38	118.45	8.9297	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0121	0.41	115.57	8.9487	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0172	0.39	112.74	8.9686	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0358	0.39	110.21	8.9867	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0482	0.38	107.92	9.0052	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

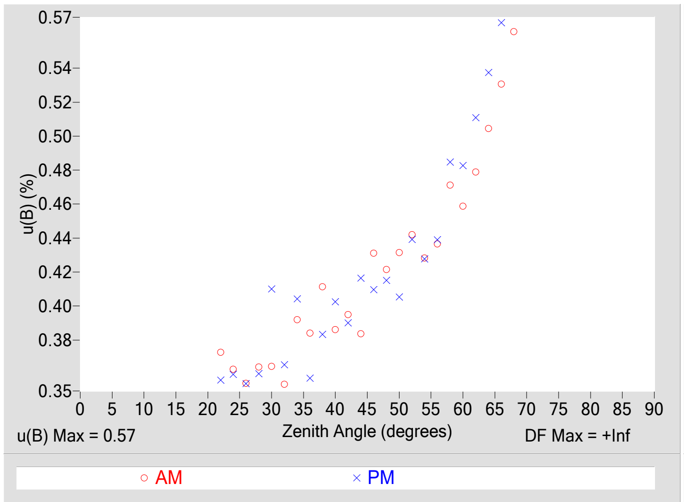


Figure 4. Residuals from Spline Interpolation

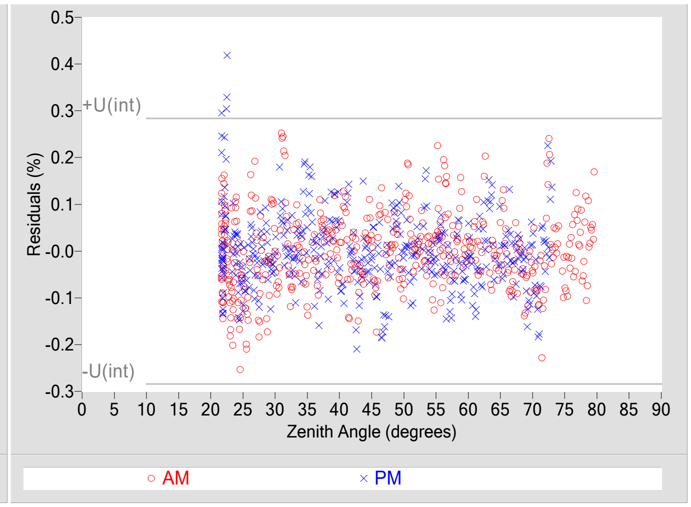


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.14
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	230516
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

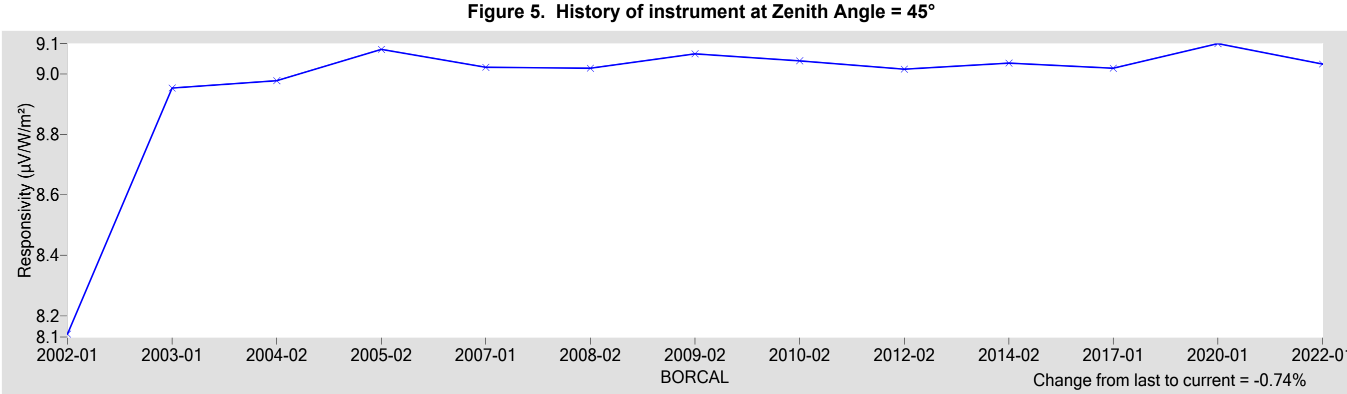
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.0328	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.4 / -1.3
Expanded Uncertainty, U (%)	+3.3 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33243
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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.

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

33243 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

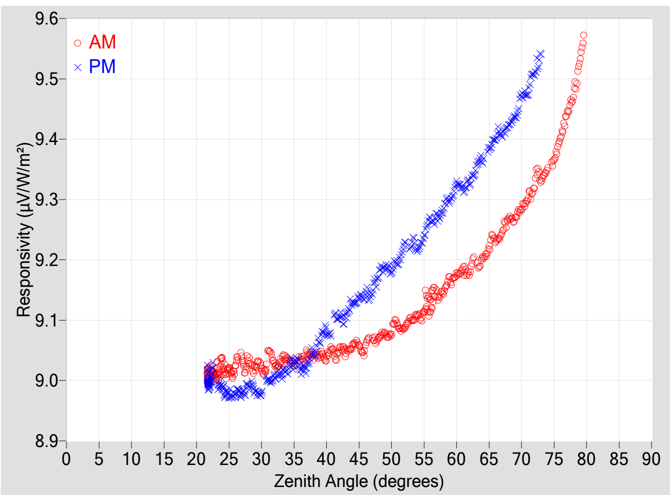


Figure 2. Responsivity vs Local Standard Time

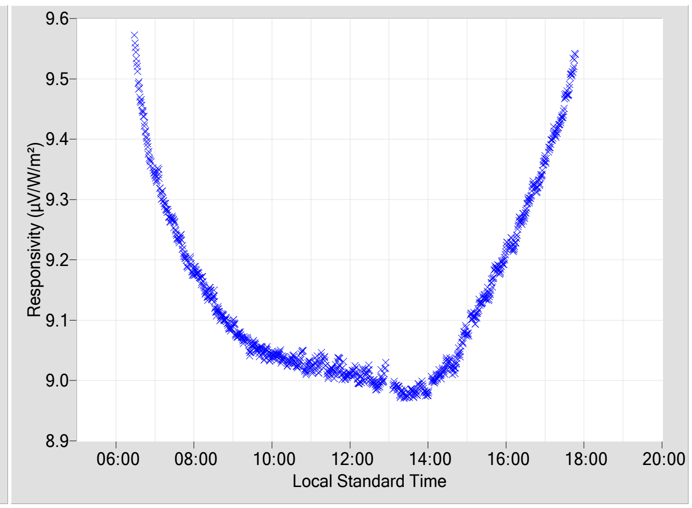


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.0559	0.43	105.77	9.1449	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.0698	0.42	103.75	9.1755	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.0834	0.43	101.79	9.1796	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.0872	0.44	100.03	9.2252	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1082	0.43	98.28	9.2169	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.1254	0.44	95.27	9.2666	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.1477	0.47	92.09	9.2865	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.1754	0.46	90.58	9.3254	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.1801	0.48	89.11	9.3302	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2025	0.50	87.65	9.3659	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2322	0.53	86.16	9.4014	0.57	271.27
22	9.0078	0.37	170.39	8.9963	0.36	189.57	68	9.2683	0.56	84.80	9.4224	N/A	272.73
24	9.0270	0.36	151.66	8.9874	0.36	208.55	70	9.2856	N/A	83.35	9.4721	N/A	274.21
26	9.0246	0.35	142.31	8.9794	0.35	218.06	72	9.3268	N/A	81.96	9.5091	N/A	275.65
28	9.0352	0.36	135.69	8.9907	0.36	224.47	74	9.3479	N/A	80.62	N/A	N/A	N/A
30	9.0188	0.36	130.10	8.9782	0.41	229.79	76	9.4018	N/A	79.14	N/A	N/A	N/A
32	9.0283	0.35	125.69	9.0056	0.37	234.35	78	9.4745	N/A	77.71	N/A	N/A	N/A
34	9.0342	0.39	121.94	9.0177	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.0371	0.38	118.45	9.0183	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.0400	0.41	115.57	9.0462	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.0384	0.39	112.74	9.0814	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.0510	0.39	110.21	9.1062	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.0572	0.38	107.92	9.1277	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

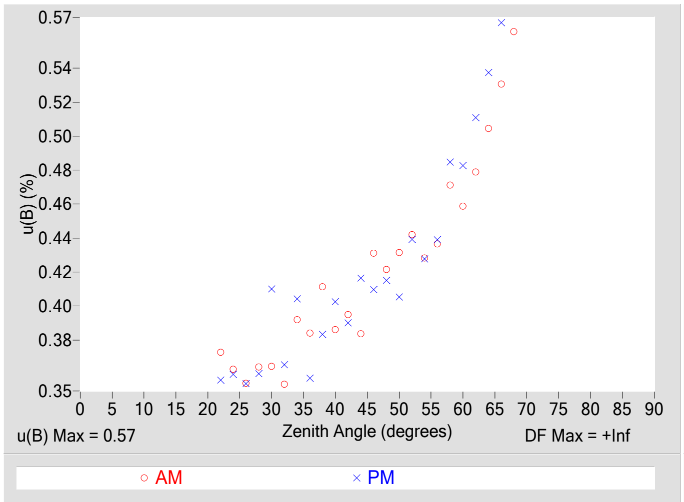


Figure 4. Residuals from Spline Interpolation

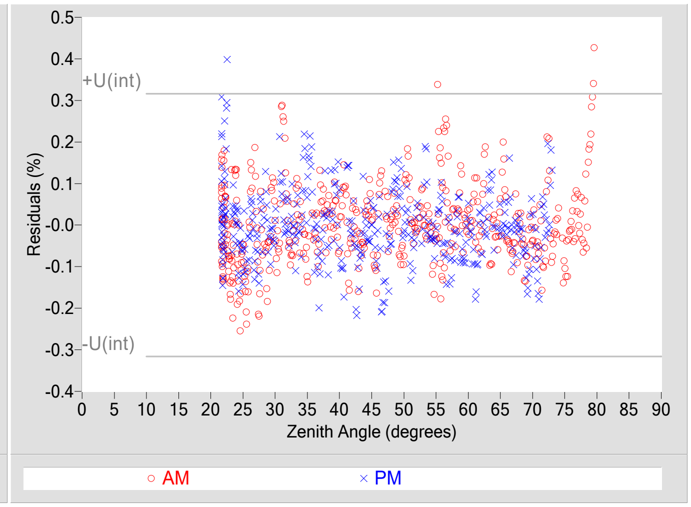


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	154757
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

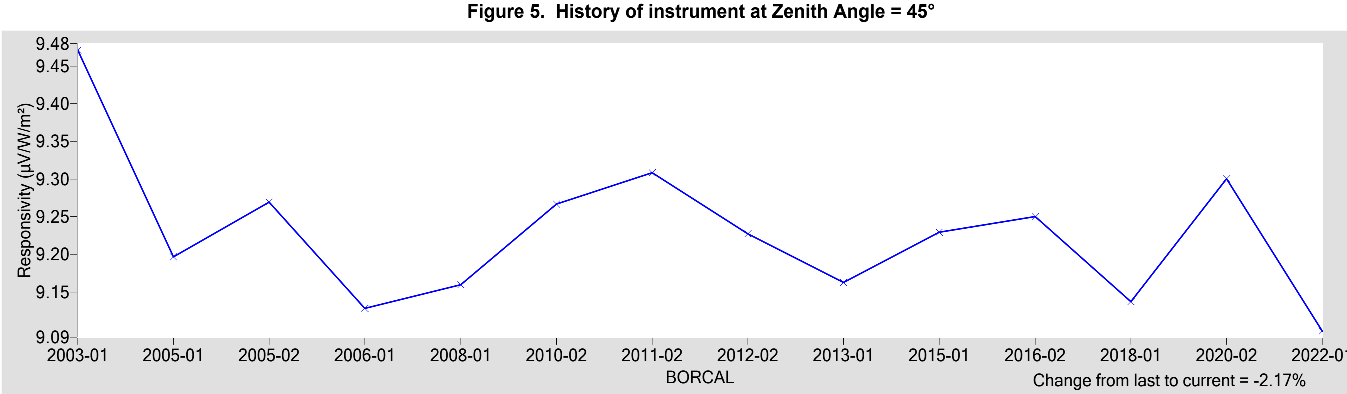
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.0981	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.5 / -1.3
Expanded Uncertainty, U (%)	+3.4 / -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:**	33259
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

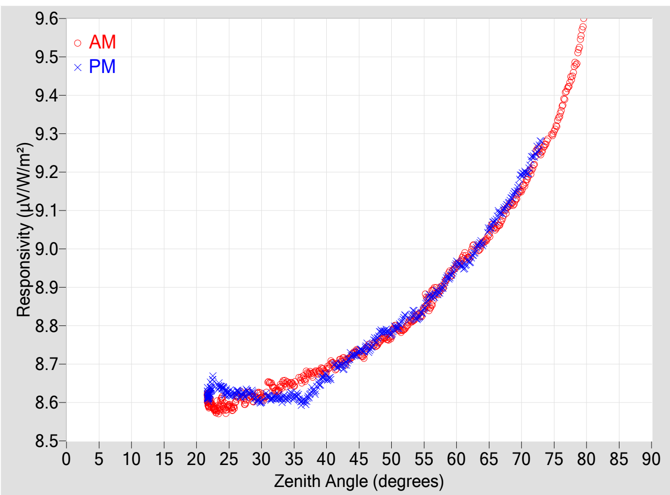


Figure 2. Responsivity vs Local Standard Time

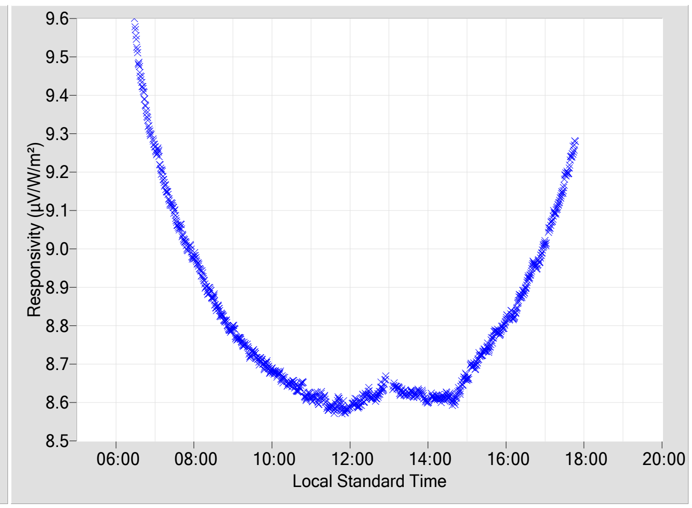


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.7323	0.43	105.77	8.7450	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7540	0.42	103.75	8.7756	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7781	0.43	101.79	8.7788	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7910	0.44	100.03	8.8234	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8274	0.43	98.28	8.8190	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8611	0.44	95.27	8.8771	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9048	0.47	92.09	8.9073	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9566	0.46	90.58	8.9629	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9800	0.48	89.11	8.9692	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0147	0.50	87.65	9.0145	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0536	0.53	86.16	9.0756	0.57	271.27
22	8.5991	0.37	170.39	8.6218	0.36	189.57	68	9.1113	0.56	84.80	9.1196	N/A	272.73
24	8.5993	0.36	151.66	8.6371	0.36	208.55	70	9.1546	N/A	83.35	9.1935	N/A	274.21
26	8.6001	0.35	142.31	8.6242	0.35	218.06	72	9.2293	N/A	81.96	9.2441	N/A	275.65
28	8.6216	0.36	135.69	8.6262	0.36	224.47	74	9.2798	N/A	80.62	N/A	N/A	N/A
30	8.6139	0.36	130.10	8.6016	0.41	229.79	76	9.3542	N/A	79.14	N/A	N/A	N/A
32	8.6347	0.35	125.69	8.6131	0.37	234.35	78	9.4619	N/A	77.71	N/A	N/A	N/A
34	8.6490	0.39	121.94	8.6103	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6600	0.38	118.45	8.6025	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6732	0.41	115.57	8.6301	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6837	0.39	112.74	8.6661	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7064	0.39	110.21	8.6966	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7235	0.38	107.92	8.7226	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

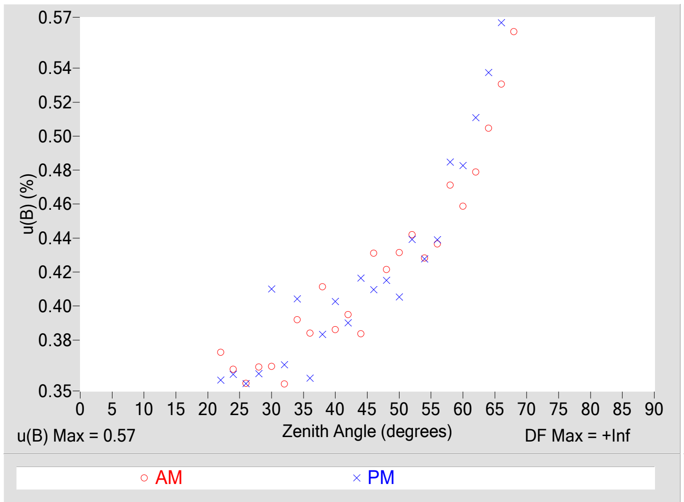


Figure 4. Residuals from Spline Interpolation

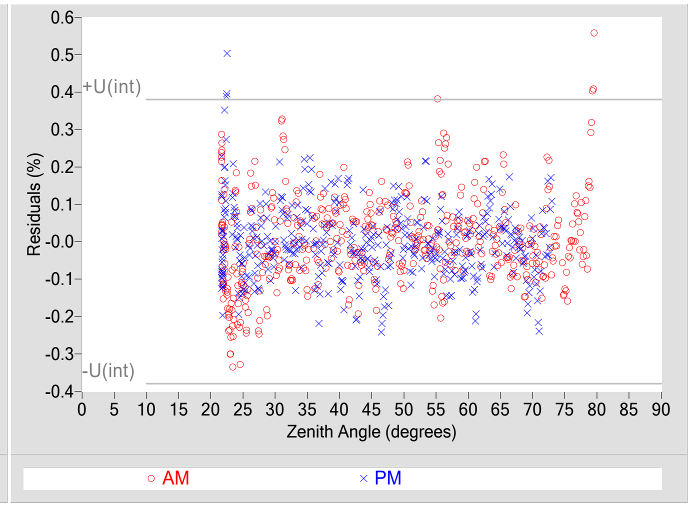


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.60
Effective degrees of freedom, DF(c)	78896
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

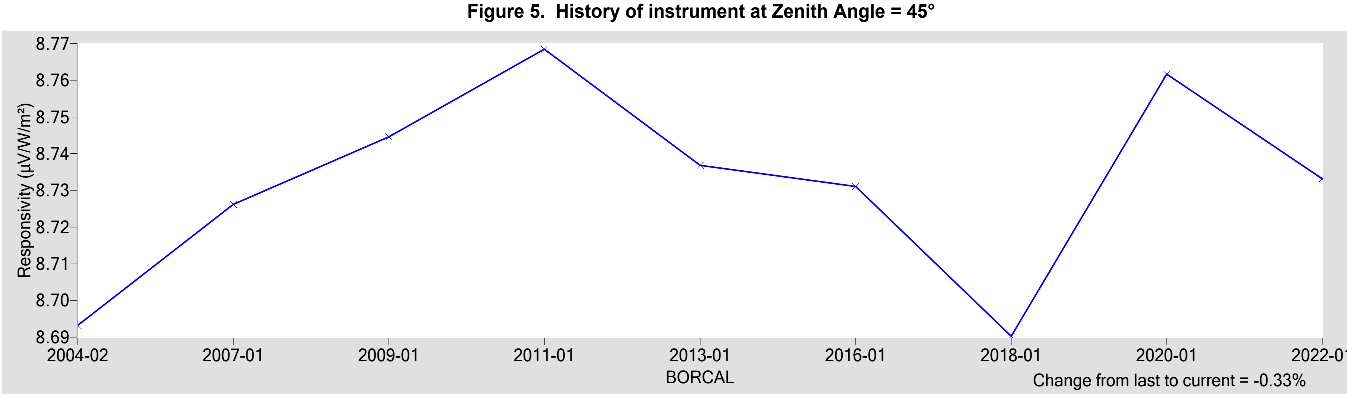
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7331	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.6 / -1.5
Expanded Uncertainty, U (%)	+3.6 / -2.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33261
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

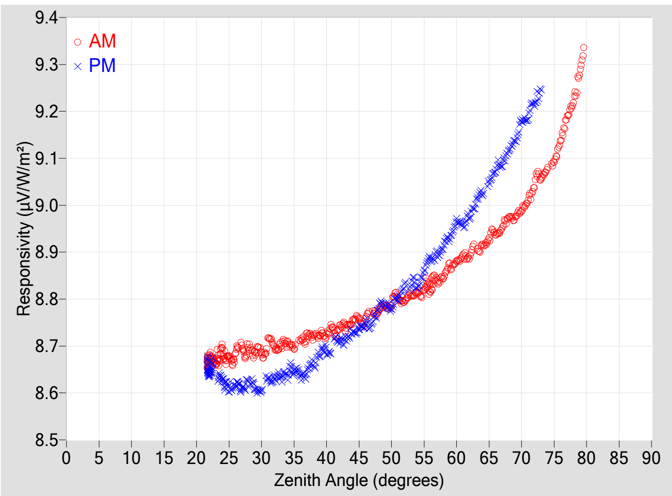


Figure 2. Responsivity vs Local Standard Time

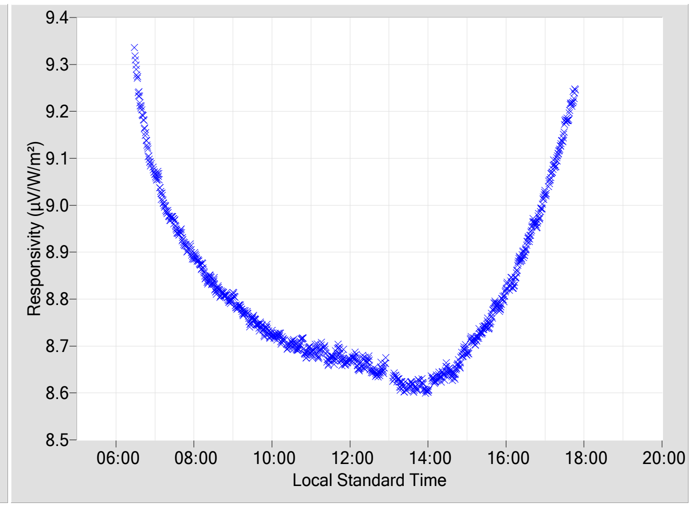


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7566	0.43	105.77	8.7496	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7730	0.42	103.75	8.7834	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7927	0.43	101.79	8.7787	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7958	0.44	100.03	8.8283	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8136	0.43	98.28	8.8256	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8246	0.44	95.27	8.8856	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8482	0.47	92.09	8.9151	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8803	0.46	90.58	8.9639	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8908	0.48	89.11	8.9772	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9150	0.50	87.65	9.0252	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9390	0.53	86.16	9.0743	0.57	271.27
22	8.6658	0.37	170.39	8.6451	0.36	189.57	68	8.9732	0.56	84.80	9.1147	N/A	272.73
24	8.6876	0.36	151.66	8.6275	0.36	208.55	70	8.9903	N/A	83.35	9.1797	N/A	274.21
26	8.6832	0.35	142.31	8.6174	0.35	218.06	72	9.0452	N/A	81.96	9.2164	N/A	275.65
28	8.6985	0.36	135.69	8.6227	0.36	224.47	74	9.0754	N/A	80.62	N/A	N/A	N/A
30	8.6832	0.36	130.10	8.6041	0.41	229.79	76	9.1364	N/A	79.14	N/A	N/A	N/A
32	8.6975	0.35	125.69	8.6305	0.37	234.35	78	9.2221	N/A	77.71	N/A	N/A	N/A
34	8.7053	0.39	121.94	8.6388	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7131	0.38	118.45	8.6357	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7195	0.41	115.57	8.6598	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7231	0.39	112.74	8.6897	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7399	0.39	110.21	8.7113	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7520	0.38	107.92	8.7281	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

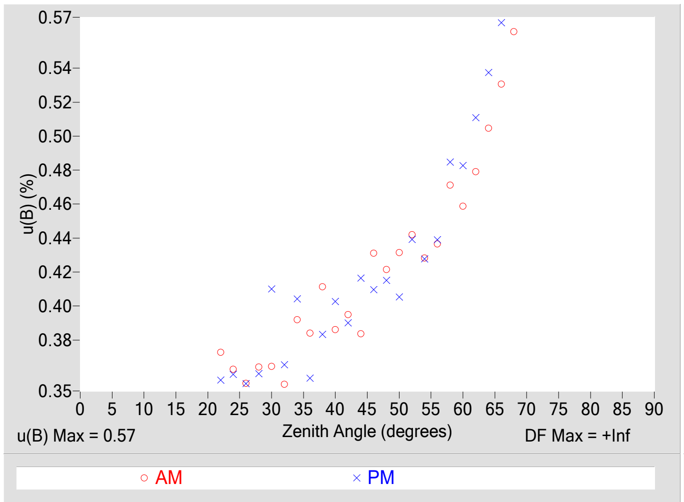


Figure 4. Residuals from Spline Interpolation

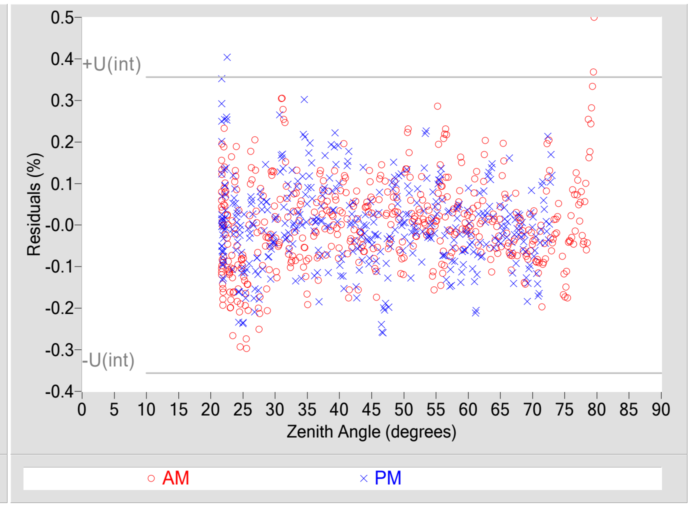


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	99724
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

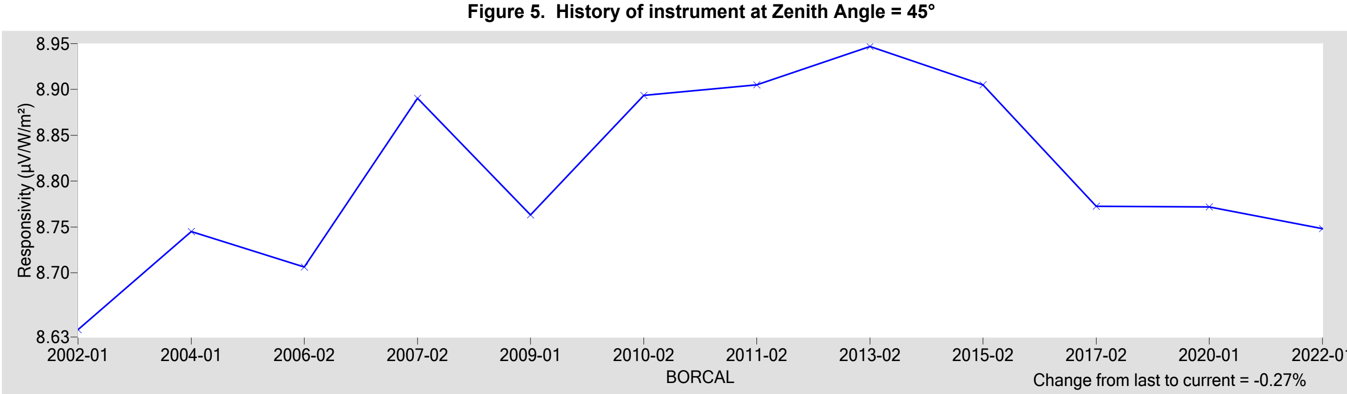
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.7483	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.5 / -1.6
Expanded Uncertainty, U (%)	+3.4 / -2.6
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33269
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

33269 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

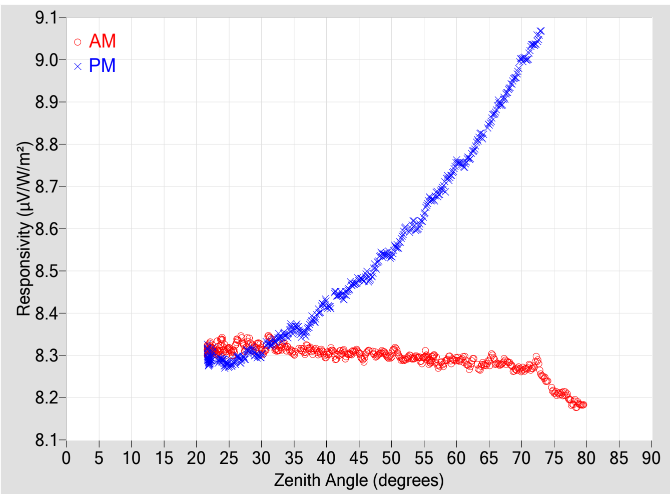


Figure 2. Responsivity vs Local Standard Time

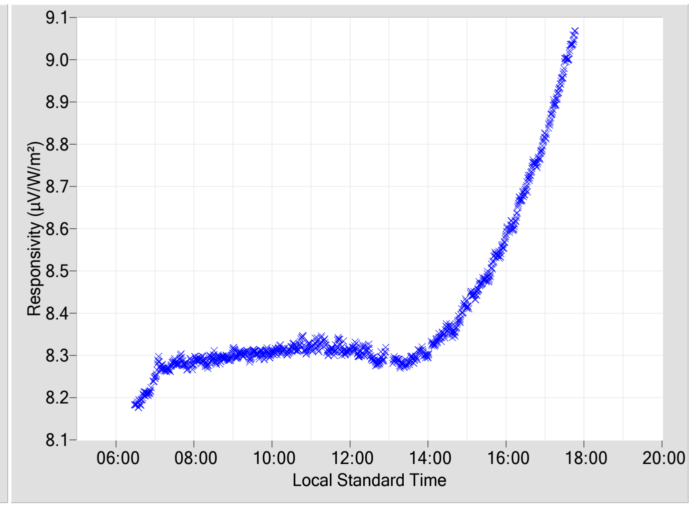


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.2988	0.43	105.77	8.4887	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3016	0.42	103.75	8.5273	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3031	0.43	101.79	8.5348	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2890	0.44	100.03	8.5965	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2957	0.43	98.28	8.5996	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2864	0.44	95.27	8.6707	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2810	0.47	92.09	8.6984	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2912	0.46	90.58	8.7558	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2747	0.48	89.11	8.7693	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2785	0.50	87.65	8.8197	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2825	0.53	86.16	8.8787	0.57	271.27
22	8.3113	0.37	170.39	8.2880	0.36	189.57	68	8.2841	0.56	84.80	8.9283	N/A	272.73
24	8.3272	0.36	151.66	8.2876	0.36	208.55	70	8.2664	N/A	83.35	9.0009	N/A	274.21
26	8.3228	0.35	142.31	8.2878	0.35	218.06	72	8.2795	N/A	81.96	9.0361	N/A	275.65
28	8.3358	0.36	135.69	8.3099	0.36	224.47	74	8.2389	N/A	80.62	N/A	N/A	N/A
30	8.3134	0.36	130.10	8.2990	0.41	229.79	76	8.2101	N/A	79.14	N/A	N/A	N/A
32	8.3193	0.35	125.69	8.3345	0.37	234.35	78	8.1876	N/A	77.71	N/A	N/A	N/A
34	8.3171	0.39	121.94	8.3505	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.3138	0.38	118.45	8.3525	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.3095	0.41	115.57	8.3844	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3004	0.39	112.74	8.4211	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3057	0.39	110.21	8.4445	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3070	0.38	107.92	8.4680	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

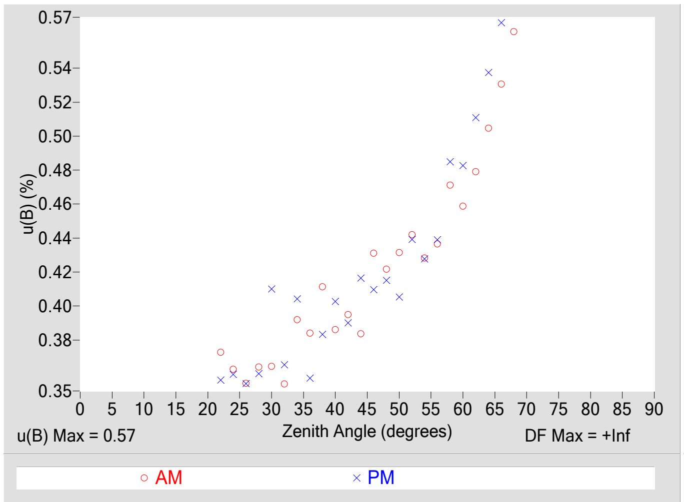


Figure 4. Residuals from Spline Interpolation

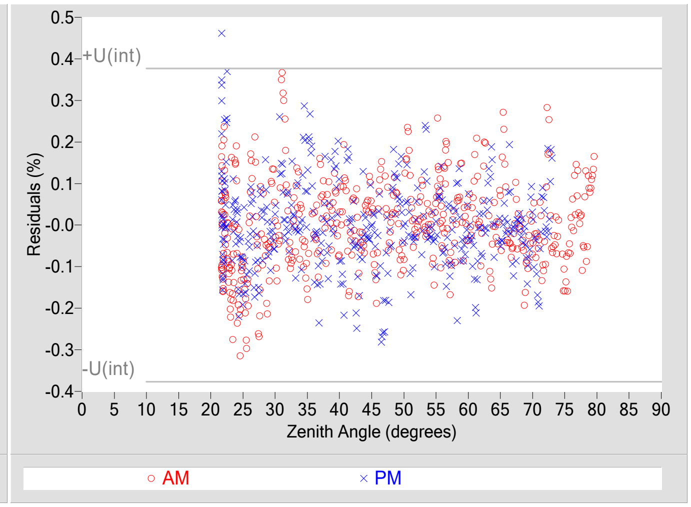


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.19
Combined Standard Uncertainty, u(c) (%)	±0.60
Effective degrees of freedom, DF(c)	81150
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

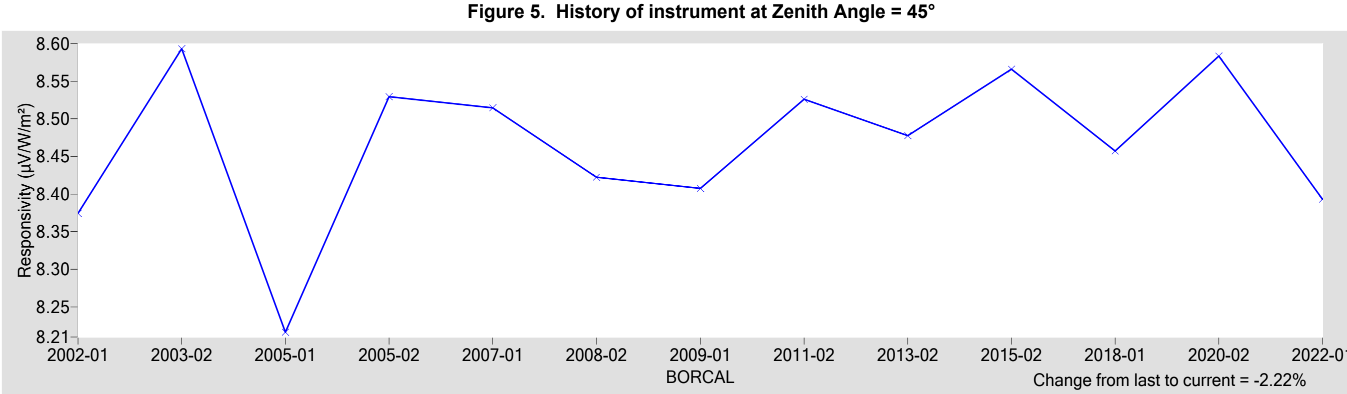
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.3932	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+4.3 / -1.3
Expanded Uncertainty, U (%)	+5.3 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33271
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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 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

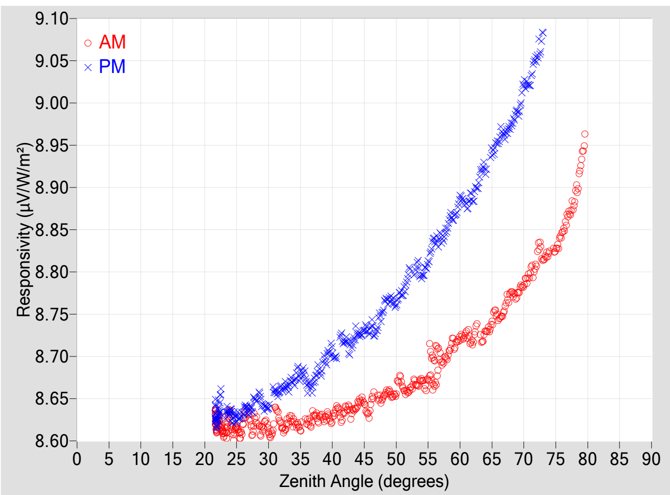


Figure 2. Responsivity vs Local Standard Time

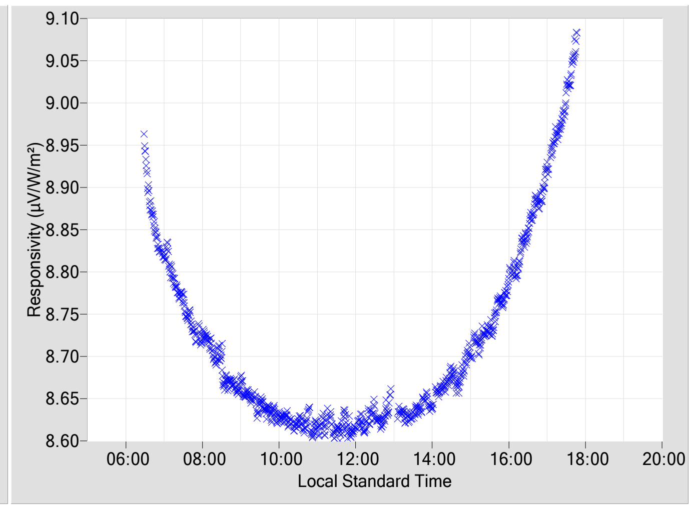


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6414	0.43	105.77	8.7349	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6517	0.42	103.75	8.7582	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6609	0.43	101.79	8.7614	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6593	0.44	100.03	8.7994	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6719	0.43	98.28	8.7949	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6809	0.44	95.27	8.8371	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7004	0.47	92.09	8.8542	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7217	0.46	90.58	8.8867	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7186	0.48	89.11	8.8882	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7289	0.50	87.65	8.9222	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7457	0.53	86.16	8.9546	0.57	271.27
22	8.6211	0.37	170.39	8.6270	0.36	189.57	68	8.7755	0.56	84.80	8.9733	N/A	272.73
24	8.6251	0.36	151.66	8.6337	0.36	208.55	70	8.7856	N/A	83.35	9.0218	N/A	274.21
26	8.6200	0.35	142.31	8.6339	0.35	218.06	72	8.8155	N/A	81.96	9.0534	N/A	275.65
28	8.6272	0.36	135.69	8.6491	0.36	224.47	74	8.8214	N/A	80.62	N/A	N/A	N/A
30	8.6104	0.36	130.10	8.6394	0.41	229.79	76	8.8456	N/A	79.14	N/A	N/A	N/A
32	8.6189	0.35	125.69	8.6617	0.37	234.35	78	8.8869	N/A	77.71	N/A	N/A	N/A
34	8.6216	0.39	121.94	8.6705	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6227	0.38	118.45	8.6662	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6260	0.41	115.57	8.6832	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6262	0.39	112.74	8.7056	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6370	0.39	110.21	8.7183	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6440	0.38	107.92	8.7262	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

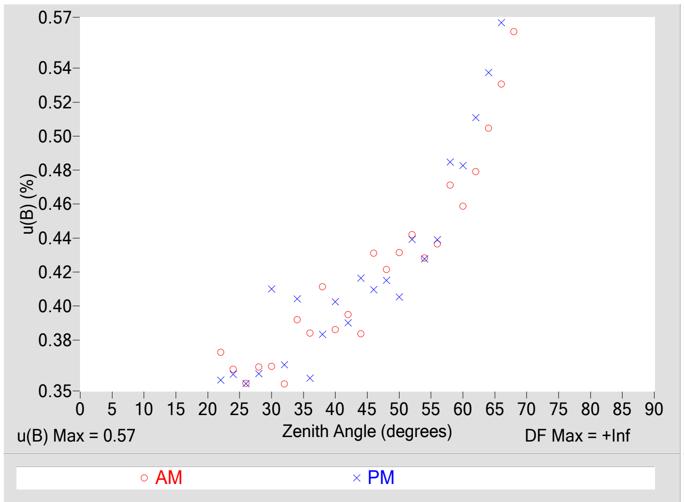


Figure 4. Residuals from Spline Interpolation

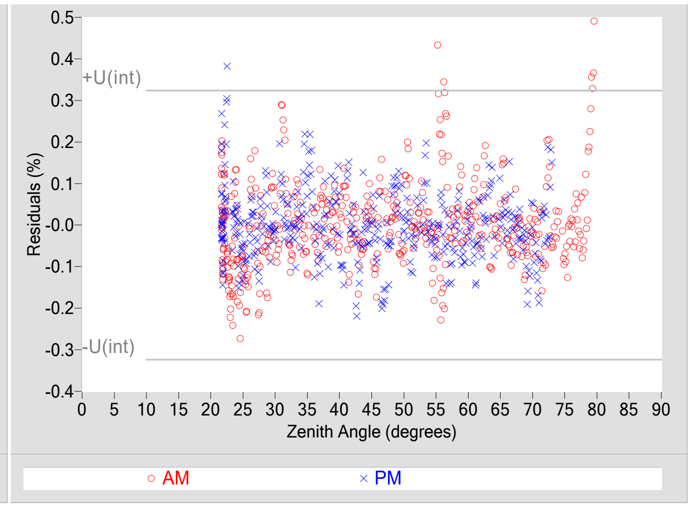


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	141763
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

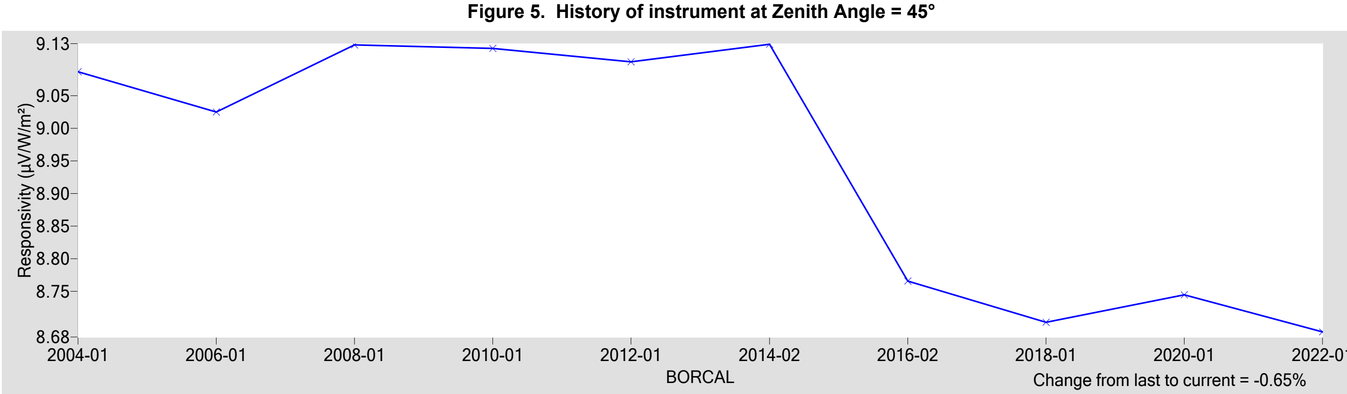
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6877	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.3 / -0.89
Expanded Uncertainty, U (%)	+3.2 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

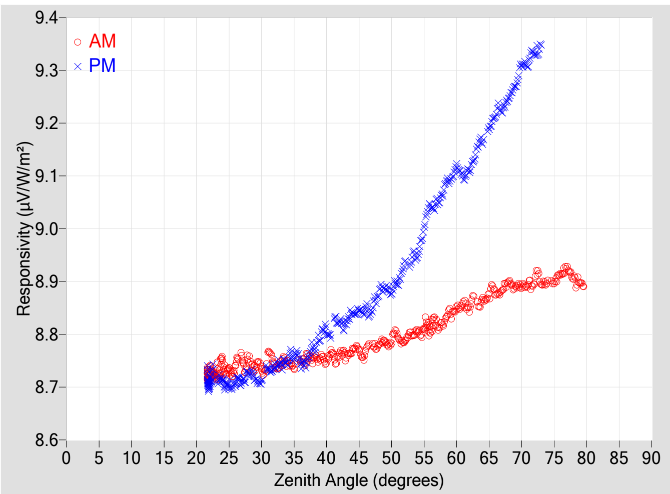


Figure 2. Responsivity vs Local Standard Time

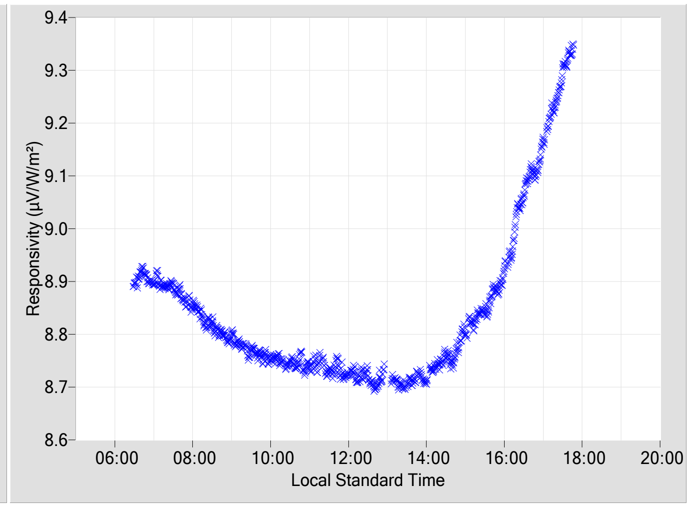


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	8.7661	0.43	105.77	8.8486	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7780	0.42	103.75	8.8775	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7899	0.43	101.79	8.8779	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7862	0.44	100.03	8.9328	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8061	0.43	98.28	8.9480	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8101	0.44	95.27	9.0429	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8220	0.47	92.09	9.0740	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8490	0.46	90.58	9.1160	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8506	0.48	89.11	9.1127	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8652	0.50	87.65	9.1664	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8779	0.53	86.16	9.2153	0.57	271.27
22	8.7227	0.37	170.39	8.7072	0.36	189.57	68	8.8987	0.56	84.80	9.2463	N/A	272.73
24	8.7440	0.36	151.66	8.7122	0.36	208.55	70	8.8919	N/A	83.35	9.3096	N/A	274.21
26	8.7404	0.35	142.31	8.7096	0.35	218.06	72	8.9022	N/A	81.96	9.3303	N/A	275.65
28	8.7545	0.36	135.69	8.7255	0.36	224.47	74	8.8974	N/A	80.62	N/A	N/A	N/A
30	8.7333	0.36	130.10	8.7096	0.41	229.79	76	8.9135	N/A	79.14	N/A	N/A	N/A
32	8.7419	0.35	125.69	8.7380	0.37	234.35	78	8.9073	N/A	77.71	N/A	N/A	N/A
34	8.7467	0.39	121.94	8.7489	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7504	0.38	118.45	8.7449	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7516	0.41	115.57	8.7739	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7501	0.39	112.74	8.8064	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7620	0.39	110.21	8.8231	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7690	0.38	107.92	8.8392	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

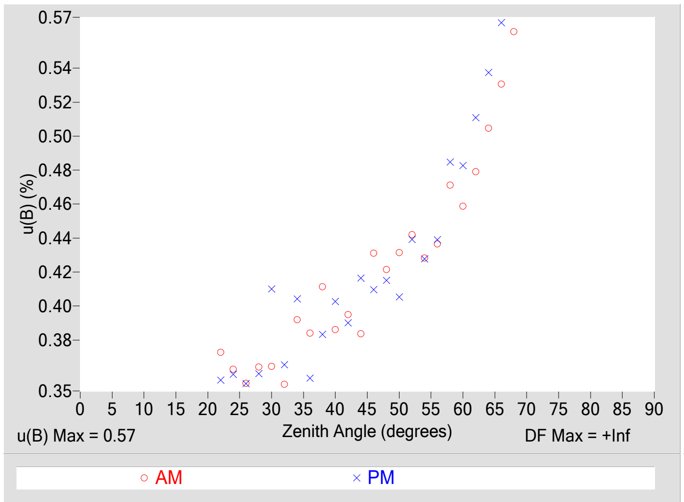


Figure 4. Residuals from Spline Interpolation

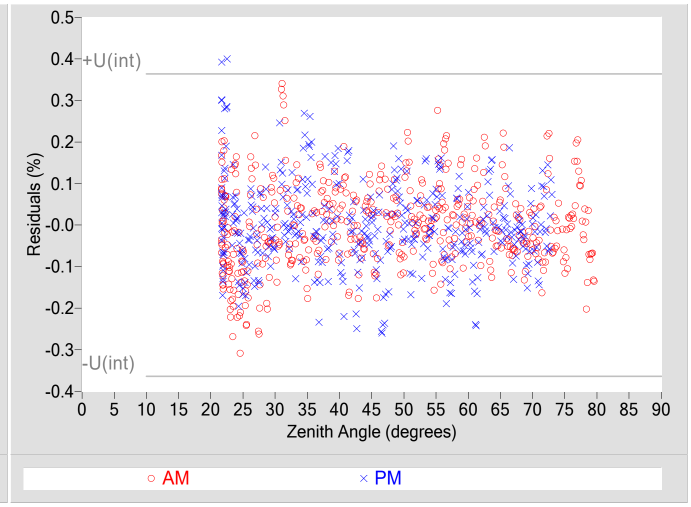


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.60
Effective degrees of freedom, DF(c)	92308
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

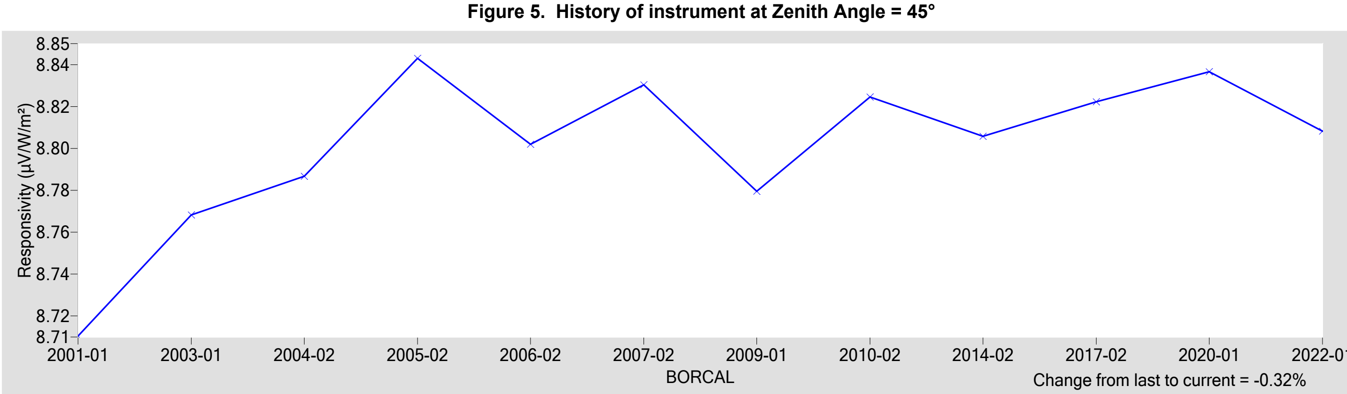
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.8083	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+3.5 / -1.1
Expanded Uncertainty, U (%)	+4.4 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33277
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

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

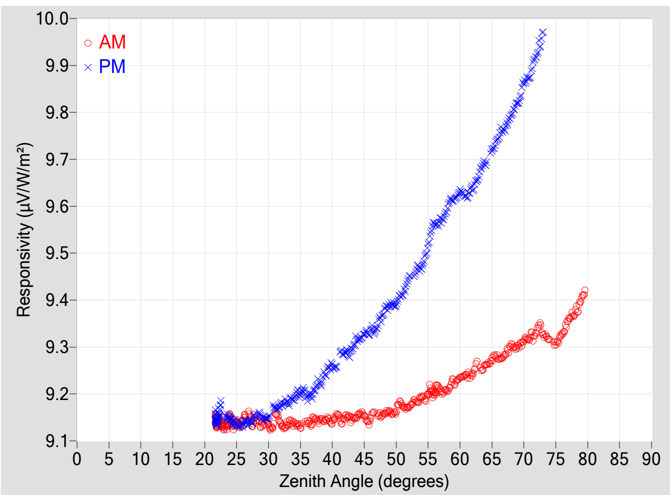


Figure 2. Responsivity vs Local Standard Time

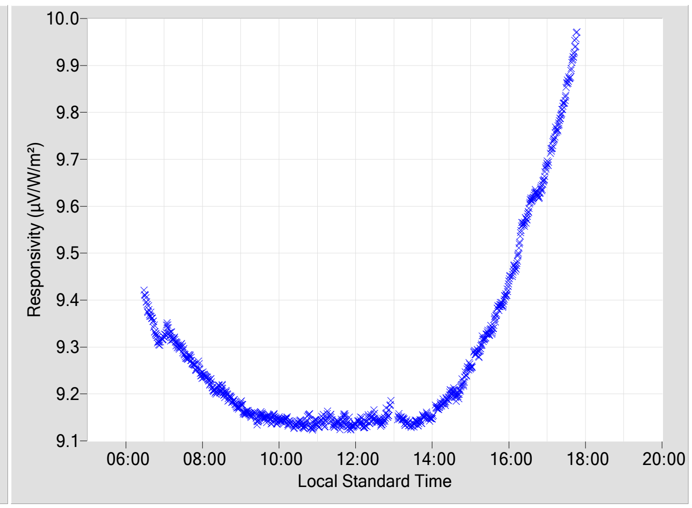


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.1478	0.43	105.77	9.3366	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.1559	0.42	103.75	9.3743	0.42	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.1669	0.43	101.79	9.3905	0.41	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.1721	0.44	100.03	9.4476	0.44	260.08
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.1934	0.43	98.28	9.4696	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.2022	0.44	95.27	9.5625	0.44	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.2083	0.47	92.09	9.5970	0.48	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.2343	0.46	90.58	9.6307	0.48	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.2437	0.48	89.11	9.6402	0.51	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.2618	0.50	87.65	9.6915	0.54	269.75
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.2769	0.53	86.16	9.7461	0.57	271.27
22	9.1391	0.37	170.39	9.1455	0.36	189.57	68	9.3034	0.56	84.80	9.7924	N/A	272.73
24	9.1469	0.36	151.66	9.1459	0.36	208.55	70	9.3144	N/A	83.35	9.8639	N/A	274.21
26	9.1434	0.35	142.31	9.1377	0.35	218.06	72	9.3340	N/A	81.96	9.9224	N/A	275.65
28	9.1503	0.36	135.69	9.1522	0.36	224.47	74	9.3162	N/A	80.62	N/A	N/A	N/A
30	9.1320	0.36	130.10	9.1501	0.41	229.79	76	9.3278	N/A	79.14	N/A	N/A	N/A
32	9.1354	0.35	125.69	9.1772	0.37	234.35	78	9.3734	N/A	77.71	N/A	N/A	N/A
34	9.1368	0.39	121.94	9.1917	0.40	238.35	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.1399	0.38	118.45	9.1932	0.36	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.1427	0.41	115.57	9.2238	0.38	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.1418	0.39	112.74	9.2592	0.40	247.44	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.1510	0.39	110.21	9.2890	0.39	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.1536	0.38	107.92	9.3158	0.42	252.24	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

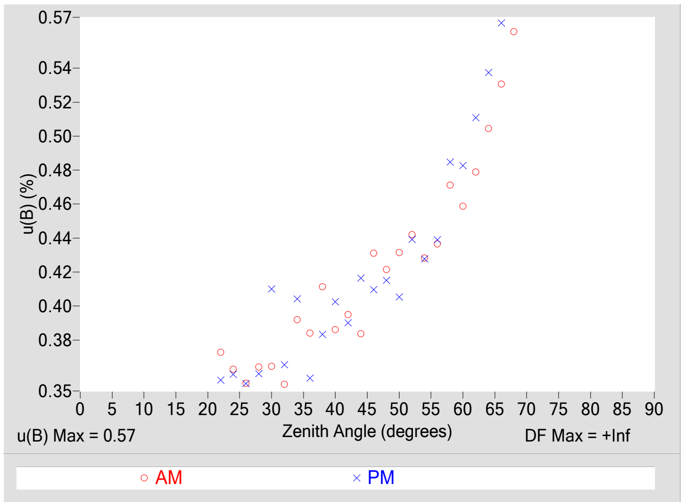


Figure 4. Residuals from Spline Interpolation

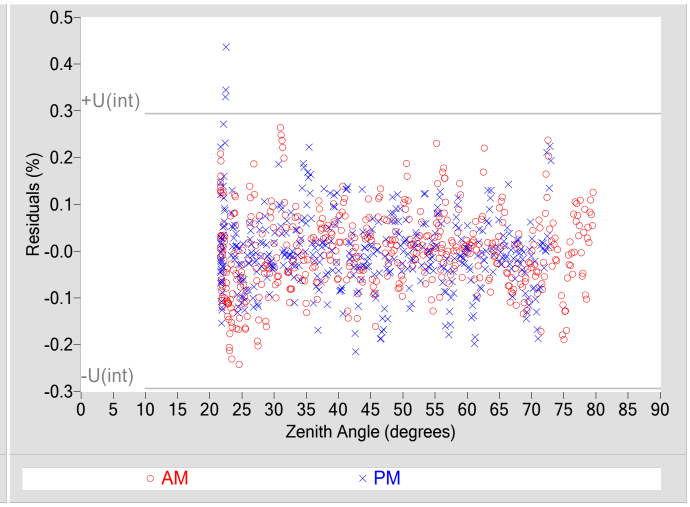


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	202765
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

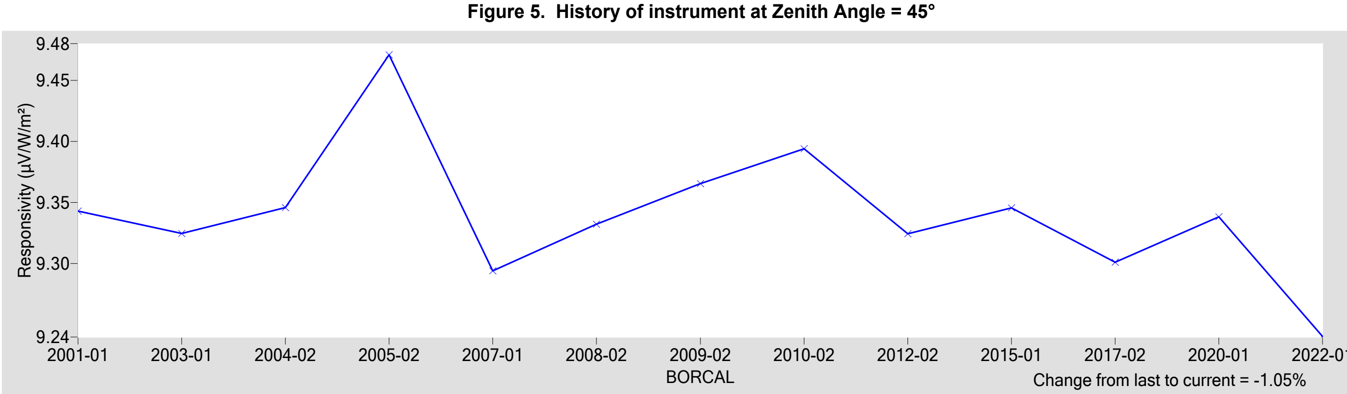
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.2406	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+4.2 / -1.2
Expanded Uncertainty, U (%)	+5.2 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33282
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

33282 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

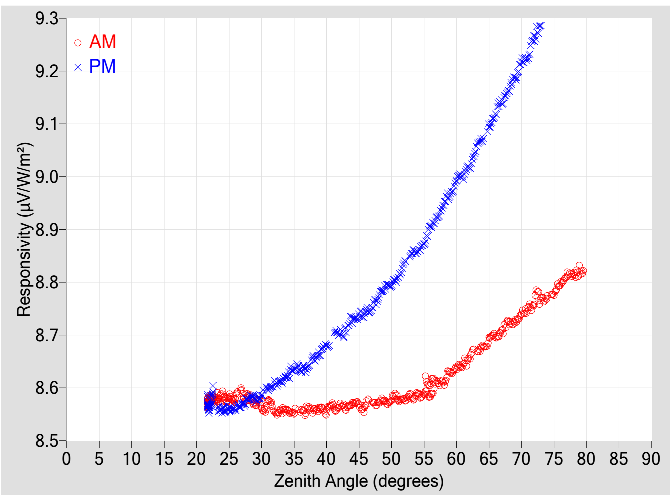


Figure 2. Responsivity vs Local Standard Time

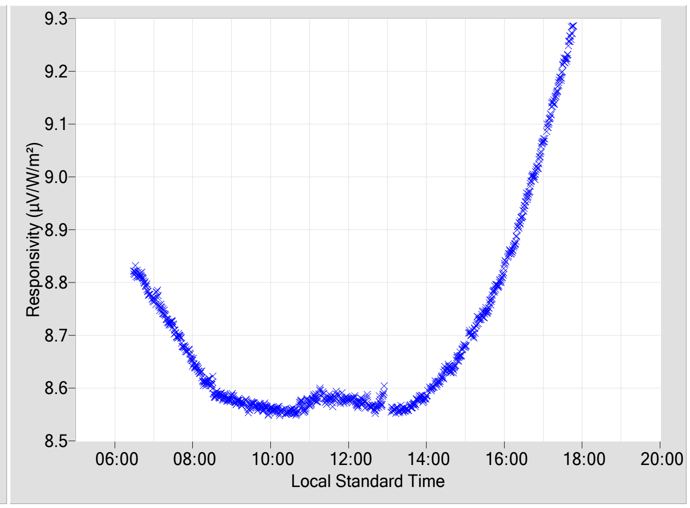


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.5655	0.43	105.77	8.7440	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5713	0.40	103.75	8.7723	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5787	0.41	101.80	8.7946	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5775	0.44	100.04	8.8376	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.5889	0.43	98.28	8.8575	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.5958	0.44	95.27	8.9057	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6105	0.47	92.10	8.9477	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6380	0.46	90.58	8.9951	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6567	0.54	89.12	9.0189	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6779	0.50	87.66	9.0699	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6976	0.53	86.17	9.1185	0.57	271.28
22	8.5749	0.37	170.69	8.5659	0.38	189.46	68	8.7250	0.56	84.76	9.1631	N/A	272.73
24	8.5844	0.36	151.24	8.5597	0.36	208.48	70	8.7408	N/A	83.35	9.2171	N/A	274.17
26	8.5822	0.34	142.38	8.5606	0.37	217.57	72	8.7659	N/A	81.96	9.2616	N/A	275.61
28	8.5841	0.36	135.57	8.5785	0.38	224.54	74	8.7706	N/A	80.62	N/A	N/A	N/A
30	8.5639	0.38	130.11	8.5864	0.38	229.93	76	8.7957	N/A	79.15	N/A	N/A	N/A
32	8.5544	0.38	125.60	8.6083	0.35	234.47	78	8.8146	N/A	77.71	N/A	N/A	N/A
34	8.5563	0.37	121.89	8.6219	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5573	0.39	118.51	8.6317	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5578	0.37	115.41	8.6563	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5568	0.39	112.67	8.6801	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5656	0.38	110.22	8.7027	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5697	0.38	107.93	8.7300	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

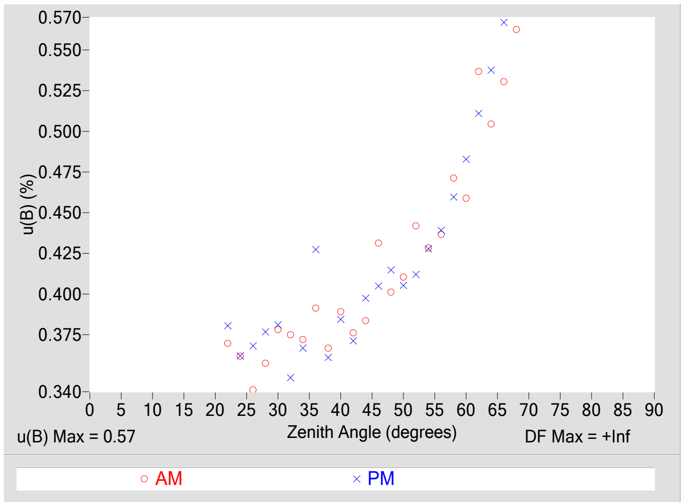


Figure 4. Residuals from Spline Interpolation

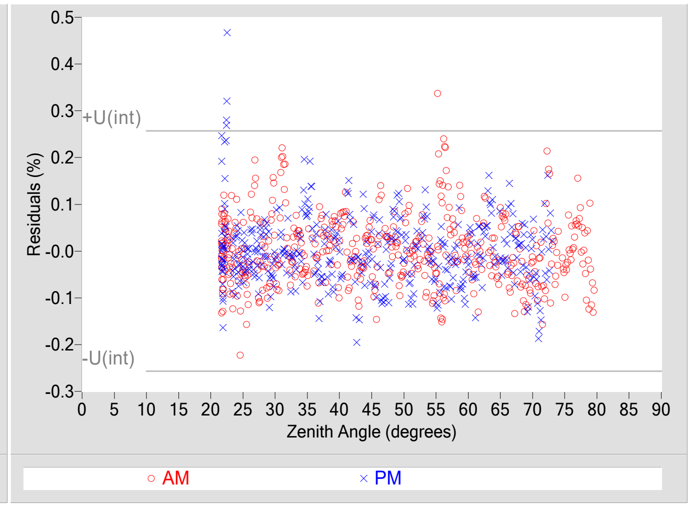


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.13
Combined Standard Uncertainty, u(c) (%)	±0.58
Effective degrees of freedom, DF(c)	333768
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

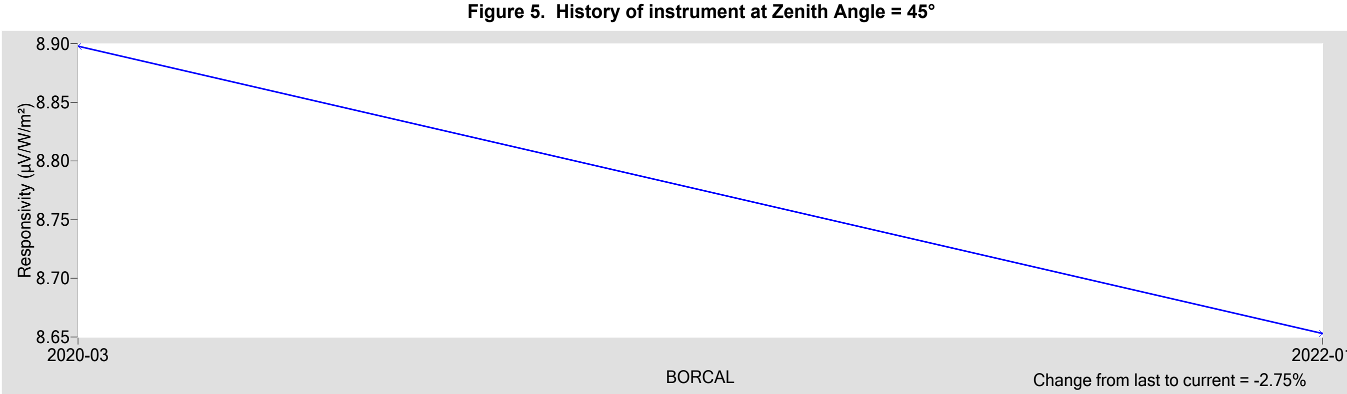
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6531	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+4.0 / -1.1
Expanded Uncertainty, U (%)	+4.9 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33376
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

33376 Eppley 8-48

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

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

where,

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

Figure 1. Responsivity vs Zenith Angle

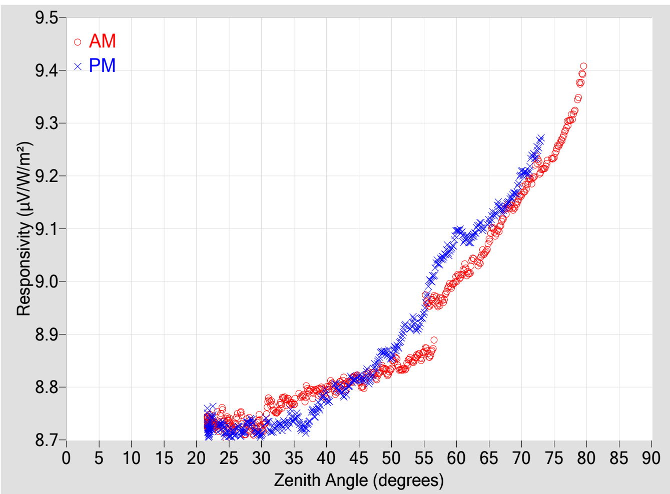


Figure 2. Responsivity vs Local Standard Time

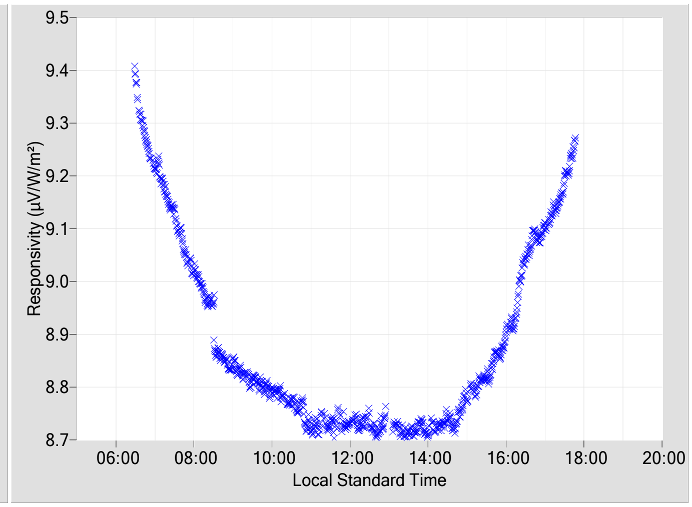


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle	R	u(B)	Azimuth	R	u(B)	Azimuth	Angle	R	u(B)	Azimuth	R	u(B)	Azimuth
(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle	(deg.)	(µV/W/m²)	± (%)	Angle	(µV/W/m²)	± (%)	Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	8.8132	0.43	105.77	8.8226	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.8231	0.40	103.75	8.8534	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.8406	0.41	101.80	8.8563	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.8341	0.44	100.04	8.9125	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8597	0.43	98.28	8.9108	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.9045	0.44	95.27	9.0015	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.9666	0.47	92.10	9.0480	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.0055	0.46	90.58	9.0946	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.0185	0.54	89.12	9.0776	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.0519	0.50	87.66	9.1028	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.0916	0.53	86.17	9.1309	0.57	271.28
22	8.7319	0.37	170.69	8.7203	0.38	189.46	68	9.1417	0.56	84.76	9.1512	N/A	272.73
24	8.7400	0.36	151.24	8.7258	0.36	208.48	70	9.1670	N/A	83.35	9.2042	N/A	274.17
26	8.7328	0.34	142.38	8.7142	0.37	217.57	72	9.2099	N/A	81.96	9.2374	N/A	275.61
28	8.7344	0.36	135.57	8.7319	0.38	224.54	74	9.2239	N/A	80.62	N/A	N/A	N/A
30	8.7236	0.38	130.11	8.7122	0.38	229.93	76	9.2626	N/A	79.15	N/A	N/A	N/A
32	8.7535	0.38	125.60	8.7234	0.35	234.47	78	9.3175	N/A	77.71	N/A	N/A	N/A
34	8.7736	0.37	121.89	8.7303	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7842	0.39	118.51	8.7245	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7889	0.37	115.41	8.7509	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7905	0.39	112.67	8.7814	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8040	0.38	110.22	8.7967	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8149	0.38	107.93	8.8132	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

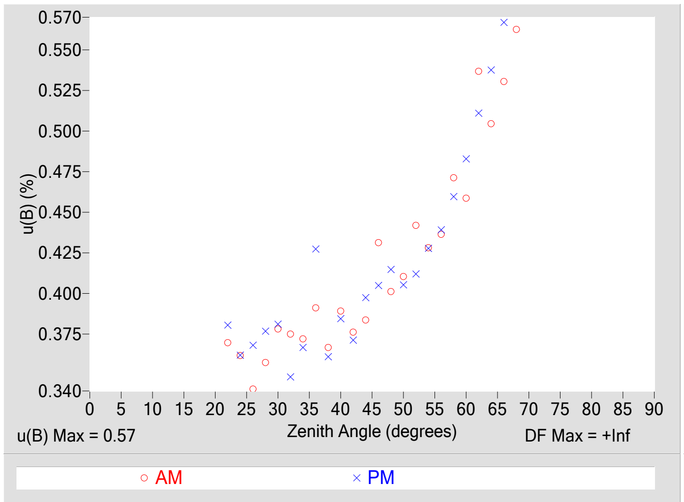


Figure 4. Residuals from Spline Interpolation

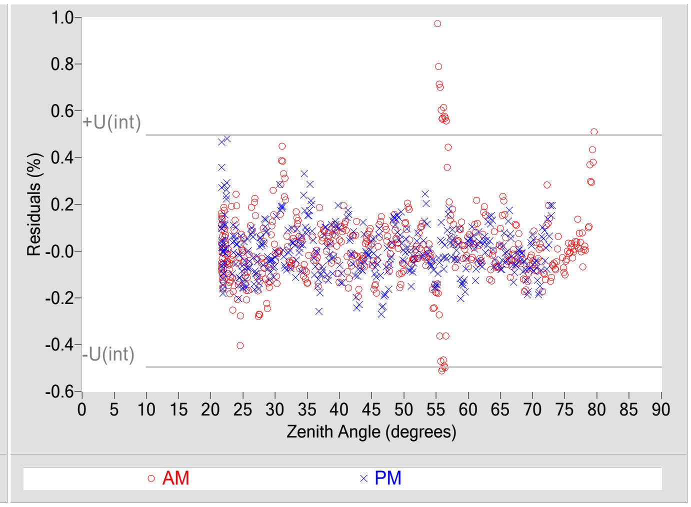


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.25
Combined Standard Uncertainty, u(c) (%)	±0.62
Effective degrees of freedom, DF(c)	30826
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

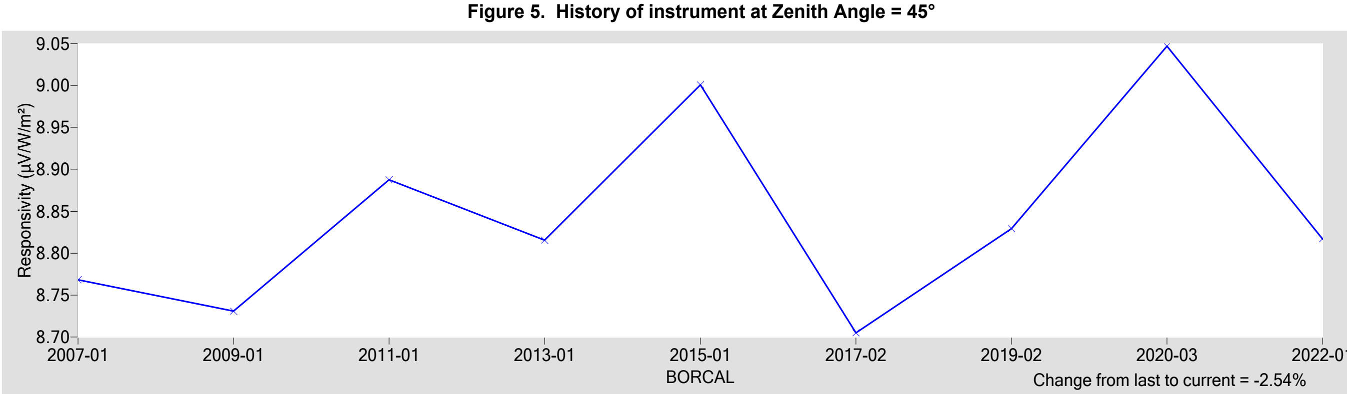
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.8171	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+3.1 / -1.2
Expanded Uncertainty, U (%)	+4.1 / -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 Thermal Offset Error During Outdoor Calibration Using the 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:**	33379
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	TWP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

33379 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

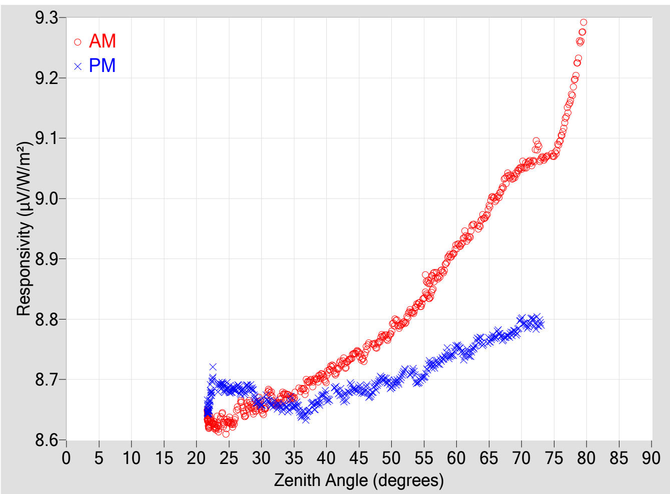


Figure 2. Responsivity vs Local Standard Time

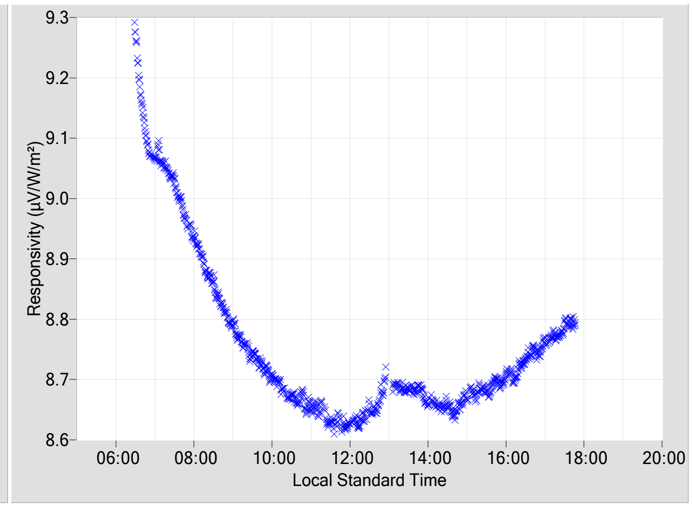


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.7441	0.43	105.77	8.6836	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7597	0.40	103.75	8.6974	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7834	0.41	101.80	8.6873	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7943	0.44	100.04	8.7148	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.8242	0.43	98.28	8.6950	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.8504	0.44	95.27	8.7252	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8817	0.47	92.10	8.7360	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.9200	0.46	90.58	8.7548	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.9375	0.54	89.12	8.7417	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.9672	0.50	87.66	8.7615	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9993	0.53	86.17	8.7718	0.57	271.28
22	8.6314	0.37	170.69	8.6592	0.38	189.46	68	9.0381	0.56	84.76	8.7730	N/A	272.73
24	8.6331	0.36	151.24	8.6902	0.36	208.48	70	9.0532	N/A	83.35	8.7981	N/A	274.17
26	8.6382	0.34	142.38	8.6845	0.37	217.57	72	9.0726	N/A	81.96	8.7929	N/A	275.61
28	8.6586	0.36	135.57	8.6871	0.38	224.54	74	9.0694	N/A	80.62	N/A	N/A	N/A
30	8.6509	0.38	130.11	8.6595	0.38	229.93	76	9.0976	N/A	79.15	N/A	N/A	N/A
32	8.6614	0.38	125.60	8.6584	0.35	234.47	78	9.1845	N/A	77.71	N/A	N/A	N/A
34	8.6722	0.37	121.89	8.6527	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6838	0.39	118.51	8.6423	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6962	0.37	115.41	8.6565	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.7051	0.39	112.67	8.6714	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7236	0.38	110.22	8.6780	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7393	0.38	107.93	8.6849	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

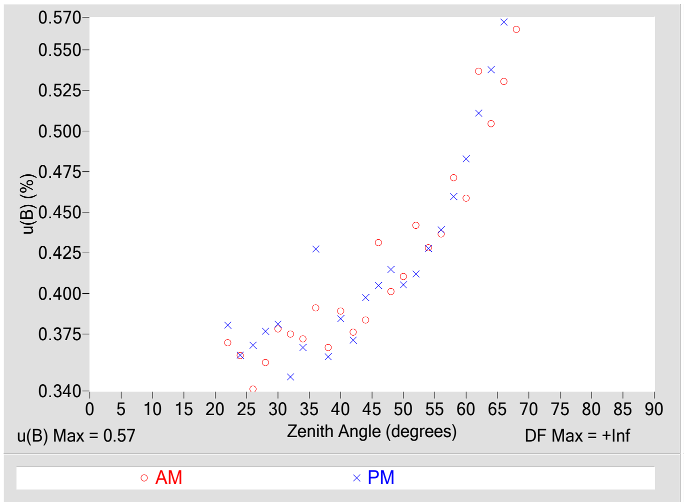


Figure 4. Residuals from Spline Interpolation

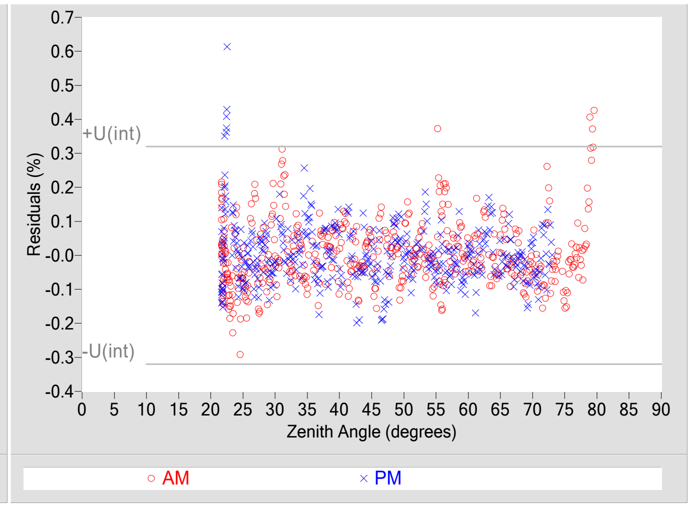


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	146484
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

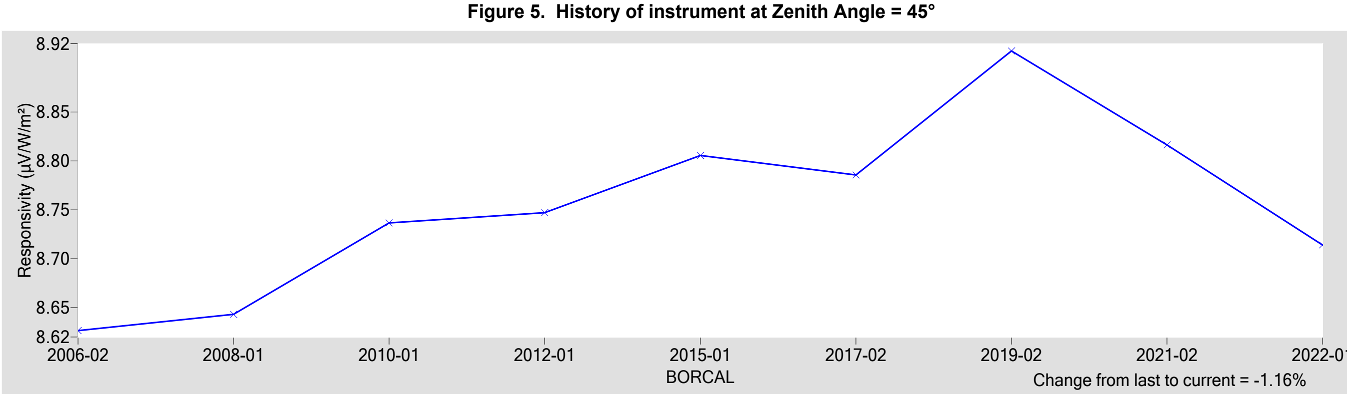
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.7143	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.4 / -0.83
Expanded Uncertainty, U (%)	+3.3 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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: 5/7/2022
Due Date: 5/7/2023
Customer: TWP
Environmental Conditions: see page 4
Test Dates: 4/30, 5/7

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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 - 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

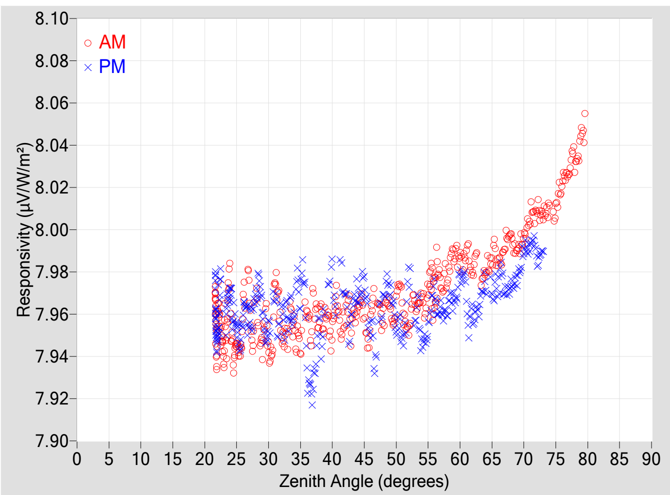


Figure 2. Responsivity vs Local Standard Time

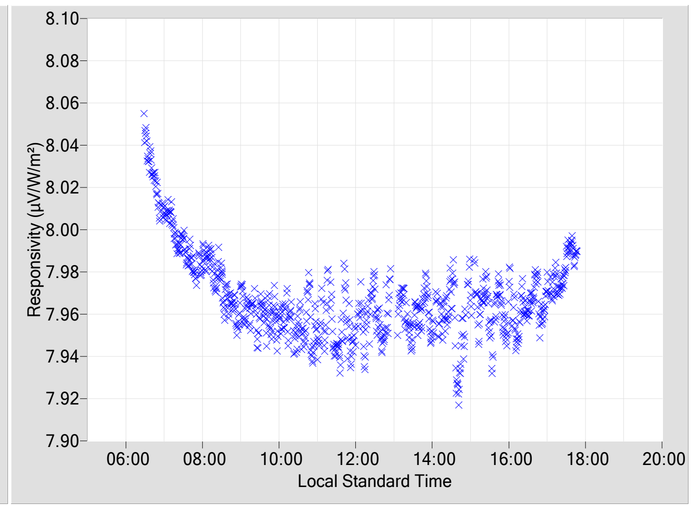


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9564	0.29	105.79	7.9541	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9563	0.29	103.83	7.9668	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9660	0.29	101.81	7.9543	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9537	0.29	100.05	7.9780	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9678	0.29	98.24	7.9469	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9687	0.30	95.29	7.9707	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9764	0.29	92.06	7.9616	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9876	0.31	90.60	7.9777	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9800	0.29	89.08	7.9592	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9813	0.30	87.62	7.9740	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9856	0.30	86.18	7.9739	0.30	271.29
22	7.9552	0.30	170.42	7.9533	0.30	189.39	68	7.9963	0.30	84.77	7.9731	N/A	272.75
24	7.9656	0.28	151.74	7.9688	0.29	208.60	70	7.9963	N/A	83.37	7.9909	N/A	274.18
26	7.9590	0.29	142.26	7.9599	0.29	217.92	72	8.0085	N/A	81.97	7.9874	N/A	275.62
28	7.9653	0.31	135.26	7.9680	0.29	224.68	74	8.0099	N/A	80.64	N/A	N/A	N/A
30	7.9438	0.29	130.14	7.9532	0.29	229.96	76	8.0220	N/A	79.11	N/A	N/A	N/A
32	7.9527	0.28	125.73	7.9615	0.31	234.66	78	8.0327	N/A	77.68	N/A	N/A	N/A
34	7.9521	0.31	121.80	7.9610	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9612	0.31	118.52	7.9379	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9584	0.31	115.51	7.9513	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9528	0.28	112.68	7.9760	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9591	0.30	110.23	7.9694	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9623	0.30	107.94	7.9699	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

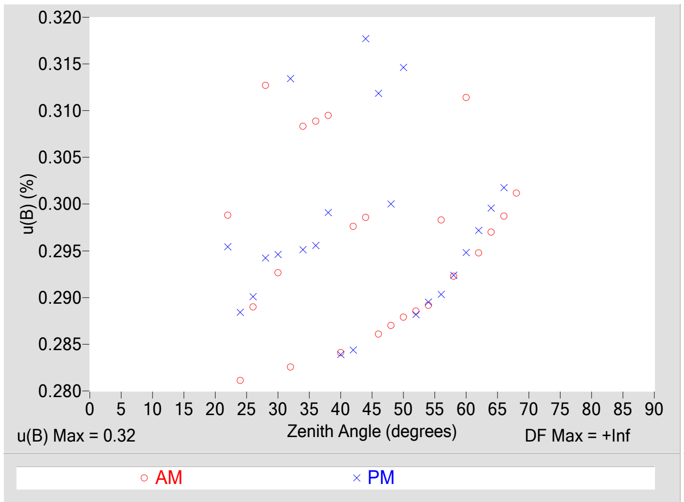


Figure 4. Residuals from Spline Interpolation

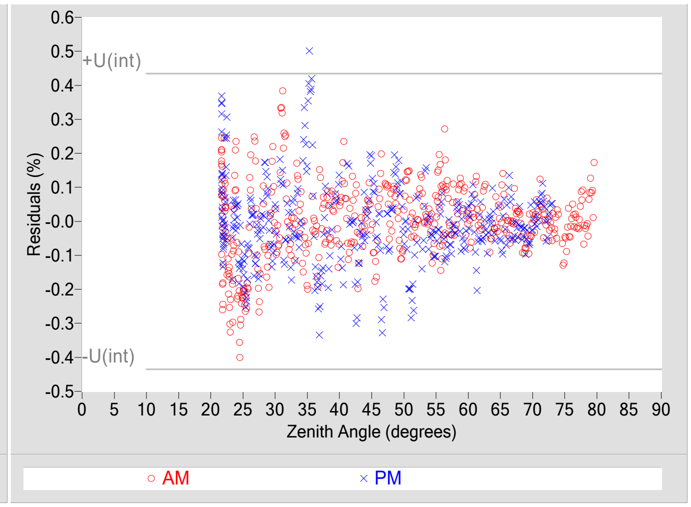


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.22
Combined Standard Uncertainty, u(c) (%)	±0.38
Effective degrees of freedom, DF(c)	7825
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.75
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

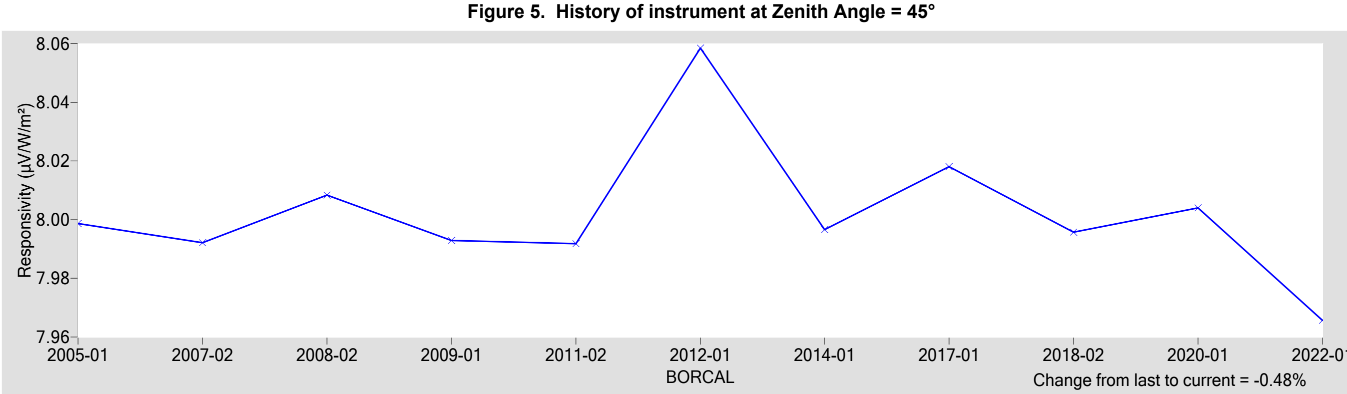
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9657	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.28 / -0.35
Expanded Uncertainty, U (%)	+0.90 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	33784
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

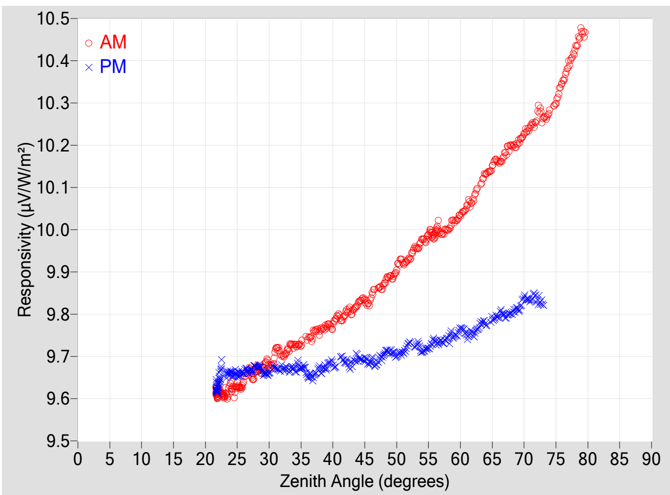


Figure 2. Responsivity vs Local Standard Time

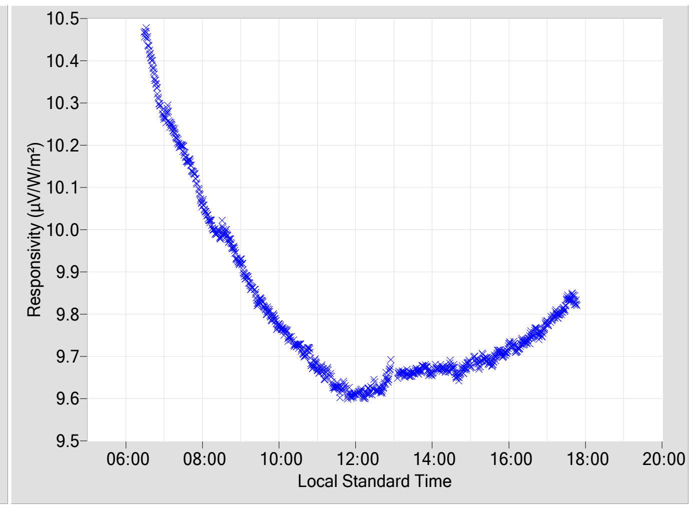


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith 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	9.8381	0.43	105.77	9.6890	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.8693	0.40	103.75	9.7058	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.9080	0.41	101.80	9.7005	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.9305	0.44	100.04	9.7320	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.9756	0.43	98.28	9.7113	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.9895	0.44	95.27	9.7359	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.001	0.47	92.10	9.7418	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.035	0.46	90.58	9.7659	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.070	0.54	89.12	9.7534	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.132	0.50	87.66	9.7774	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.160	0.53	86.17	9.7960	0.57	271.28
22	9.6129	0.37	170.69	9.6295	0.38	189.46	68	10.200	0.56	84.76	9.8024	N/A	272.73
24	9.6277	0.36	151.24	9.6609	0.36	208.48	70	10.228	N/A	83.35	9.8380	N/A	274.17
26	9.6406	0.34	142.38	9.6626	0.37	217.57	72	10.268	N/A	81.96	9.8347	N/A	275.61
28	9.6706	0.36	135.57	9.6755	0.38	224.54	74	10.277	N/A	80.62	N/A	N/A	N/A
30	9.6775	0.38	130.11	9.6620	0.38	229.93	76	10.347	N/A	79.15	N/A	N/A	N/A
32	9.7021	0.37	125.60	9.6721	0.35	234.47	78	10.425	N/A	77.71	N/A	N/A	N/A
34	9.7257	0.37	121.89	9.6694	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.7438	0.39	118.51	9.6535	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.7608	0.37	115.41	9.6685	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.7748	0.39	112.67	9.6811	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.8021	0.38	110.22	9.6866	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.8254	0.38	107.93	9.6956	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

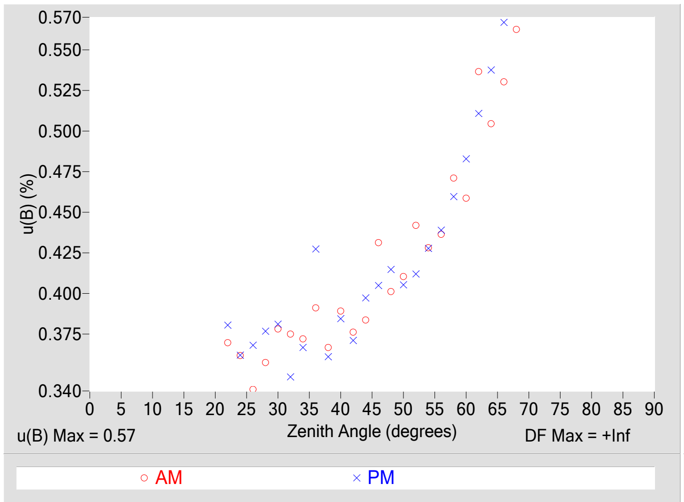


Figure 4. Residuals from Spline Interpolation

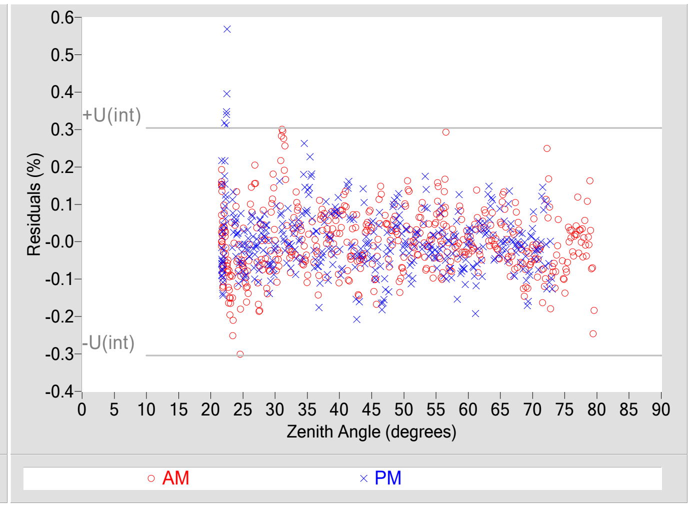


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	176306
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

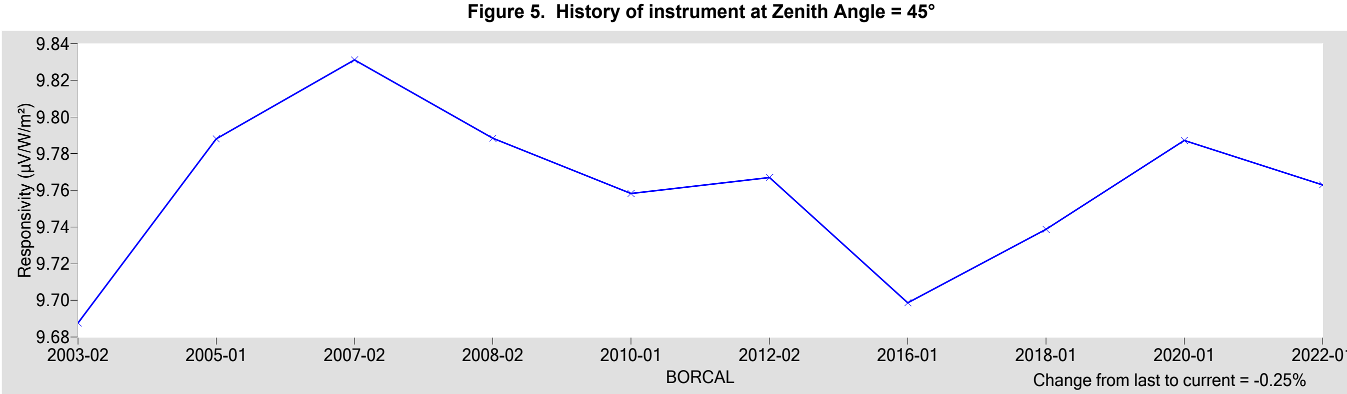
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
9.7630	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.8 / -1.1
Expanded Uncertainty, U (%)	+3.7 / -2.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

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

Figure 1. Responsivity vs Zenith Angle

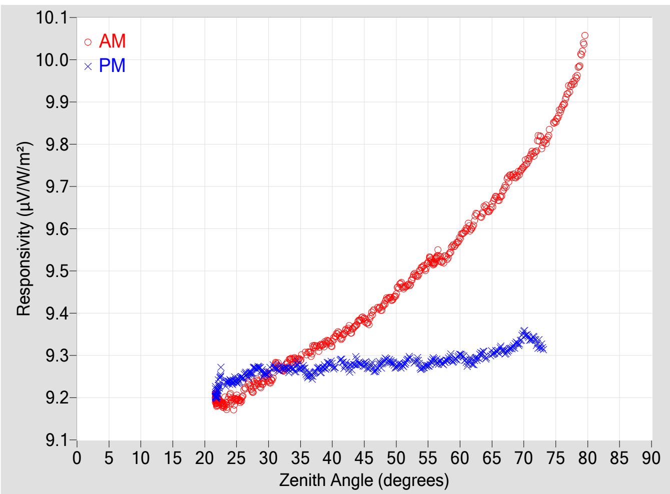


Figure 2. Responsivity vs Local Standard Time

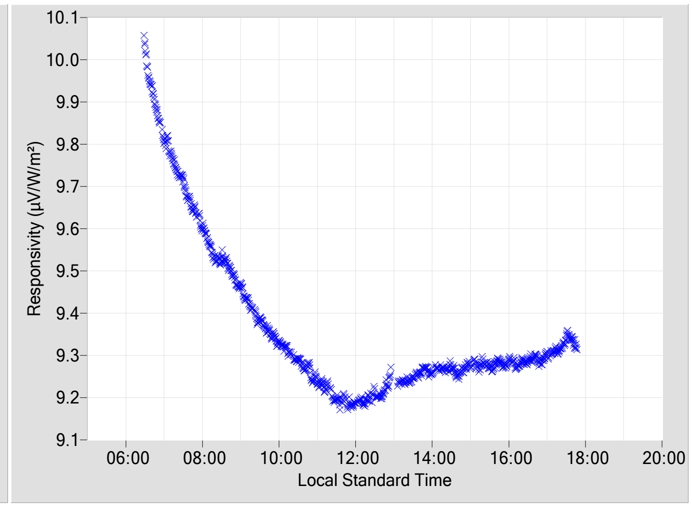


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.3898	0.43	105.77	9.2758	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.4170	0.40	103.75	9.2863	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.4496	0.41	101.80	9.2718	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.4669	0.44	100.04	9.2935	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.5069	0.43	98.28	9.2692	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.5218	0.44	95.27	9.2880	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.5332	0.47	92.10	9.2896	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.5783	0.46	90.58	9.3011	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6059	0.54	89.12	9.2827	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.6516	0.50	87.66	9.2983	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.6712	0.53	86.17	9.3103	0.57	271.28
22	9.1928	0.37	170.69	9.2123	0.38	189.46	68	9.7256	0.56	84.76	9.3172	N/A	272.73
24	9.1977	0.36	151.24	9.2385	0.36	208.48	70	9.7500	N/A	83.35	9.3528	N/A	274.17
26	9.2067	0.34	142.38	9.2489	0.37	217.57	72	9.7952	N/A	81.96	9.3286	N/A	275.61
28	9.2362	0.36	135.57	9.2703	0.38	224.54	74	9.8240	N/A	80.62	N/A	N/A	N/A
30	9.2418	0.38	130.11	9.2607	0.38	229.93	76	9.8864	N/A	79.15	N/A	N/A	N/A
32	9.2657	0.37	125.60	9.2697	0.35	234.47	78	9.9512	N/A	77.71	N/A	N/A	N/A
34	9.2896	0.37	121.89	9.2669	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.3057	0.39	118.51	9.2529	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.3201	0.37	115.41	9.2660	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.3313	0.39	112.67	9.2762	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.3556	0.38	110.22	9.2756	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.3781	0.38	107.93	9.2822	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

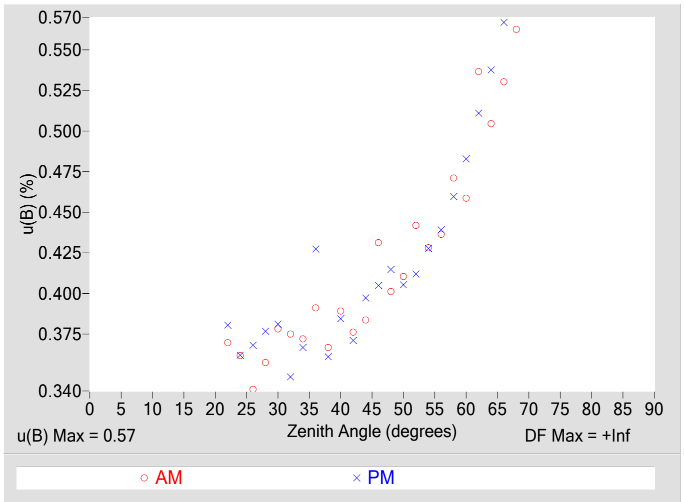


Figure 4. Residuals from Spline Interpolation

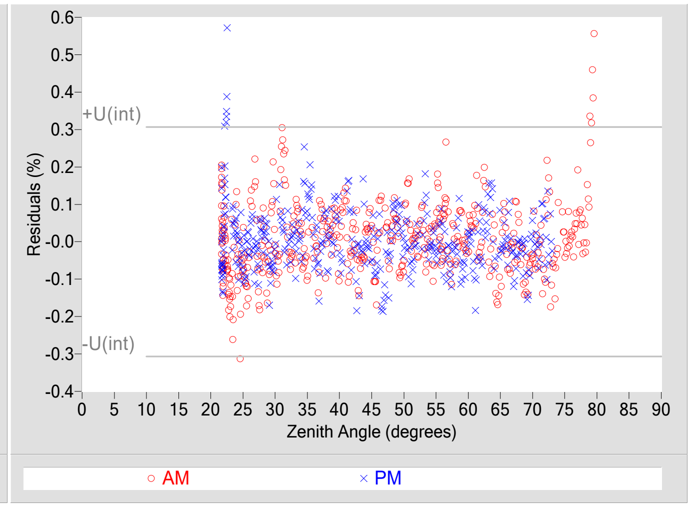


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	171176
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

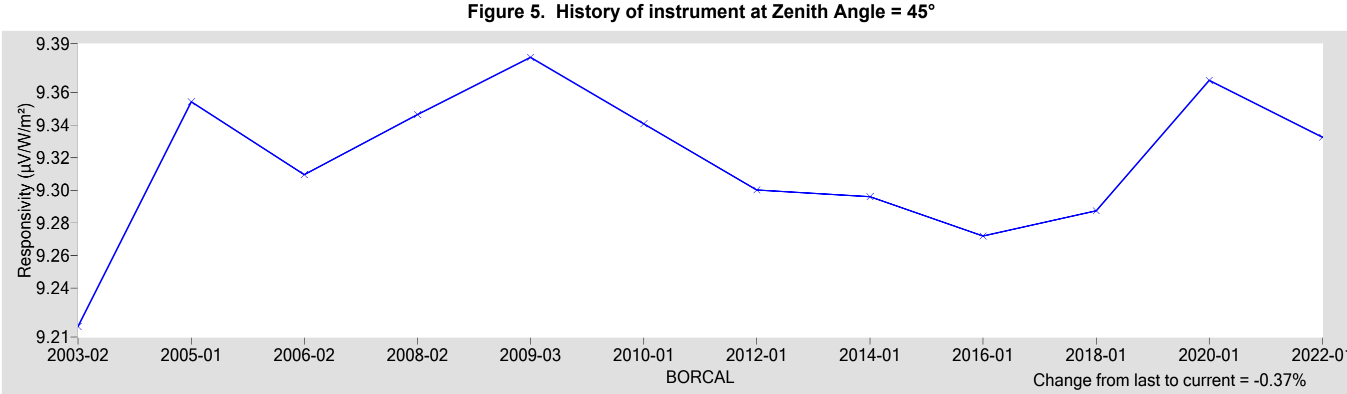
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.3326	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.6 / -0.97
Expanded Uncertainty, U (%)	+3.6 / -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 Thermal Offset Error During Outdoor Calibration Using the 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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

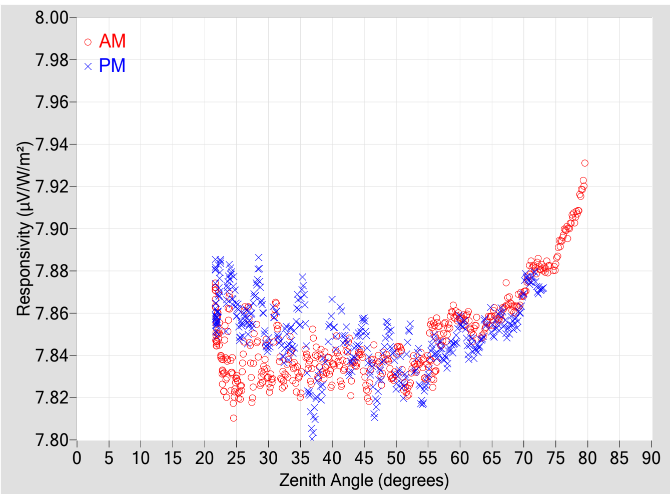


Figure 2. Responsivity vs Local Standard Time

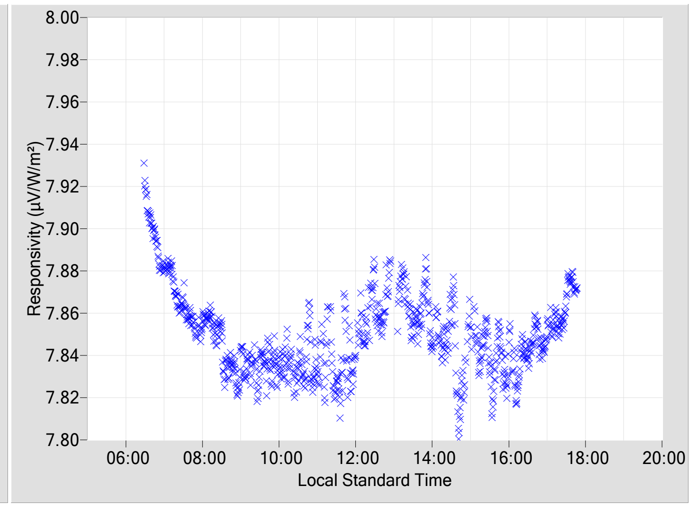


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	7.8305	0.29	105.79	7.8348	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8330	0.29	103.89	7.8416	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8384	0.29	101.81	7.8299	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8239	0.29	100.05	7.8511	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8376	0.29	98.24	7.8191	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8400	0.30	95.29	7.8449	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8511	0.29	92.06	7.8378	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8581	0.31	90.60	7.8561	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8500	0.29	89.08	7.8434	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8536	0.30	87.62	7.8556	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8574	0.30	86.18	7.8559	0.30	271.29
22	7.8529	0.30	170.42	7.8604	0.30	189.39	68	7.8643	0.30	84.77	7.8549	N/A	272.75
24	7.8492	0.28	151.74	7.8775	0.29	208.60	70	7.8694	N/A	83.37	7.8720	N/A	274.18
26	7.8411	0.29	142.26	7.8555	0.29	217.92	72	7.8821	N/A	81.97	7.8732	N/A	275.62
28	7.8494	0.31	135.26	7.8720	0.29	224.68	74	7.8814	N/A	80.64	N/A	N/A	N/A
30	7.8278	0.29	130.14	7.8447	0.29	229.96	76	7.8953	N/A	79.11	N/A	N/A	N/A
32	7.8318	0.28	125.73	7.8427	0.31	234.66	78	7.9060	N/A	77.68	N/A	N/A	N/A
34	7.8319	0.31	121.80	7.8472	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8391	0.31	118.52	7.8353	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8354	0.31	115.51	7.8270	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8316	0.28	112.68	7.8579	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8382	0.30	110.23	7.8501	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8386	0.30	107.94	7.8474	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

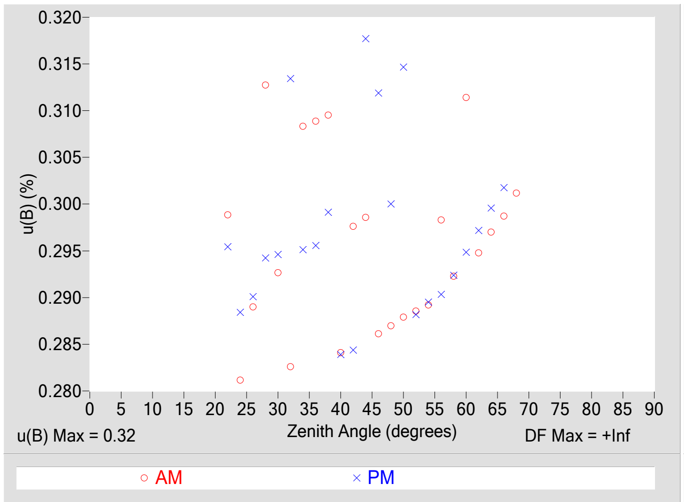


Figure 4. Residuals from Spline Interpolation

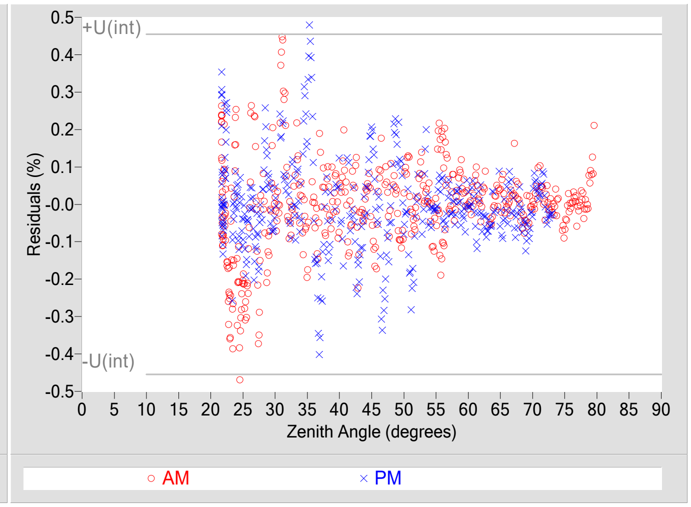


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.23
Combined Standard Uncertainty, u(c) (%)	±0.39
Effective degrees of freedom, DF(c)	6963
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.77
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

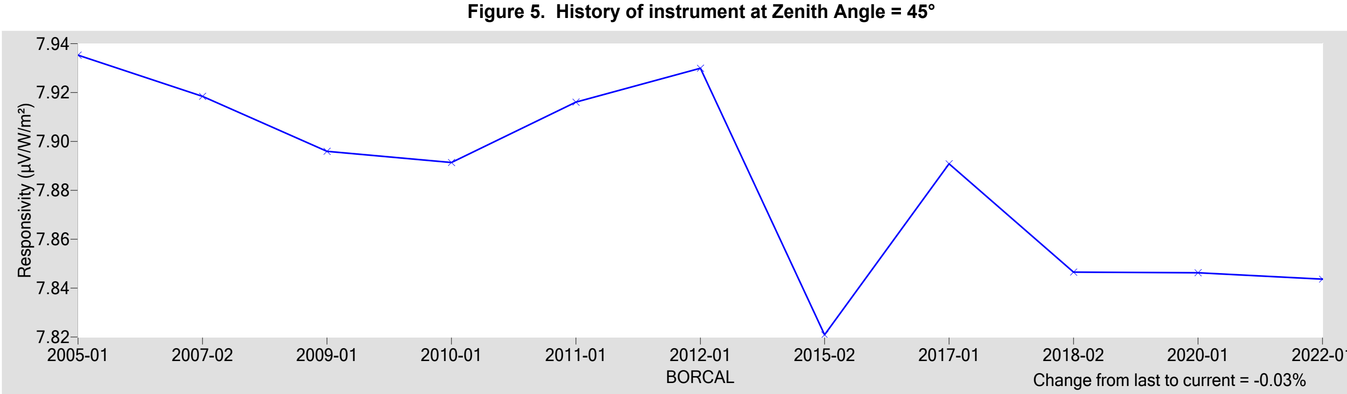
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8436	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.18 / -0.31
Expanded Uncertainty, U (%)	+0.81 / -0.94
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

[1] Reda, I.; Hickey, J.; Long, C.; Myers, D.; Stoffel, T.; Wilcox, S.; Michalsky, J. J.; Dutton, E. G.; Nelson, D. (2005). "Using a Blackbody to Calculate Net Longwave Responsivity of Shortwave Solar Pyranometers to Correct for Their Thermal Offset Error During Outdoor Calibration Using the 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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

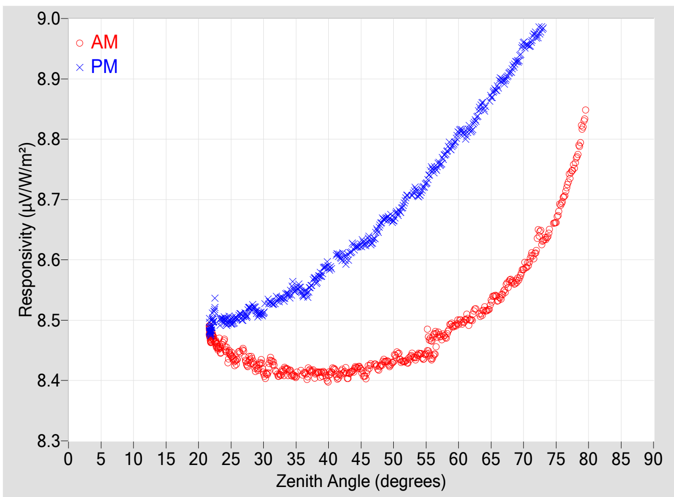


Figure 2. Responsivity vs Local Standard Time

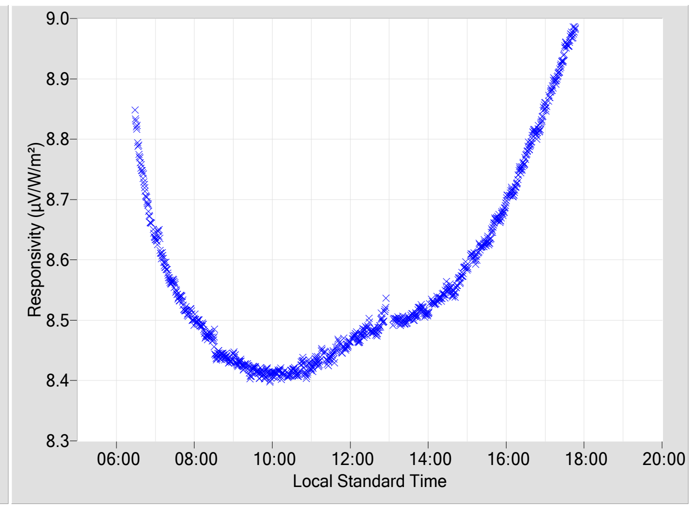


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	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	8.4154	0.43	105.77	8.6315	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4233	0.40	103.75	8.6609	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4351	0.41	101.80	8.6655	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4311	0.44	100.04	8.7038	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4440	0.43	98.28	8.7075	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4525	0.44	95.27	8.7499	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4734	0.47	92.10	8.7770	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4969	0.46	90.58	8.8123	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5021	0.54	89.12	8.8170	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5175	0.50	87.66	8.8531	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5354	0.53	86.17	8.8866	0.57	271.28
22	8.4734	0.37	170.69	8.4874	0.38	189.46	68	8.5652	0.56	84.76	8.9120	N/A	272.73
24	8.4573	0.36	151.24	8.5005	0.36	208.48	70	8.5868	N/A	83.35	8.9558	N/A	274.17
26	8.4377	0.34	142.38	8.5042	0.37	217.57	72	8.6247	N/A	81.96	8.9720	N/A	275.61
28	8.4355	0.36	135.57	8.5198	0.38	224.54	74	8.6443	N/A	80.62	N/A	N/A	N/A
30	8.4139	0.38	130.11	8.5142	0.38	229.93	76	8.6976	N/A	79.15	N/A	N/A	N/A
32	8.4125	0.38	125.60	8.5338	0.35	234.47	78	8.7620	N/A	77.71	N/A	N/A	N/A
34	8.4142	0.37	121.89	8.5427	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4128	0.39	118.51	8.5428	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4104	0.37	115.41	8.5667	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4062	0.39	112.67	8.5892	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4134	0.38	110.22	8.6041	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4188	0.38	107.93	8.6214	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

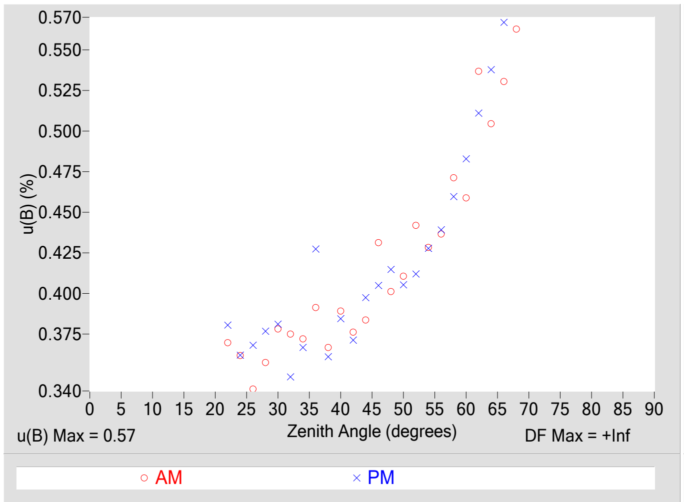


Figure 4. Residuals from Spline Interpolation

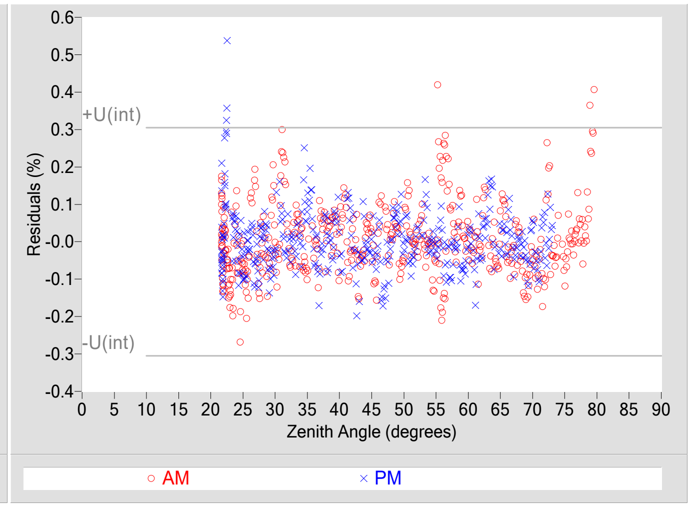


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	175030
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

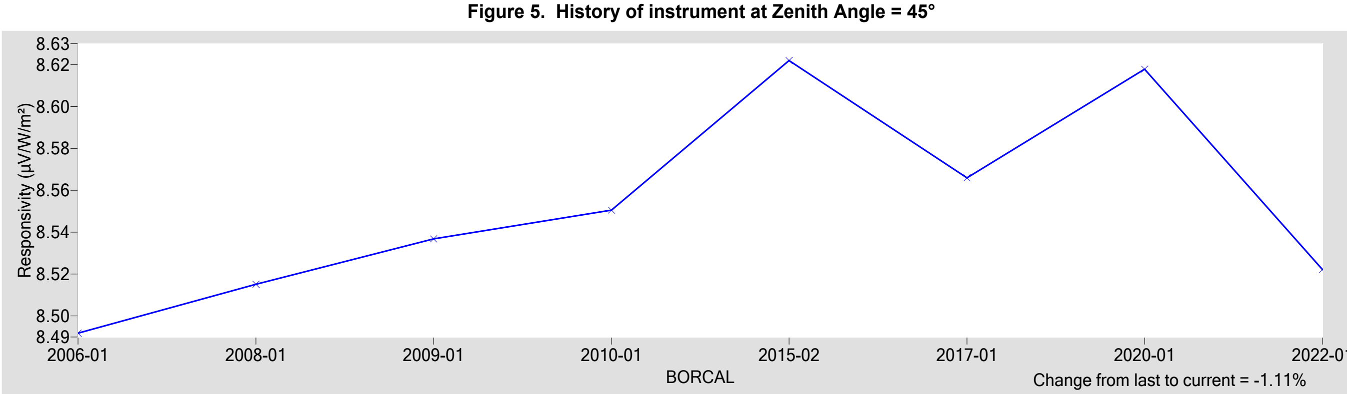
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.5222	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+3.4 / -1.4
Expanded Uncertainty, U (%)	+4.3 / -2.3
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument: Normal Incidence Pyrheliometer

Manufacturer: Eppley

Model: NIP

Serial Number: 34504E6

Calibration Date: 5/7/2022

Due Date: 5/7/2023

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 4/30, 5/7

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

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

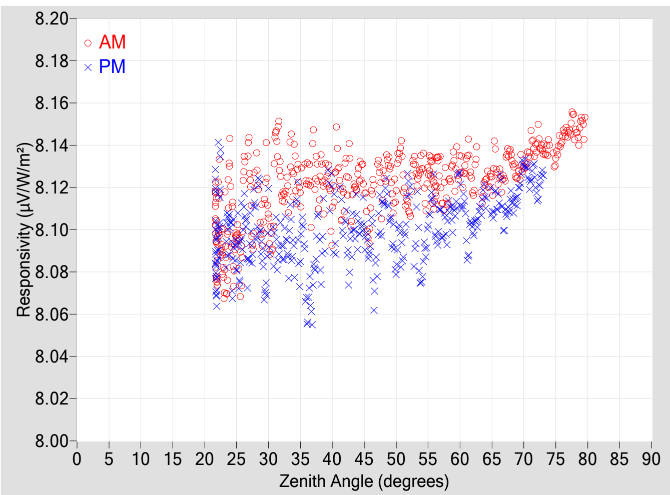


Figure 2. Responsivity vs Local Standard Time

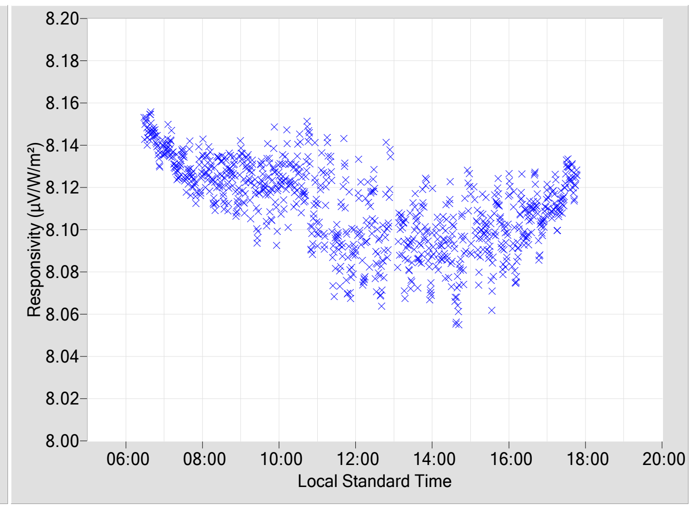


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1080	0.29	105.79	8.0957	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.1178	0.29	103.83	8.1141	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.1246	0.29	101.81	8.0850	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.1096	0.29	100.05	8.1217	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.1312	0.29	98.24	8.0775	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.1177	0.30	95.29	8.1082	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.1158	0.29	92.06	8.1021	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.1301	0.31	90.60	8.1194	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.1192	0.29	89.08	8.1009	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.1238	0.30	87.62	8.1155	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.1256	0.30	86.18	8.1149	0.30	271.29
22	8.0974	0.30	170.42	8.0872	0.30	189.23	68	8.1348	0.30	84.77	8.1137	N/A	272.75
24	8.1146	0.28	151.74	8.0975	0.29	208.60	70	8.1294	N/A	83.37	8.1314	N/A	274.18
26	8.1087	0.29	142.26	8.1048	0.29	217.92	72	8.1405	N/A	81.97	8.1180	N/A	275.62
28	8.1281	0.31	135.26	8.1033	0.29	224.68	74	8.1392	N/A	80.64	N/A	N/A	N/A
30	8.1051	0.29	130.14	8.0972	0.29	229.96	76	8.1434	N/A	79.11	N/A	N/A	N/A
32	8.1222	0.28	125.73	8.0935	0.31	234.66	78	8.1477	N/A	77.68	N/A	N/A	N/A
34	8.1272	0.31	121.80	8.0929	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.1258	0.31	118.52	8.0627	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1215	0.31	115.51	8.0894	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1072	0.28	112.68	8.1132	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1234	0.30	110.23	8.1057	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1232	0.30	107.94	8.1000	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

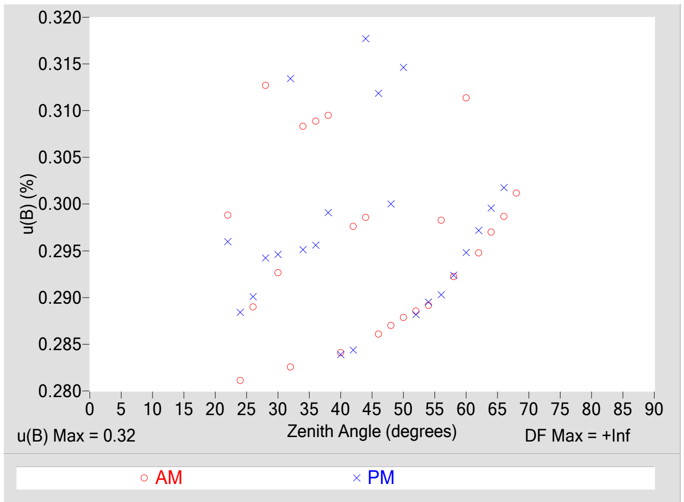


Figure 4. Residuals from Spline Interpolation

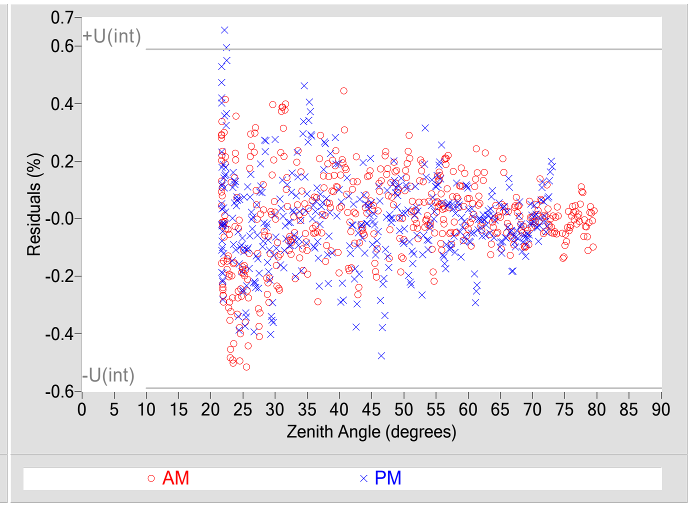


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.29
Combined Standard Uncertainty, u(c) (%)	±0.43
Effective degrees of freedom, DF(c)	3734
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.85
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

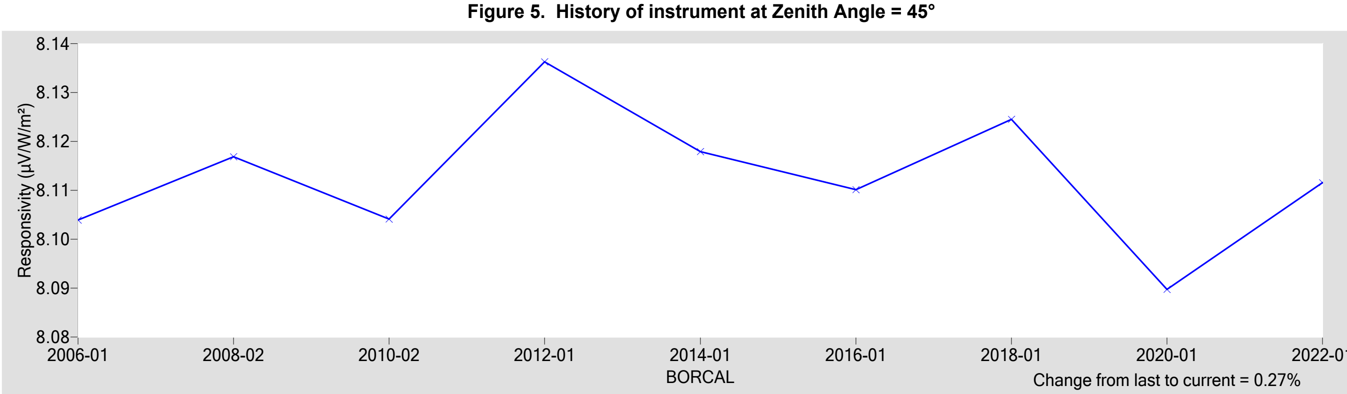
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.1115	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.24 / -0.60
Expanded Uncertainty, U (%)	+0.87 / -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:**	34505E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

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

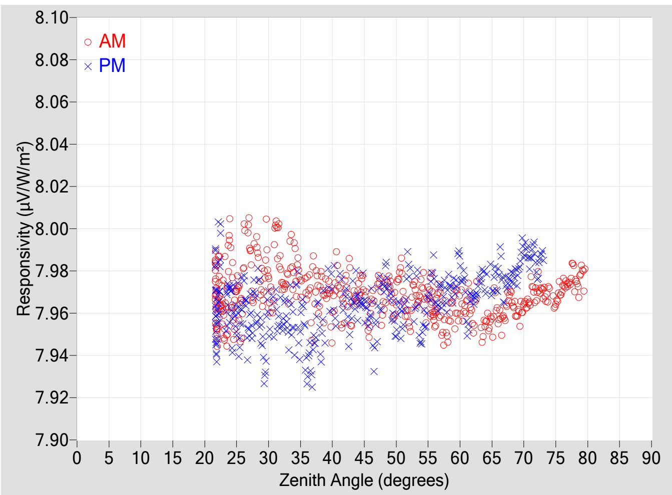


Figure 2. Responsivity vs Local Standard Time

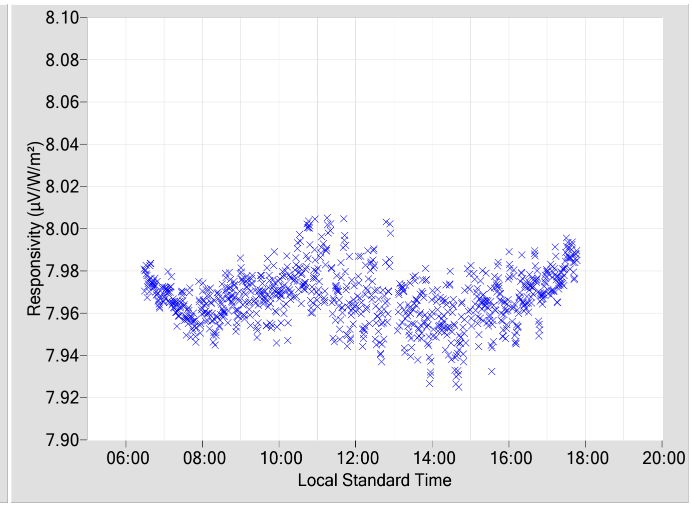


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.9586	0.29	105.79	7.9622	0.31	254.33
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.9602	0.29	103.83	7.9746	0.30	256.42
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9688	0.29	101.81	7.9532	0.31	258.26
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9561	0.29	100.05	7.9827	0.29	260.10
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9734	0.29	98.24	7.9486	0.29	261.86
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9583	0.30	95.29	7.9735	0.29	263.58
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9507	0.29	92.06	7.9686	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9638	0.31	90.60	7.9819	0.29	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9554	0.29	89.08	7.9673	0.30	268.33
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9565	0.30	87.62	7.9747	0.30	269.77
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9590	0.30	86.18	7.9784	0.30	271.29
22	7.9655	0.30	170.42	7.9577	0.30	189.23	68	7.9674	0.30	84.77	7.9766	N/A	272.75
24	7.9827	0.28	151.74	7.9656	0.29	208.60	70	7.9637	N/A	83.37	7.9909	N/A	274.18
26	7.9755	0.29	142.26	7.9683	0.29	217.92	72	7.9705	N/A	81.97	7.9808	N/A	275.62
28	7.9922	0.31	135.26	7.9614	0.29	224.68	74	7.9699	N/A	80.64	N/A	N/A	N/A
30	7.9749	0.29	130.14	7.9598	0.29	229.96	76	7.9721	N/A	79.11	N/A	N/A	N/A
32	7.9783	0.28	125.73	7.9576	0.31	234.66	78	7.9759	N/A	77.68	N/A	N/A	N/A
34	7.9819	0.31	121.80	7.9561	0.30	238.22	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.9717	0.31	118.52	7.9337	0.30	241.67	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.9697	0.31	115.51	7.9490	0.30	244.71	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.9579	0.28	112.68	7.9735	0.28	247.46	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.9691	0.30	110.23	7.9699	0.28	249.97	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.9686	0.30	107.94	7.9648	0.32	252.19	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

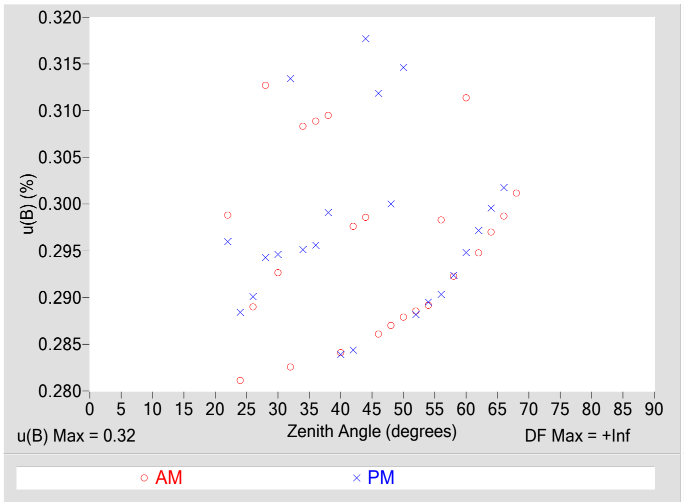


Figure 4. Residuals from Spline Interpolation

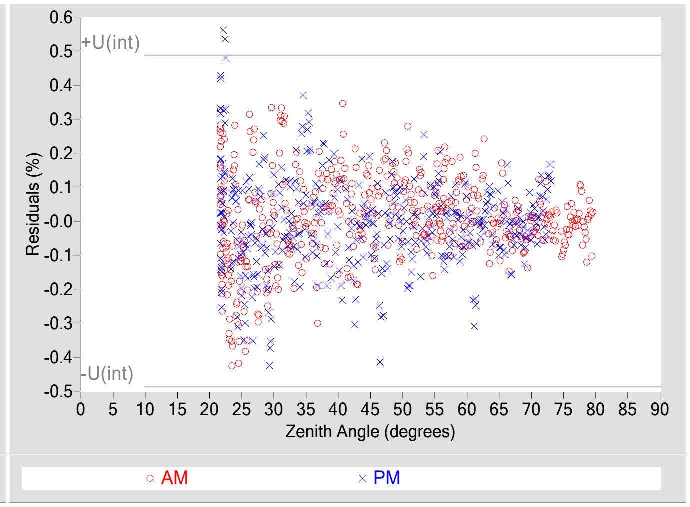


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.32
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	5830
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

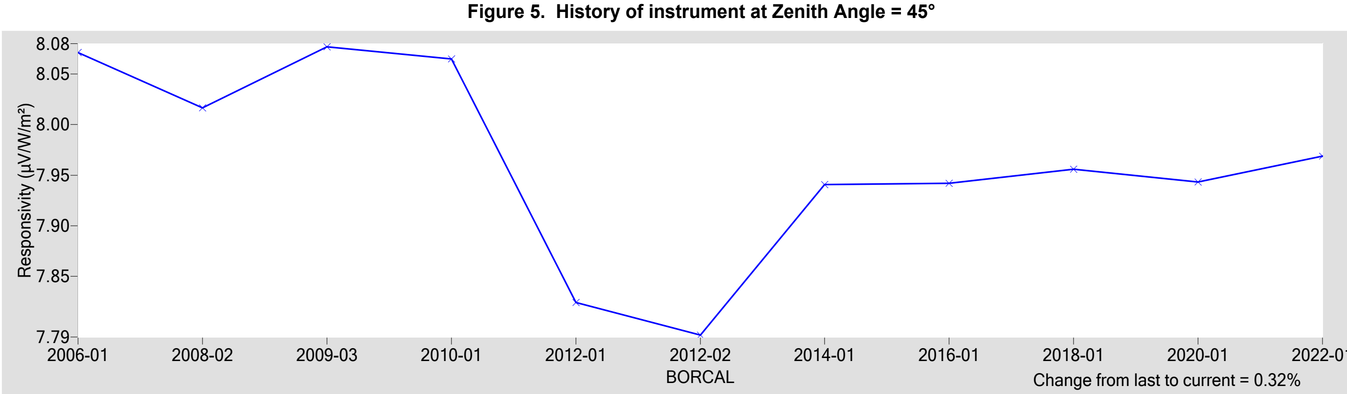
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.9688	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.17 / -0.44
Expanded Uncertainty, U (%)	+0.80 / -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: 34506E6

Calibration Date: 5/7/2022

Due Date: 5/7/2023

Customer: SGP

Environmental Conditions: see page 4

Test Dates: 4/30, 5/7

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

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

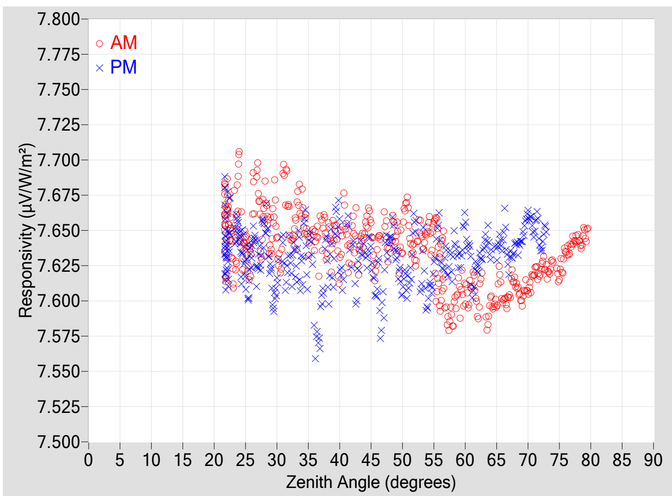


Figure 2. Responsivity vs Local Standard Time

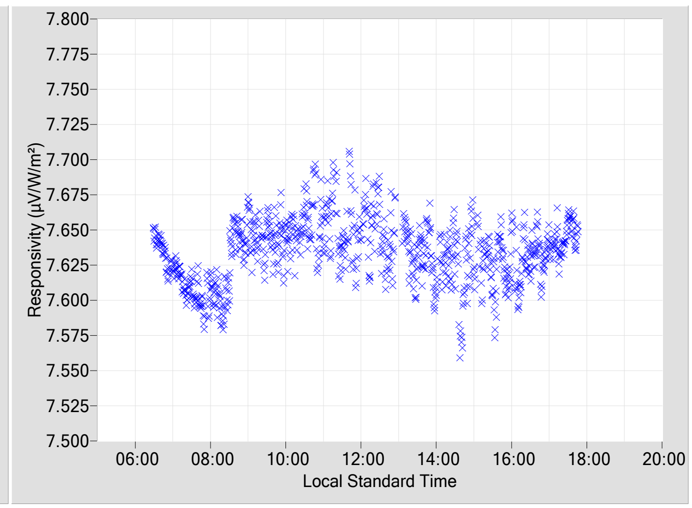


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.6348	0.29	105.79	7.6147	0.31	254.34
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.6350	0.29	103.84	7.6437	0.30	256.43
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.6479	0.29	101.82	7.6095	0.29	258.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.6307	0.29	100.00	7.6560	0.31	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.6527	0.29	98.25	7.5994	0.29	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.6209	0.31	95.29	7.6428	0.29	263.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.5885	0.29	92.07	7.6289	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.6046	0.29	90.60	7.6536	0.29	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.5929	0.29	89.09	7.6229	0.30	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.5975	0.30	87.63	7.6351	0.30	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.6006	0.30	86.19	7.6464	0.30	271.29
22	7.6539	0.30	170.56	7.6344	0.30	189.46	68	7.6123	0.30	84.77	7.6396	N/A	272.75
24	7.6734	0.30	151.60	7.6440	0.29	208.48	70	7.6072	N/A	83.37	7.6601	N/A	274.19
26	7.6528	0.30	142.30	7.6378	0.30	217.87	72	7.6214	N/A	81.93	7.6385	N/A	275.63
28	7.6678	0.29	135.57	7.6489	0.29	224.59	74	7.6283	N/A	80.64	N/A	N/A	N/A
30	7.6449	0.31	130.15	7.6122	0.28	229.84	76	7.6349	N/A	79.12	N/A	N/A	N/A
32	7.6584	0.28	125.81	7.6346	0.28	234.40	78	7.6435	N/A	77.68	N/A	N/A	N/A
34	7.6610	0.28	121.81	7.6275	0.31	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.6449	0.31	118.53	7.5721	0.30	241.81	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.6422	0.28	115.52	7.6250	0.30	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.6287	0.30	112.70	7.6424	0.30	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.6450	0.30	110.24	7.6355	0.31	249.92	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.6478	0.29	107.95	7.6351	0.31	252.23	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

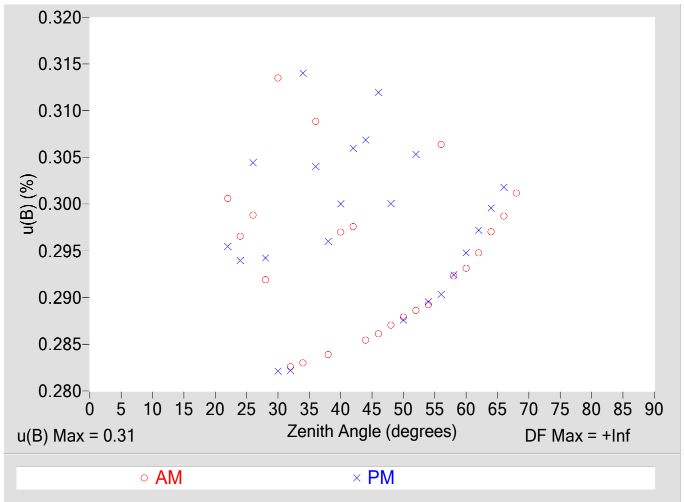


Figure 4. Residuals from Spline Interpolation

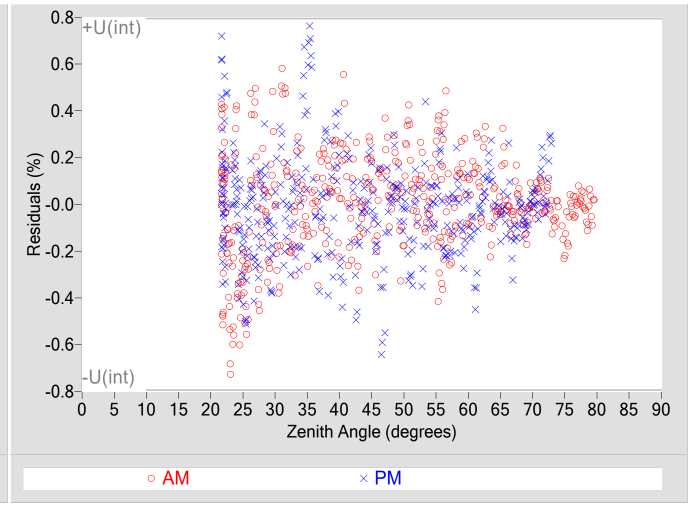


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.40
Combined Standard Uncertainty, u(c) (%)	±0.51
Effective degrees of freedom, DF(c)	2110
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.99
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

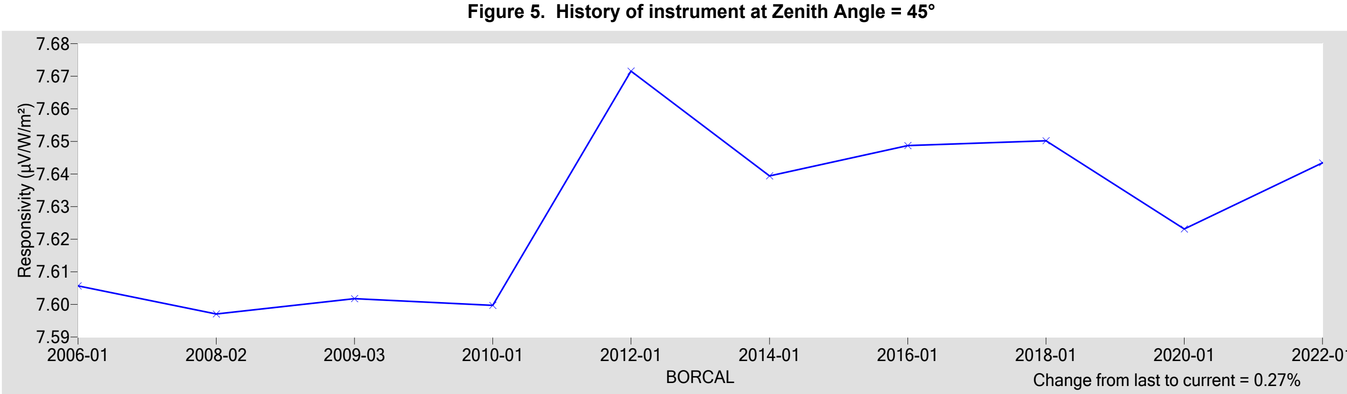
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
7.6435	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.23 / -0.93
Expanded Uncertainty, U (%)	+0.85 / -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:**	34580
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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 - 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

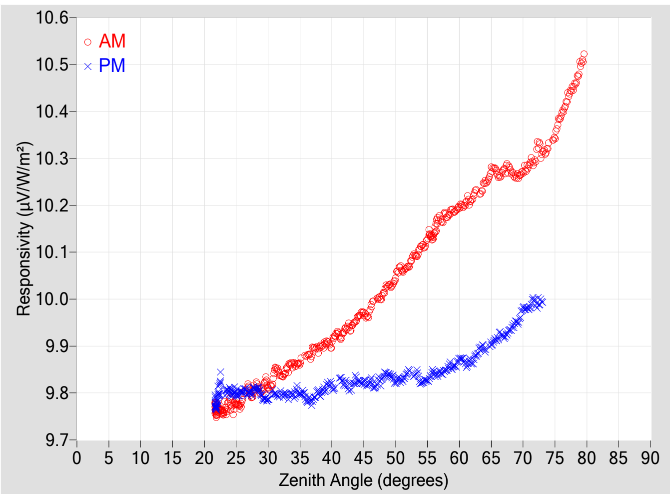


Figure 2. Responsivity vs Local Standard Time

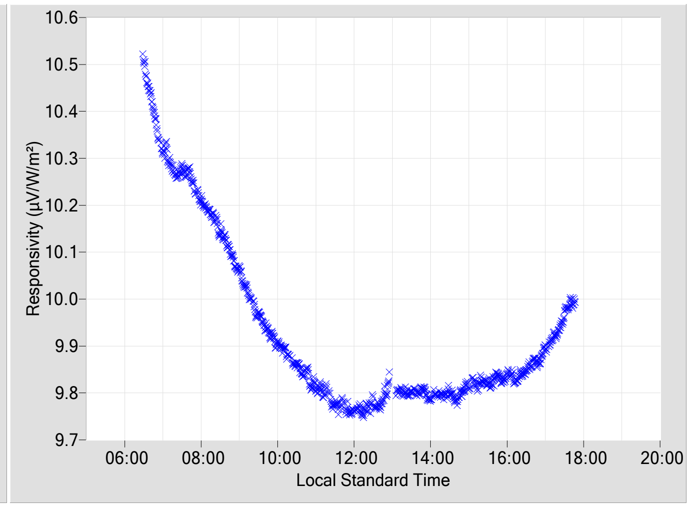


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	9.9766	0.43	105.77	9.8239	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	10.009	0.40	103.75	9.8347	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	10.048	0.41	101.80	9.8218	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	10.069	0.44	100.04	9.8454	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	10.111	0.43	98.28	9.8216	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	10.137	0.44	95.27	9.8426	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	10.178	0.47	92.10	9.8510	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	10.197	0.46	90.58	9.8725	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	10.212	0.54	89.12	9.8663	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	10.248	0.50	87.66	9.8940	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	10.265	0.53	86.17	9.9170	0.57	271.28
22	9.7639	0.37	170.69	9.7808	0.38	189.46	68	10.275	0.56	84.76	9.9352	N/A	272.73
24	9.7771	0.36	151.24	9.8049	0.36	208.48	70	10.274	N/A	83.35	9.9790	N/A	274.17
26	9.7864	0.34	142.38	9.8029	0.37	217.57	72	10.307	N/A	81.96	9.9910	N/A	275.61
28	9.8135	0.36	135.57	9.8082	0.38	224.54	74	10.325	N/A	80.62	N/A	N/A	N/A
30	9.8132	0.38	130.11	9.7879	0.38	229.93	76	10.391	N/A	79.15	N/A	N/A	N/A
32	9.8364	0.37	125.60	9.7972	0.35	234.47	78	10.454	N/A	77.71	N/A	N/A	N/A
34	9.8604	0.37	121.89	9.7954	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.8800	0.39	118.51	9.7846	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.8948	0.37	115.41	9.7998	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.9071	0.39	112.67	9.8139	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.9333	0.38	110.22	9.8193	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.9590	0.38	107.93	9.8257	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

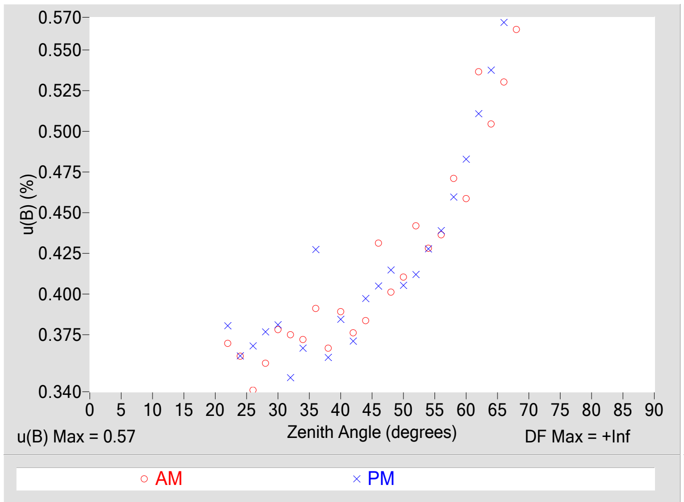


Figure 4. Residuals from Spline Interpolation

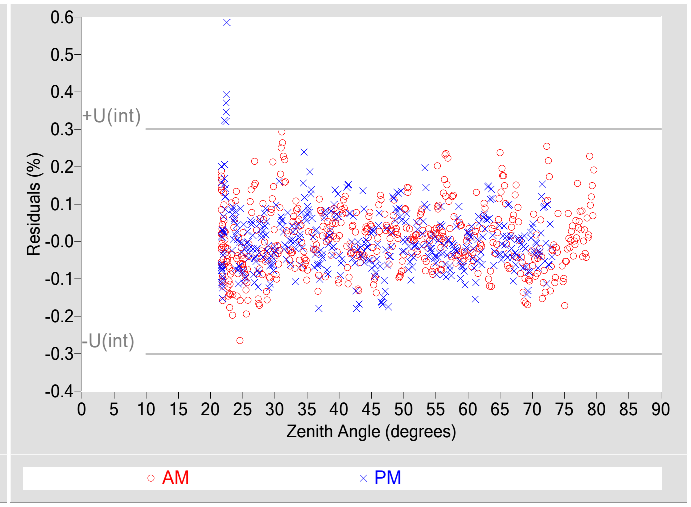


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.15
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	185104
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.1
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

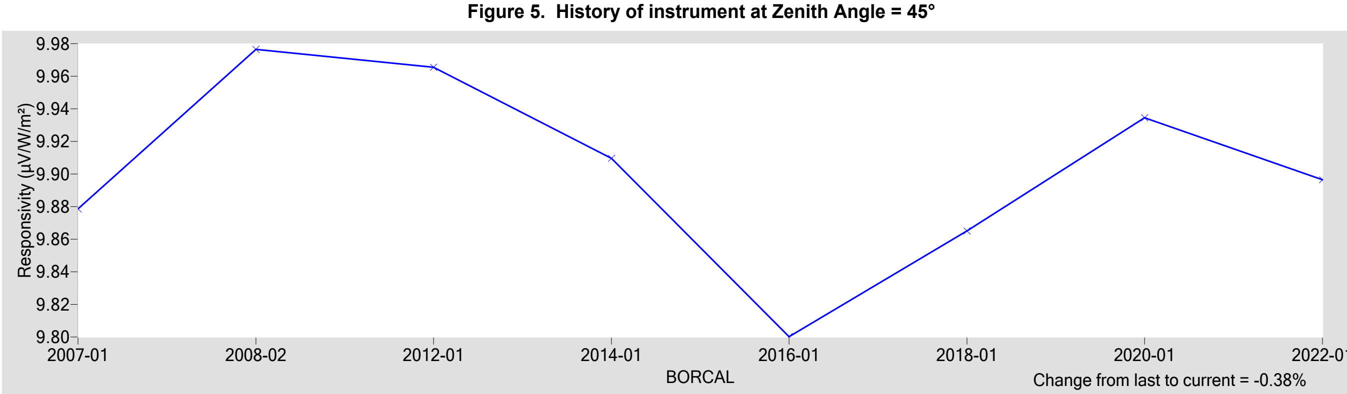
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.8965	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+3.0 / -1.1
Expanded Uncertainty, U (%)	+4.0 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	35751
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF#2	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

where,

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

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

Figure 1. Responsivity vs Zenith Angle

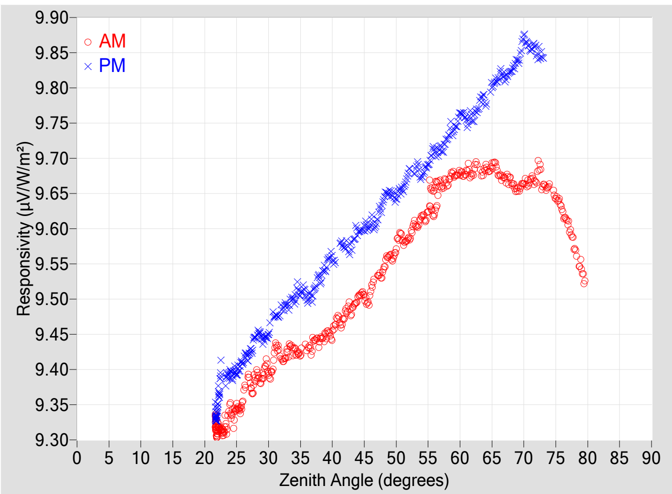


Figure 2. Responsivity vs Local Standard Time

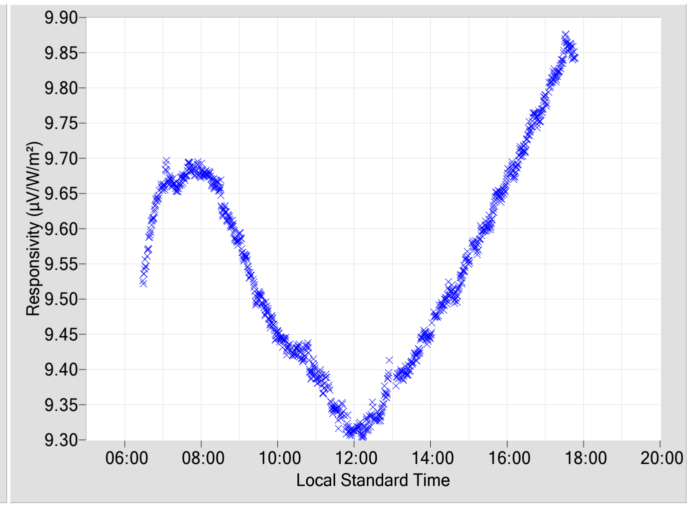


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle	Zenith Angle (deg.)	AM R (µV/W/m²)	AM u(B) ± (%)	AM Azimuth Angle	PM R (µV/W/m²)	PM u(B) ± (%)	PM Azimuth Angle
0	N/A	N/A	N/A	N/A	N/A	N/A	46	9.5088	0.43	105.77	9.6084	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	9.5404	0.40	103.75	9.6422	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	9.5751	0.41	101.80	9.6423	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	9.5855	0.44	100.04	9.6811	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	9.6168	0.43	98.28	9.6738	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	9.6384	0.44	95.27	9.7100	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	9.6654	0.47	92.10	9.7294	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	9.6796	0.46	90.58	9.7631	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	9.6784	0.54	89.12	9.7565	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	9.6868	0.50	87.66	9.7804	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	9.6776	0.53	86.17	9.8131	0.57	271.28
22	9.3157	0.37	170.69	9.3440	0.38	189.46	68	9.6673	0.56	84.76	9.8243	N/A	272.73
24	9.3403	0.36	151.24	9.3945	0.36	208.48	70	9.6656	N/A	83.35	9.8700	N/A	274.17
26	9.3582	0.34	142.38	9.4113	0.37	217.57	72	9.6756	N/A	81.96	9.8506	N/A	275.61
28	9.3905	0.36	135.57	9.4462	0.38	224.54	74	9.6607	N/A	80.62	N/A	N/A	N/A
30	9.3943	0.38	130.11	9.4525	0.38	229.93	76	9.6263	N/A	79.15	N/A	N/A	N/A
32	9.4150	0.37	125.60	9.4852	0.35	234.47	78	9.5720	N/A	77.71	N/A	N/A	N/A
34	9.4269	0.37	121.89	9.4995	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	9.4315	0.39	118.51	9.4997	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	9.4403	0.37	115.41	9.5290	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	9.4518	0.39	112.67	9.5576	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	9.4786	0.38	110.22	9.5752	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	9.5006	0.38	107.93	9.5958	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

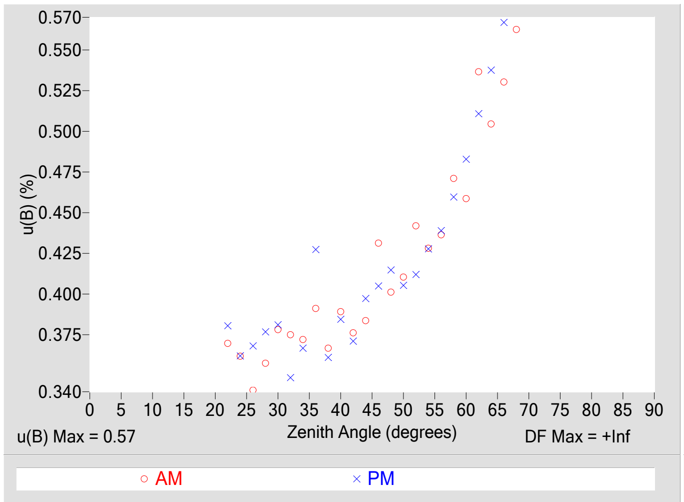


Figure 4. Residuals from Spline Interpolation

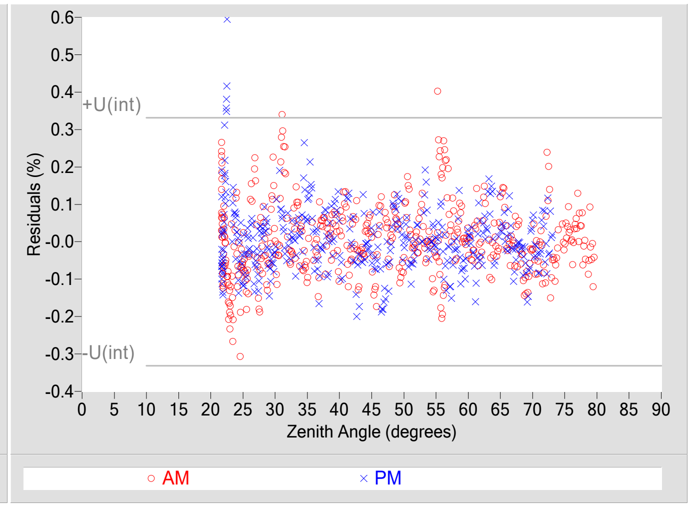


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	128649
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

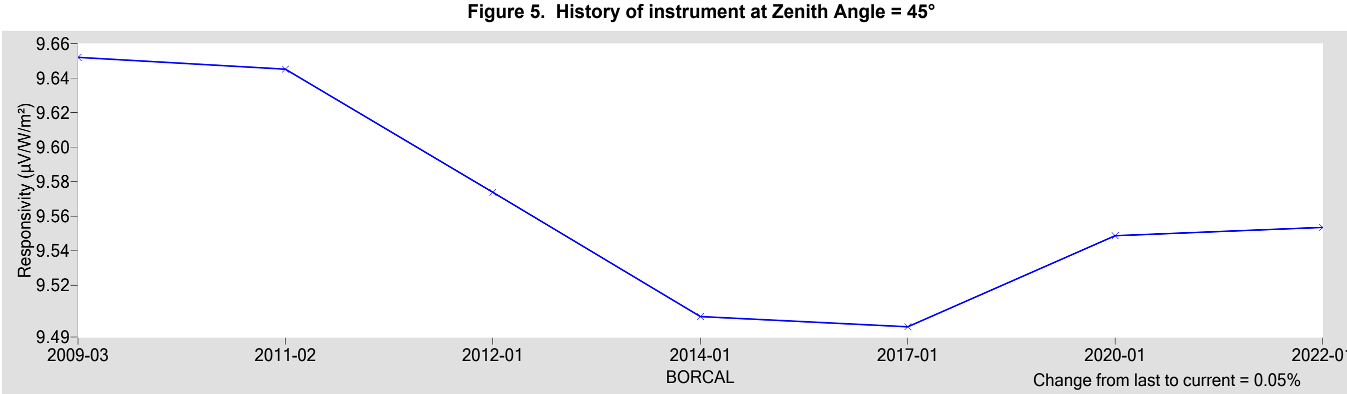
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
9.5536	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.2 / -1.7
Expanded Uncertainty, U (%)	+3.1 / -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:**	35834F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF#2	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

35834F3 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

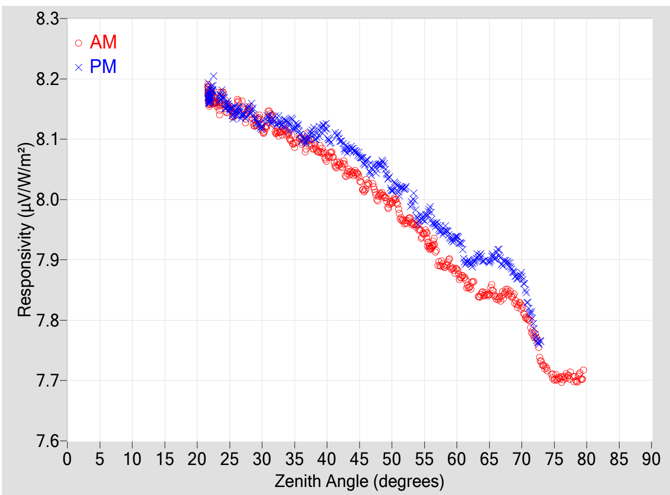


Figure 2. Responsivity vs Local Standard Time

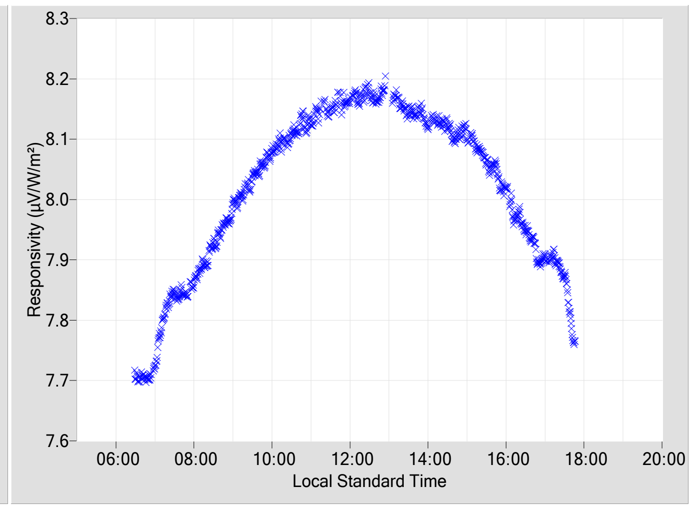


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.0203	0.44	105.82	8.0625	0.41	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0051	0.41	103.74	8.0582	0.45	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.9959	0.44	101.84	8.0160	0.43	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.9626	0.43	100.03	8.0187	0.42	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.9538	0.43	98.27	7.9659	0.44	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.9206	0.44	94.94	7.9756	0.45	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.8895	0.45	92.09	7.9479	0.50	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.8816	0.47	90.58	7.9382	0.49	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.8538	0.52	89.11	7.8959	0.52	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.8434	0.54	87.65	7.8997	0.55	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.8387	0.54	86.21	7.9074	0.58	271.32
22	8.1695	0.37	170.40	8.1693	0.36	189.51	68	7.8468	0.57	84.80	7.8929	N/A	272.77
24	8.1673	0.38	151.10	8.1671	0.36	208.57	70	7.8210	N/A	83.35	7.8709	N/A	274.21
26	8.1517	0.37	142.46	8.1464	0.40	217.79	72	7.7739	N/A	81.96	7.7788	N/A	275.65
28	8.1497	0.36	135.81	8.1480	0.35	224.59	74	7.7184	N/A	80.61	N/A	N/A	N/A
30	8.1196	0.35	130.21	8.1212	0.37	229.82	76	7.7030	N/A	79.14	N/A	N/A	N/A
32	8.1137	0.42	125.57	8.1307	0.41	234.52	78	7.7038	N/A	77.66	N/A	N/A	N/A
34	8.1073	0.41	121.86	8.1229	0.41	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.0985	0.38	118.49	8.1046	0.36	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.0869	0.39	115.39	8.1065	0.37	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.0682	0.38	112.73	8.1122	0.39	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.0580	0.40	110.28	8.1001	0.40	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.0437	0.41	107.99	8.0834	0.40	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

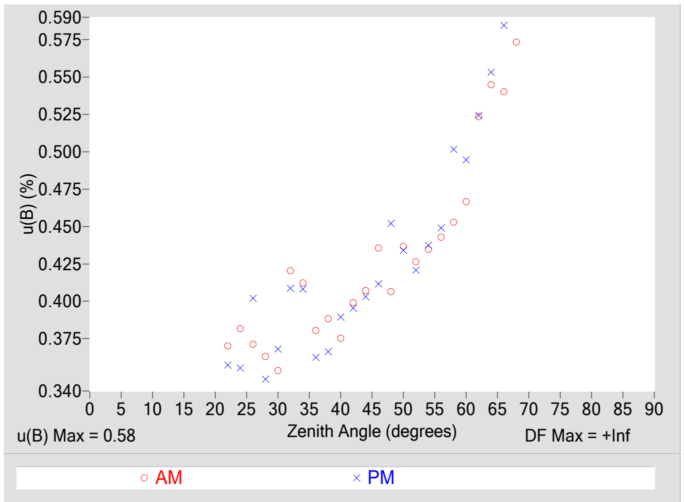


Figure 4. Residuals from Spline Interpolation

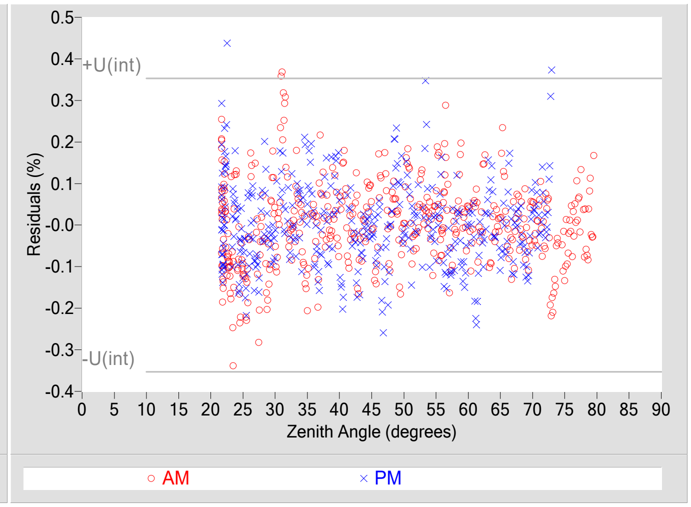


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.58
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.61
Effective degrees of freedom, DF(c)	113025
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

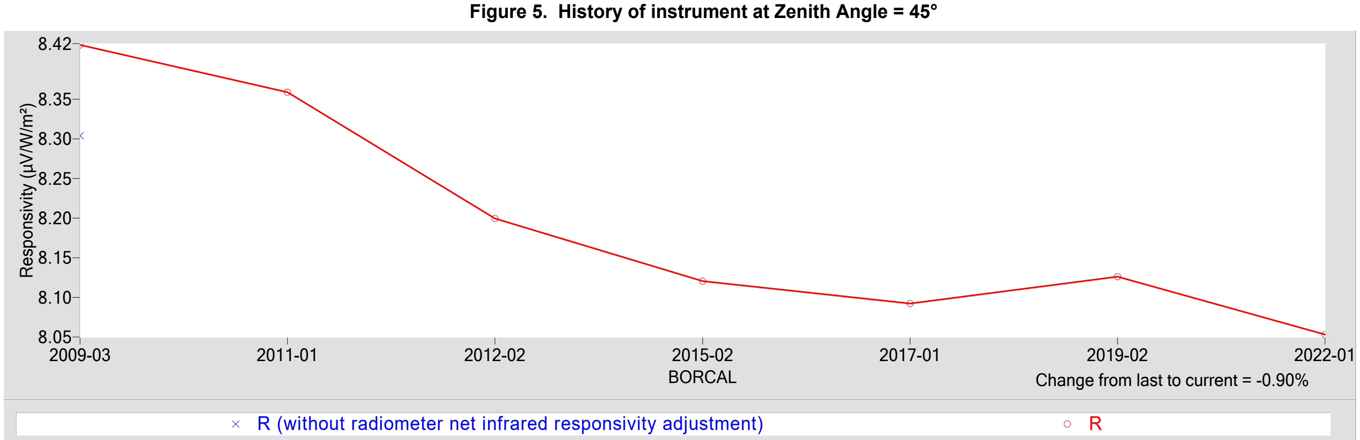
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.0534	0.54922

† Rnet determination date: 08/05/2009

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.98
Offset Uncertainty, U(off) (%)	+0.96 / -2.1
Expanded Uncertainty, U (%)	+1.9 / -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:	Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	8-48	**Serial Number:**	37166
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

37166 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

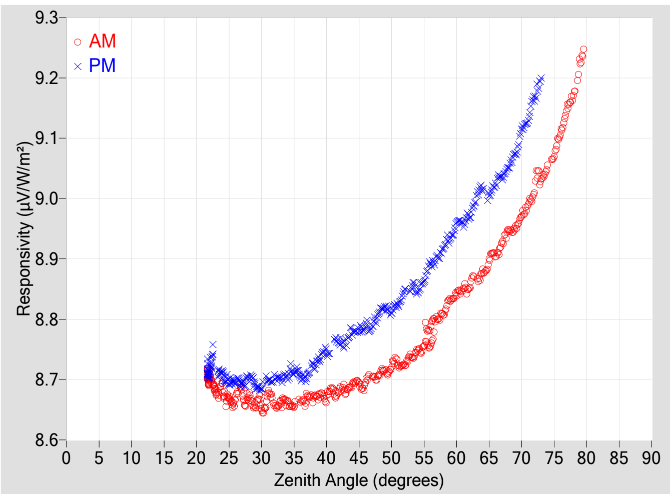


Figure 2. Responsivity vs Local Standard Time

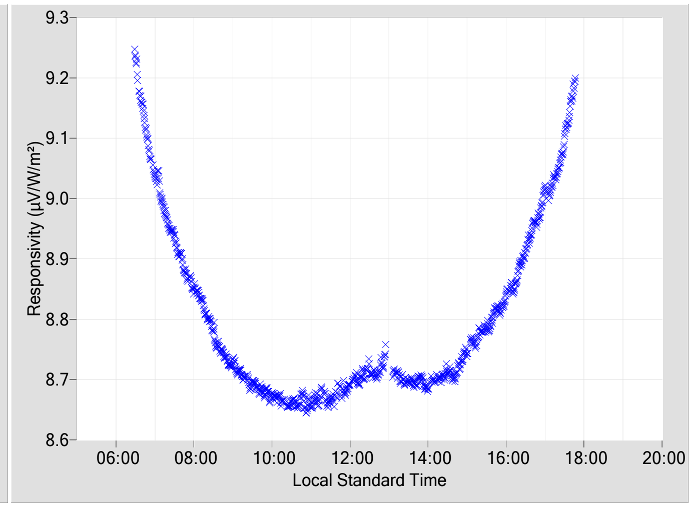


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6937	0.43	105.77	8.7887	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7053	0.40	103.75	8.8102	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7231	0.41	101.80	8.8107	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7243	0.44	100.04	8.8469	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7483	0.43	98.28	8.8450	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7702	0.44	95.27	8.8913	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.8094	0.47	92.10	8.9193	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.8424	0.46	90.58	8.9592	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.8529	0.54	89.12	8.9709	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8775	0.50	87.66	9.0166	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.9068	0.53	86.17	9.0238	0.57	271.28
22	8.7020	0.37	170.69	8.7134	0.38	189.46	68	8.9469	0.56	84.76	9.0522	N/A	272.73
24	8.6812	0.36	151.24	8.7085	0.36	208.48	70	8.9722	N/A	83.35	9.1125	N/A	274.17
26	8.6678	0.34	142.38	8.6968	0.37	217.57	72	9.0188	N/A	81.96	9.1661	N/A	275.61
28	8.6720	0.36	135.57	8.7025	0.38	224.54	74	9.0493	N/A	80.62	N/A	N/A	N/A
30	8.6525	0.38	130.11	8.6861	0.38	229.93	76	9.1067	N/A	79.15	N/A	N/A	N/A
32	8.6569	0.38	125.60	8.7020	0.35	234.47	78	9.1715	N/A	77.71	N/A	N/A	N/A
34	8.6618	0.37	121.89	8.7046	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6653	0.39	118.51	8.7033	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6696	0.37	115.41	8.7230	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6709	0.39	112.67	8.7458	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6820	0.38	110.22	8.7618	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6917	0.38	107.93	8.7794	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

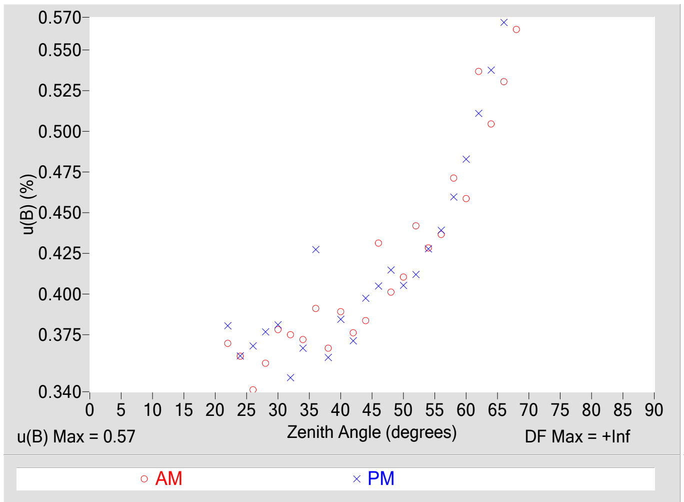


Figure 4. Residuals from Spline Interpolation

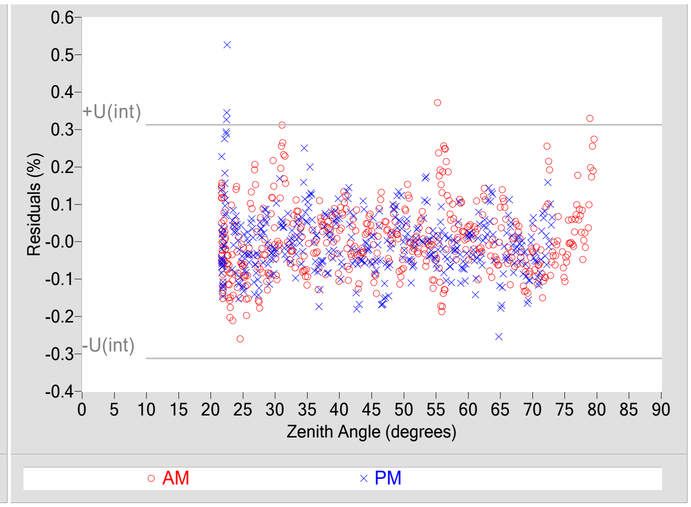


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	160346
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

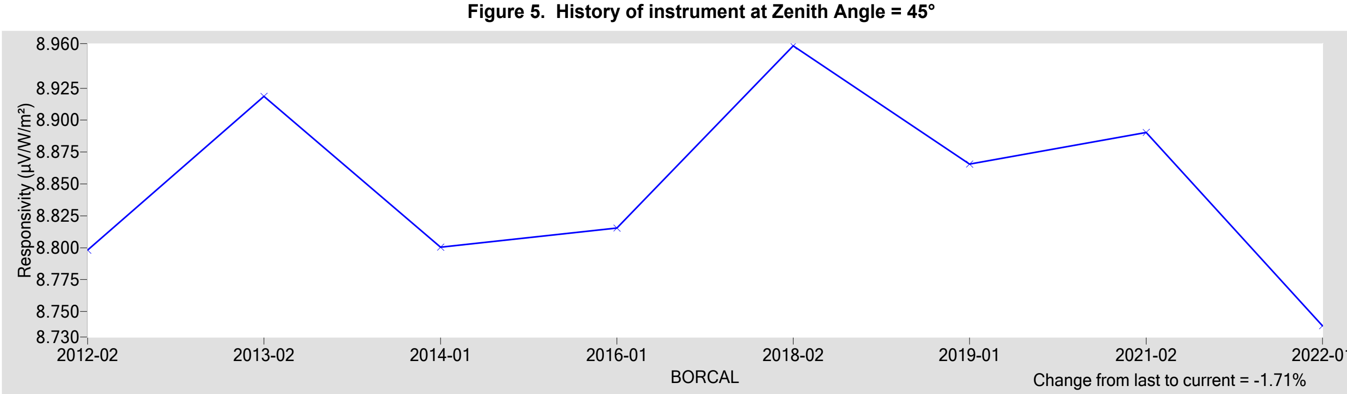
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.7387	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.5 / -0.99
Expanded Uncertainty, U (%)	+3.5 / -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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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 - 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

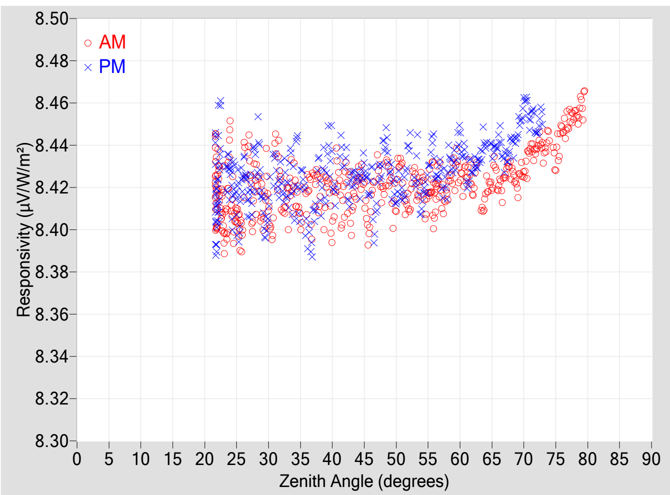


Figure 2. Responsivity vs Local Standard Time

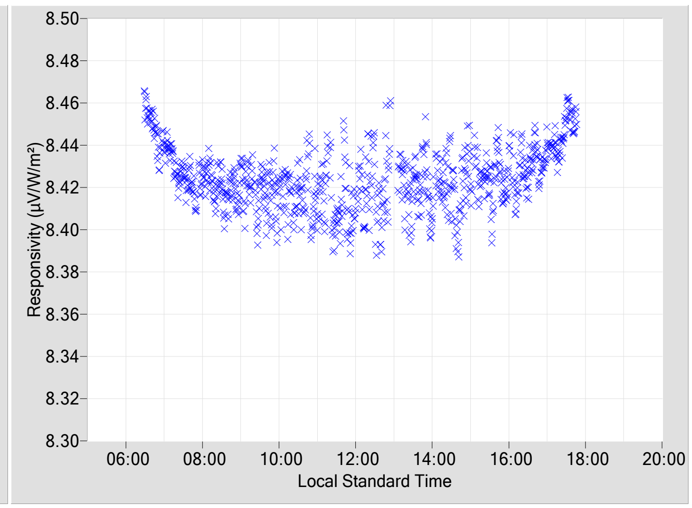


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.4086	0.29	105.79	8.4232	0.31	254.34
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4174	0.29	103.84	8.4381	0.30	256.43
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4195	0.29	101.82	8.4145	0.29	258.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4113	0.29	100.00	8.4406	0.31	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4234	0.29	98.25	8.4111	0.29	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4143	0.31	95.29	8.4340	0.29	263.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4183	0.29	92.07	8.4254	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4256	0.29	90.60	8.4431	0.29	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.4185	0.29	89.09	8.4277	0.30	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.4168	0.30	87.63	8.4402	0.30	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.4206	0.30	86.19	8.4426	0.30	271.29
22	8.4193	0.30	170.77	8.4129	0.30	189.46	68	8.4286	0.30	84.77	8.4415	N/A	272.75
24	8.4277	0.30	151.60	8.4249	0.29	208.48	70	8.4263	N/A	83.37	8.4590	N/A	274.19
26	8.4122	0.30	142.30	8.4268	0.30	217.87	72	8.4380	N/A	81.93	8.4460	N/A	275.63
28	8.4219	0.29	135.57	8.4288	0.29	224.59	74	8.4452	N/A	80.64	N/A	N/A	N/A
30	8.4108	0.31	130.15	8.4099	0.28	229.84	76	8.4475	N/A	79.12	N/A	N/A	N/A
32	8.4189	0.28	125.81	8.4240	0.28	234.40	78	8.4546	N/A	77.68	N/A	N/A	N/A
34	8.4188	0.28	121.81	8.4204	0.31	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4177	0.31	118.53	8.3989	0.30	241.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4168	0.28	115.52	8.4223	0.30	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4041	0.30	112.70	8.4311	0.30	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.4216	0.30	110.24	8.4343	0.31	249.92	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.4231	0.29	107.95	8.4249	0.31	252.23	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

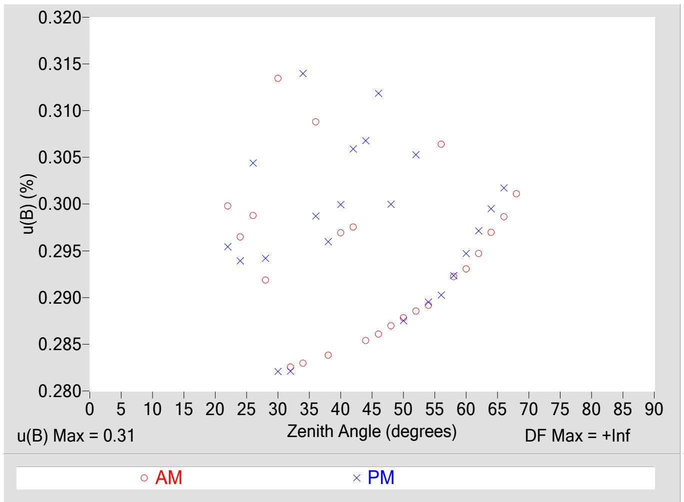


Figure 4. Residuals from Spline Interpolation

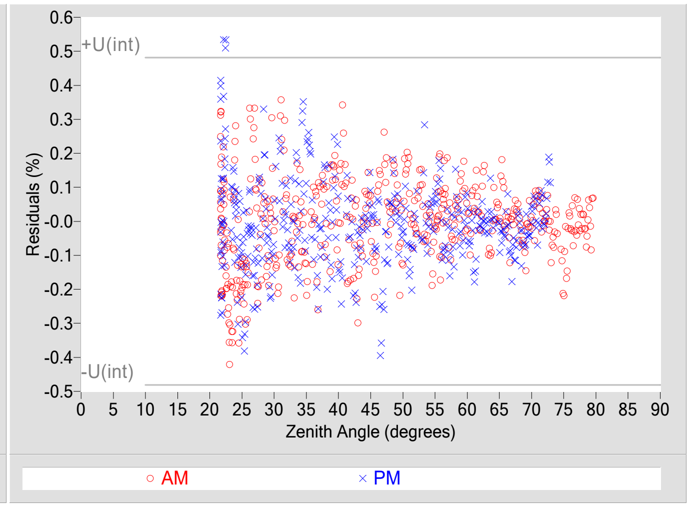


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.24
Combined Standard Uncertainty, u(c) (%)	±0.40
Effective degrees of freedom, DF(c)	5878
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.78
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

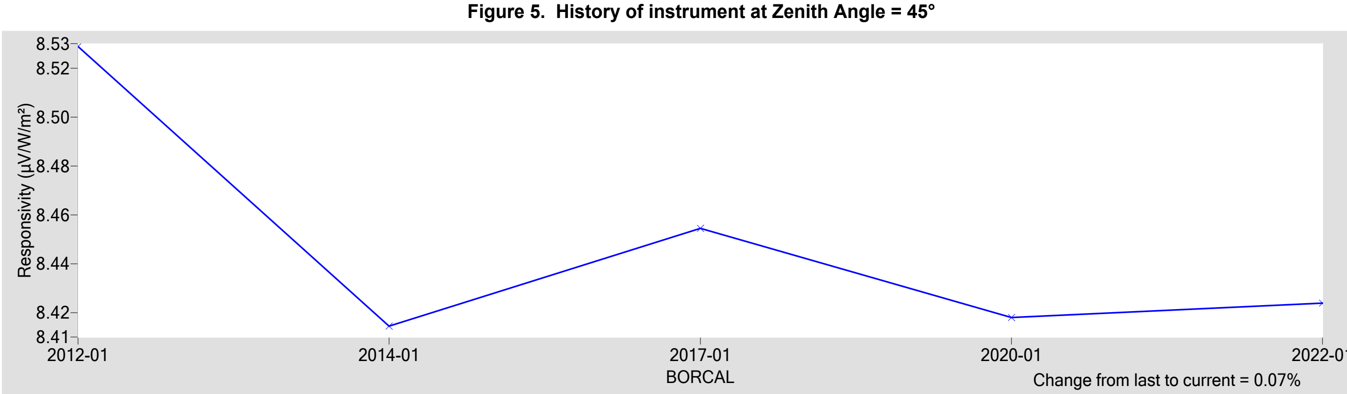
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.4238	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.23 / -0.30
Expanded Uncertainty, U (%)	+0.84 / -0.91
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer (Ventilated)	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	37298F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

37298F3 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

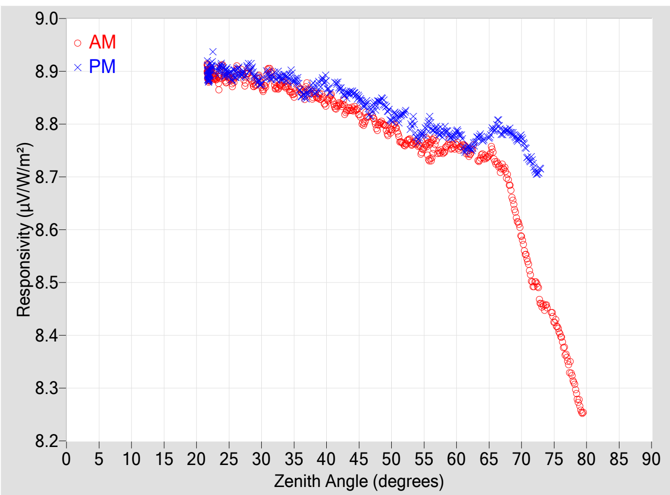


Figure 2. Responsivity vs Local Standard Time

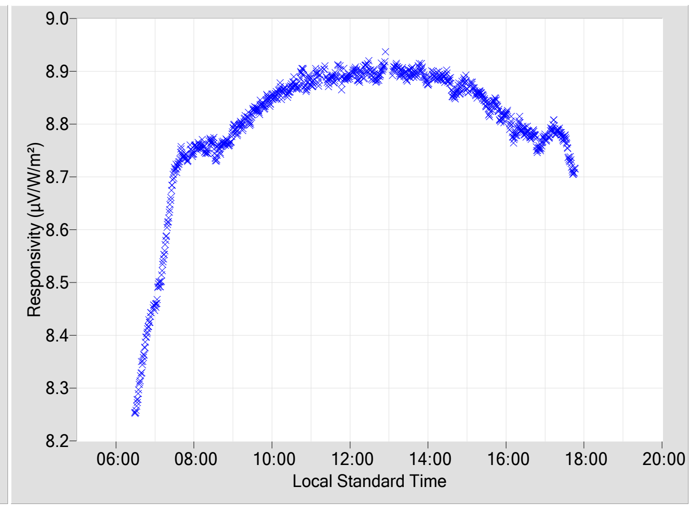


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.8078	0.45	105.82	8.8375	0.43	254.37
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.7969	0.42	103.74	8.8432	0.47	256.40
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.7901	0.45	101.84	8.8076	0.45	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.7612	0.44	100.03	8.8215	0.44	260.13
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.7618	0.45	98.27	8.7719	0.46	261.89
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.7509	0.46	94.94	8.8006	0.48	263.55
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7467	0.47	92.09	8.7849	0.53	265.20
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7591	0.49	90.58	8.7863	0.53	266.77
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7421	0.54	89.11	8.7553	0.56	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.7383	0.57	87.65	8.7712	0.59	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.7290	0.57	86.21	8.7948	0.63	271.32
22	8.8946	0.38	170.40	8.8933	0.37	189.51	68	8.6930	0.60	84.80	8.7875	N/A	272.77
24	8.9006	0.39	151.10	8.9050	0.36	208.57	70	8.5864	N/A	83.35	8.7736	N/A	274.21
26	8.8928	0.38	142.46	8.8961	0.41	217.79	72	8.4967	N/A	81.96	8.7140	N/A	275.65
28	8.8989	0.37	135.81	8.9060	0.36	224.59	74	8.4550	N/A	80.61	N/A	N/A	N/A
30	8.8734	0.36	130.21	8.8780	0.38	229.82	76	8.4005	N/A	79.14	N/A	N/A	N/A
32	8.8722	0.43	125.57	8.8908	0.42	234.52	78	8.3139	N/A	77.71	N/A	N/A	N/A
34	8.8709	0.42	121.86	8.8858	0.42	238.23	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.8648	0.39	118.49	8.8617	0.38	241.63	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.8549	0.40	115.39	8.8650	0.38	244.80	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.8407	0.39	112.73	8.8775	0.40	247.35	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.8370	0.41	110.28	8.8697	0.41	249.86	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.8277	0.42	107.99	8.8602	0.42	252.16	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

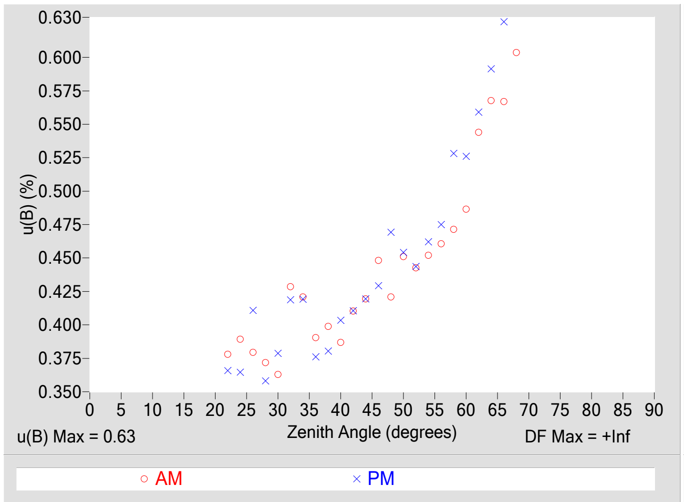


Figure 4. Residuals from Spline Interpolation

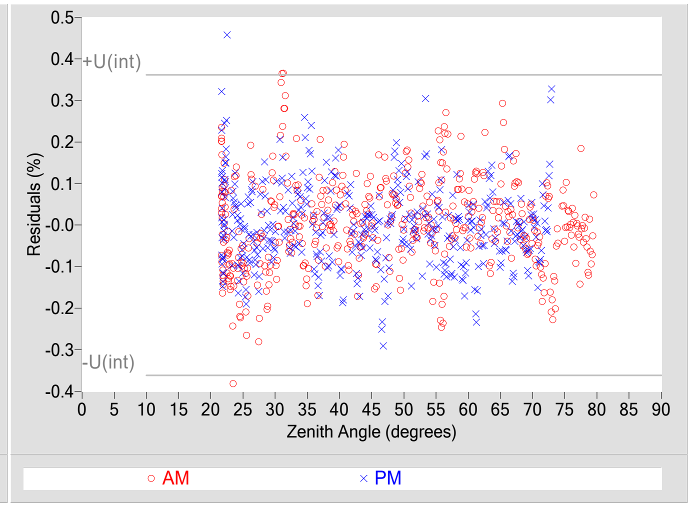


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	133290
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

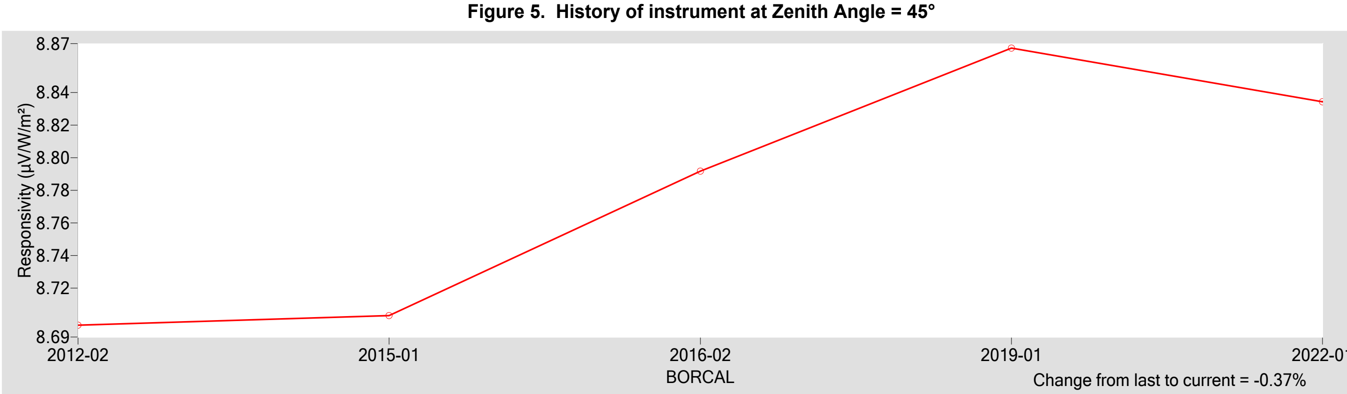
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.8344	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+0.64 / -0.99
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:**	37299F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer (Ventilated) Model PIR-V, S/N 30020F3	04/09/2021	04/09/2023

† 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

37299F3 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

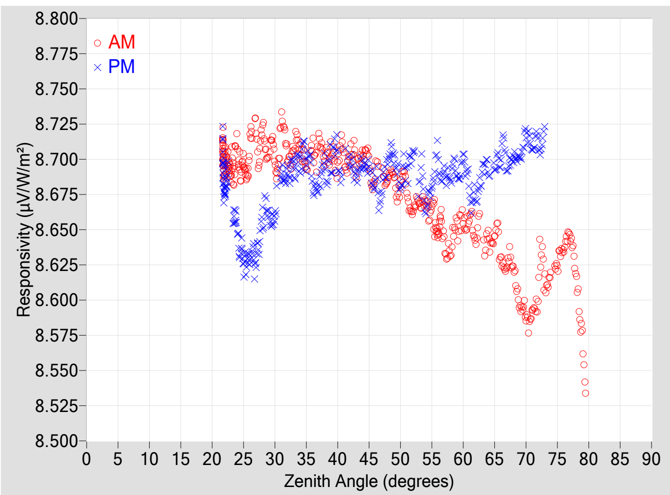


Figure 2. Responsivity vs Local Standard Time

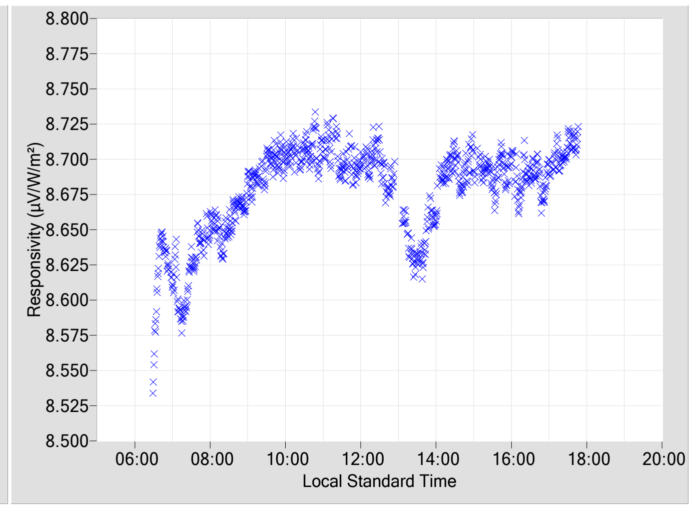


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6896	0.41	105.83	8.6850	0.41	254.38
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6860	0.42	103.75	8.6971	0.42	256.34
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6822	0.43	101.85	8.6811	0.46	258.30
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6640	0.44	99.97	8.7046	0.44	260.14
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6692	0.45	98.28	8.6658	0.46	261.90
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6490	0.46	94.94	8.6992	0.48	263.56
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6339	0.47	92.10	8.6870	0.50	265.16
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6553	0.51	90.58	8.7009	0.53	266.78
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6426	0.51	89.12	8.6733	0.56	268.31
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6435	0.54	87.66	8.6917	0.59	269.80
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6284	0.57	86.22	8.6999	0.63	271.27
22	8.6991	0.37	170.87	8.6841	0.37	189.54	68	8.6223	0.60	84.80	8.7012	N/A	272.78
24	8.7041	0.38	151.18	8.6480	0.39	208.67	70	8.5901	N/A	83.35	8.7176	N/A	274.22
26	8.7073	0.36	142.37	8.6297	0.37	217.50	72	8.6126	N/A	81.96	8.7096	N/A	275.65
28	8.7194	0.37	135.56	8.6565	0.39	224.56	74	8.6178	N/A	80.62	N/A	N/A	N/A
30	8.6982	0.39	130.22	8.6626	0.36	229.91	76	8.6353	N/A	79.14	N/A	N/A	N/A
32	8.7039	0.38	125.70	8.6909	0.38	234.47	78	8.6159	N/A	77.71	N/A	N/A	N/A
34	8.7080	0.39	121.87	8.6959	0.40	238.25	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.7062	0.42	118.50	8.6836	0.40	241.64	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.7020	0.38	115.40	8.6921	0.40	244.73	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6956	0.40	112.74	8.7028	0.39	247.36	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.7026	0.39	110.29	8.6985	0.42	249.94	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.7014	0.40	107.92	8.6964	0.44	252.17	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

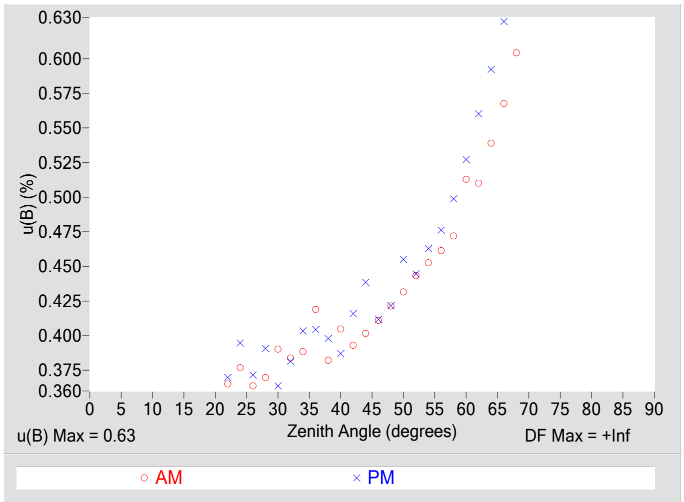


Figure 4. Residuals from Spline Interpolation

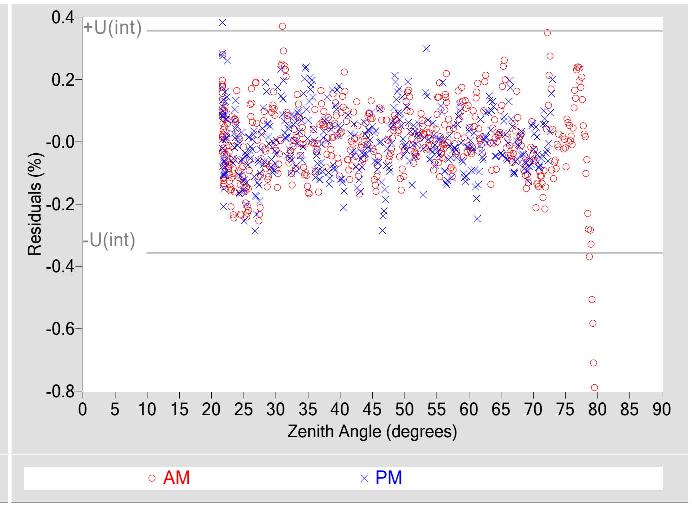


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.63
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.65
Effective degrees of freedom, DF(c)	143471
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

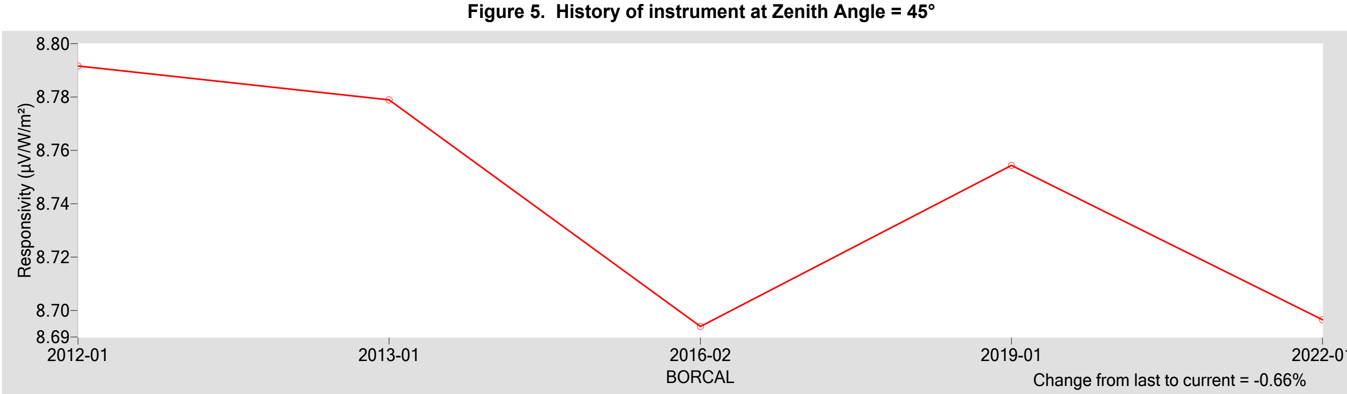
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.6965	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+0.13 / -0.72
Expanded Uncertainty, U (%)	+1.2 / -1.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

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:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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:

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

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

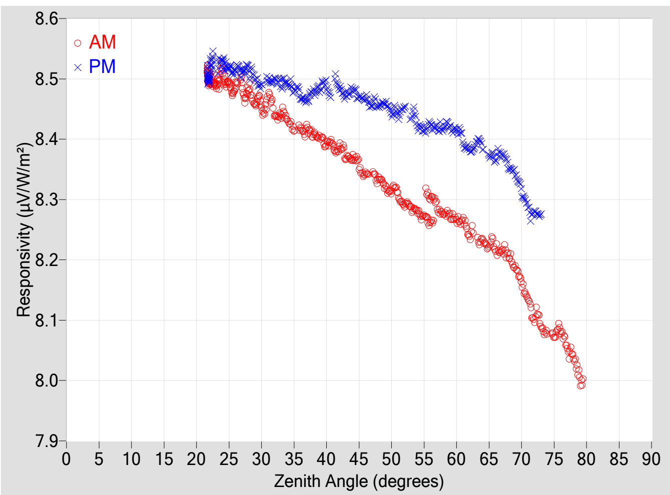


Figure 2. Responsivity vs Local Standard Time

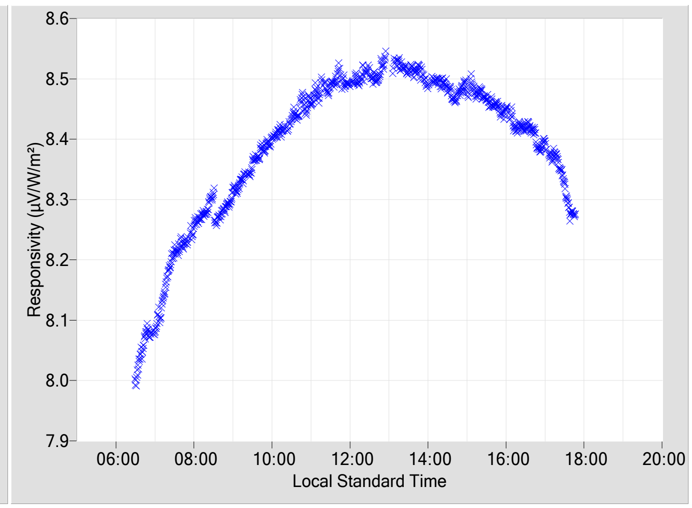


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.3425	0.45	105.74	8.4671	0.41	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.3326	0.44	103.73	8.4545	0.46	256.38
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.3149	0.46	101.83	8.4422	0.44	258.34
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.2917	0.47	100.01	8.4522	0.45	260.06
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.2806	0.46	98.26	8.4201	0.47	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.2823	0.48	95.12	8.4237	0.51	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.2770	0.47	92.08	8.4174	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.2676	0.49	90.56	8.4142	0.53	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.2405	0.51	89.10	8.3835	0.57	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.2325	0.54	87.64	8.3885	0.60	269.74
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.2177	0.60	86.20	8.3662	0.64	271.30
22	8.5001	0.37	170.39	8.5068	0.36	189.59	68	8.2069	0.60	84.78	8.3537	N/A	272.76
24	8.5067	0.40	151.45	8.5276	0.37	208.53	70	8.1642	N/A	83.38	8.3126	N/A	274.19
26	8.4872	0.39	142.31	8.5141	0.40	217.59	72	8.1058	N/A	81.94	8.2799	N/A	275.63
28	8.4829	0.37	135.50	8.5136	0.39	224.64	74	8.0803	N/A	80.65	N/A	N/A	N/A
30	8.4505	0.37	130.05	8.4883	0.39	229.87	76	8.0845	N/A	79.12	N/A	N/A	N/A
32	8.4413	0.39	125.59	8.4986	0.39	234.36	78	8.0383	N/A	77.69	N/A	N/A	N/A
34	8.4319	0.41	121.90	8.4909	0.39	238.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4178	0.41	118.46	8.4703	0.38	241.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4069	0.42	115.45	8.4784	0.43	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.3915	0.42	112.79	8.4878	0.44	247.41	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.3858	0.47	110.18	8.4848	0.43	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.3673	0.42	107.90	8.4822	0.41	252.22	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

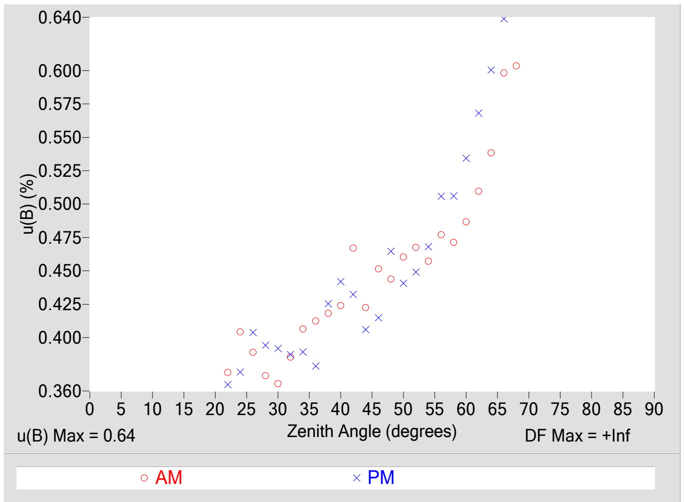


Figure 4. Residuals from Spline Interpolation

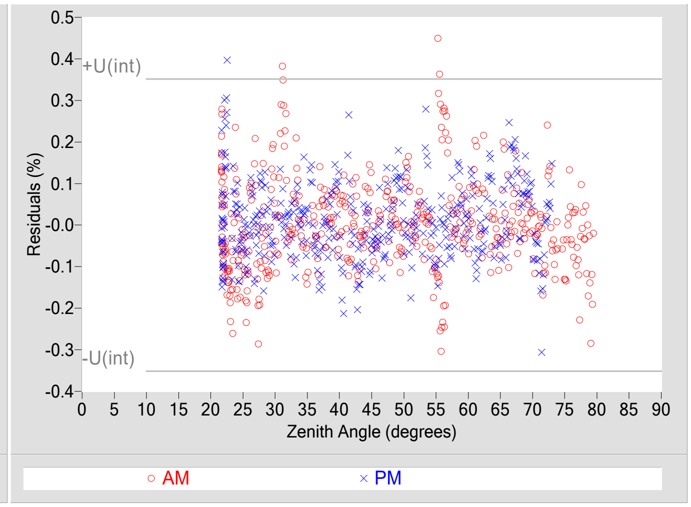


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	160406
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

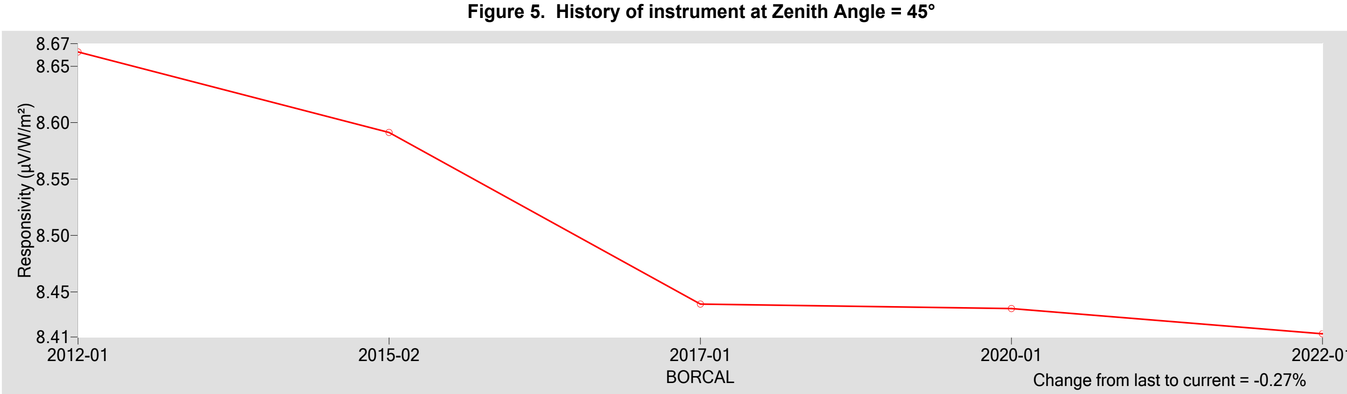
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.4127	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.0 / -1.7
Expanded Uncertainty, U (%)	+2.1 / -2.8
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Precision Spectral Pyranometer	**Manufacturer:**	Eppley
Model:	PSP	**Serial Number:**	37317F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

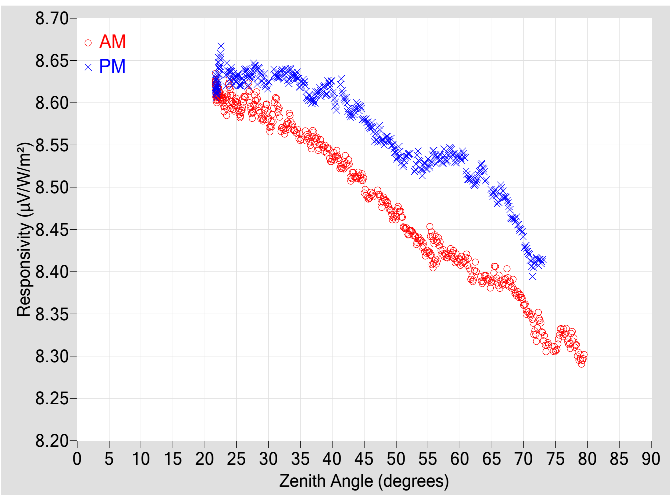


Figure 2. Responsivity vs Local Standard Time

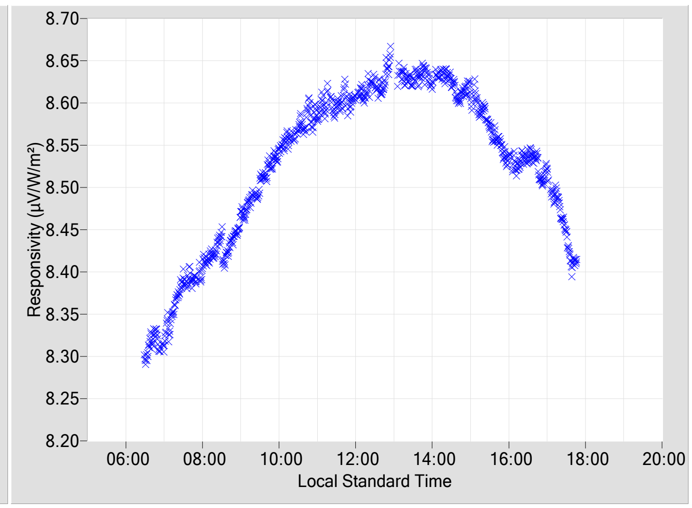


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

Zenith	AM			PM			Zenith	AM			PM		
Angle (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	8.4901	0.45	105.74	8.5719	0.41	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.4834	0.44	103.73	8.5544	0.46	256.38
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.4671	0.46	101.83	8.5370	0.44	258.34
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.4460	0.47	100.01	8.5389	0.45	260.06
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.4343	0.46	98.26	8.5189	0.47	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.4245	0.48	95.12	8.5378	0.50	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.4189	0.47	92.08	8.5341	0.50	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.4139	0.49	90.56	8.5354	0.53	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.3929	0.51	89.10	8.5072	0.57	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.3941	0.54	87.64	8.5139	0.60	269.74
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.3878	0.60	86.20	8.4842	0.64	271.30
22	8.6116	0.37	170.21	8.6240	0.36	189.59	68	8.3851	0.60	84.78	8.4661	N/A	272.76
24	8.6092	0.40	151.45	8.6343	0.37	208.53	70	8.3639	N/A	83.38	8.4366	N/A	274.19
26	8.5994	0.39	142.31	8.6288	0.40	217.59	72	8.3317	N/A	81.94	8.4145	N/A	275.63
28	8.6048	0.37	135.50	8.6370	0.39	224.64	74	8.3148	N/A	80.65	N/A	N/A	N/A
30	8.5764	0.37	130.05	8.6219	0.39	229.87	76	8.3295	N/A	79.12	N/A	N/A	N/A
32	8.5718	0.39	125.59	8.6365	0.39	234.36	78	8.3153	N/A	77.69	N/A	N/A	N/A
34	8.5683	0.41	121.90	8.6309	0.39	238.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.5603	0.41	118.46	8.6097	0.38	241.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.5492	0.42	115.45	8.6131	0.42	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5341	0.42	112.79	8.6156	0.44	247.41	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5285	0.47	110.18	8.6033	0.43	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5124	0.42	107.90	8.5960	0.41	252.22	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

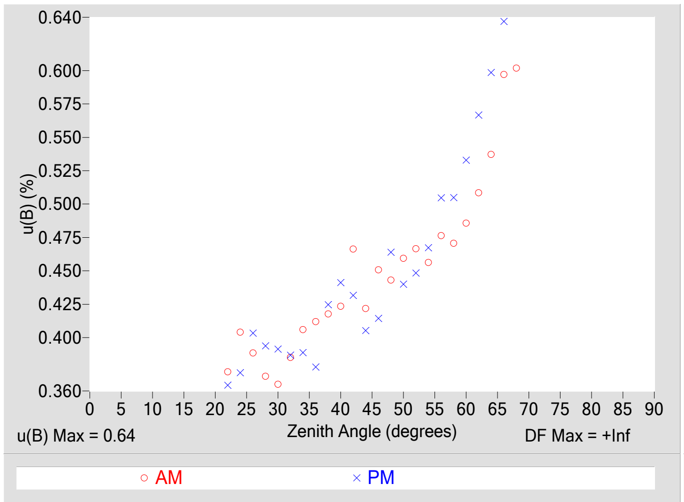


Figure 4. Residuals from Spline Interpolation

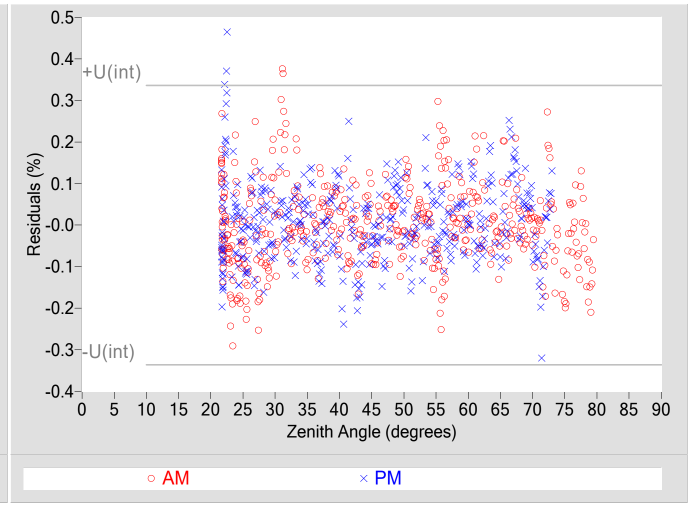


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.17
Combined Standard Uncertainty, u(c) (%)	±0.66
Effective degrees of freedom, DF(c)	187833
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

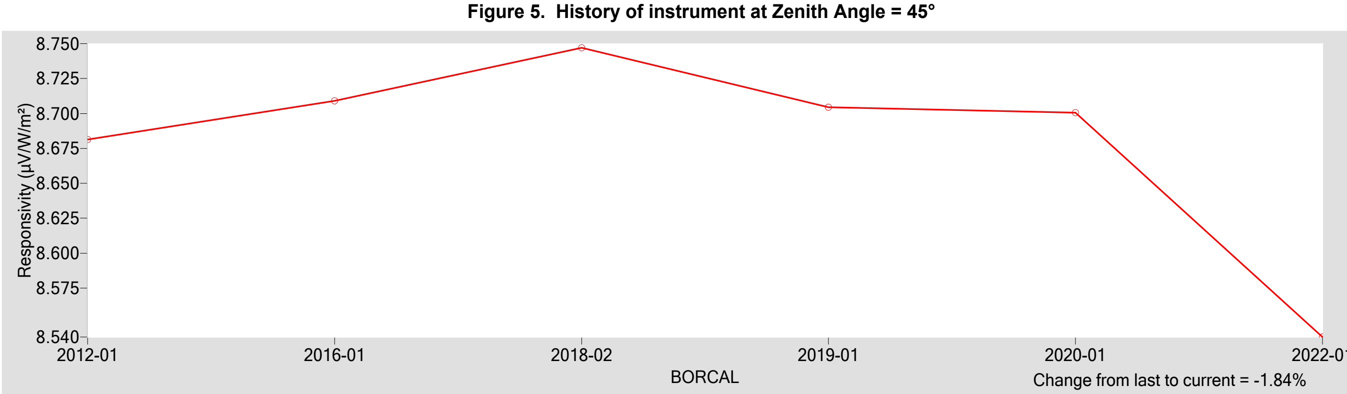
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
8.5401	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.0
Offset Uncertainty, U(off) (%)	+1.1 / -1.5
Expanded Uncertainty, U (%)	+2.2 / -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:**	37319F3
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	AMF	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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

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

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

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

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Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29222	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023
Infrared Irradiance ‡	Eppley Downwelling Pyrgeometer Model PIR, S/N 30170F3	04/09/2021	04/09/2023

† 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

37319F3 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

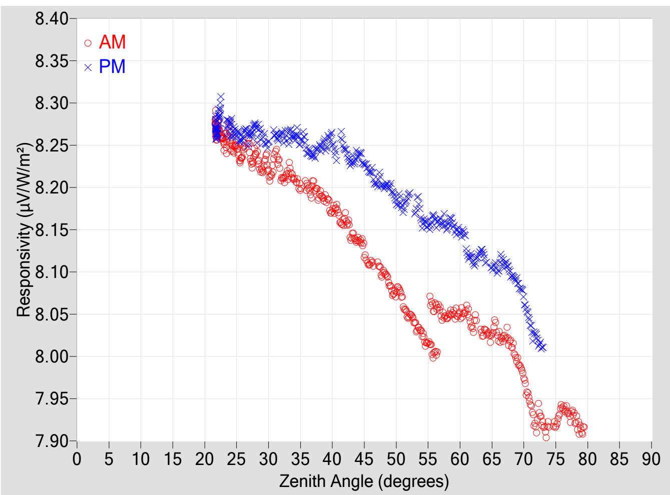


Figure 2. Responsivity vs Local Standard Time

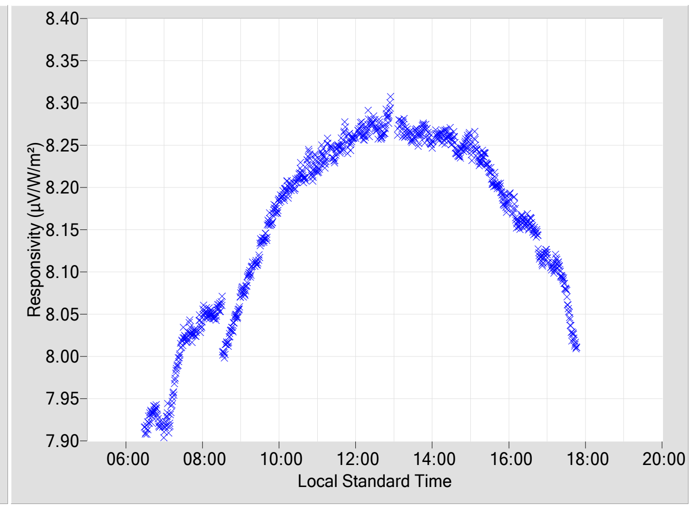


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.1107	0.45	105.74	8.2192	0.42	254.35
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.0982	0.45	103.73	8.2016	0.47	256.38
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.0768	0.46	101.83	8.1822	0.44	258.34
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.0475	0.47	100.01	8.1915	0.45	260.06
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.0280	0.46	98.26	8.1586	0.47	261.88
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.0306	0.48	95.12	8.1622	0.51	263.59
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.0469	0.47	92.08	8.1539	0.51	265.19
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.0511	0.49	90.56	8.1467	0.54	266.76
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.0349	0.51	89.10	8.1136	0.57	268.29
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.0302	0.54	87.64	8.1147	0.60	269.74
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.0236	0.60	86.20	8.1031	0.64	271.30
22	8.2668	0.38	170.21	8.2708	0.37	189.59	68	8.0148	0.61	84.78	8.0964	N/A	272.76
24	8.2585	0.41	151.45	8.2729	0.37	208.53	70	7.9756	N/A	83.38	8.0676	N/A	274.19
26	8.2422	0.39	142.31	8.2609	0.40	217.59	72	7.9233	N/A	81.94	8.0235	N/A	275.63
28	8.2427	0.37	135.50	8.2682	0.40	224.64	74	7.9196	N/A	80.65	N/A	N/A	N/A
30	8.2166	0.37	130.05	8.2517	0.39	229.87	76	7.9399	N/A	79.12	N/A	N/A	N/A
32	8.2129	0.39	125.59	8.2634	0.39	234.36	78	7.9271	N/A	77.69	N/A	N/A	N/A
34	8.2106	0.41	121.90	8.2594	0.39	238.31	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.2022	0.41	118.46	8.2440	0.38	241.61	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.1900	0.42	115.45	8.2472	0.43	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.1728	0.42	112.79	8.2550	0.44	247.41	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.1607	0.47	110.18	8.2442	0.43	249.91	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.1371	0.42	107.90	8.2396	0.41	252.22	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

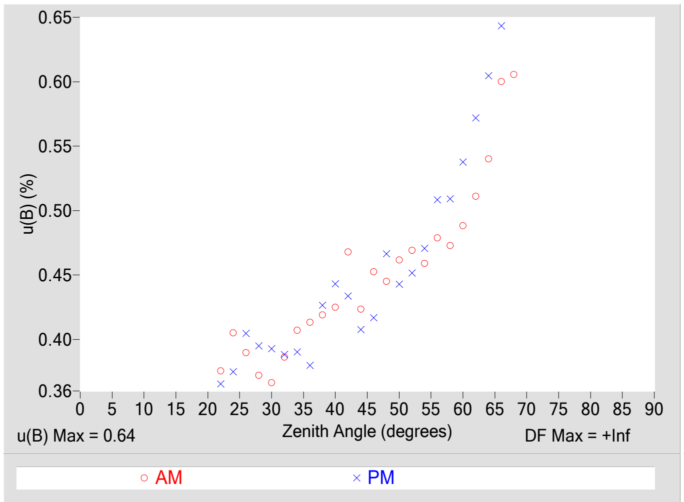


Figure 4. Residuals from Spline Interpolation

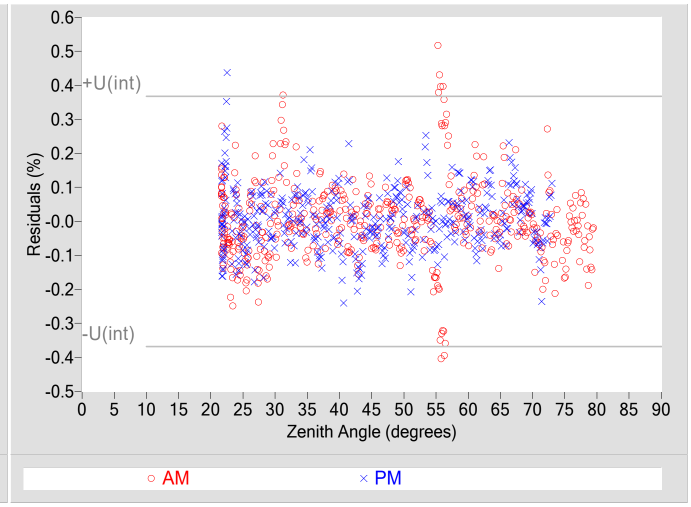


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.64
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.67
Effective degrees of freedom, DF(c)	138848
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.3
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

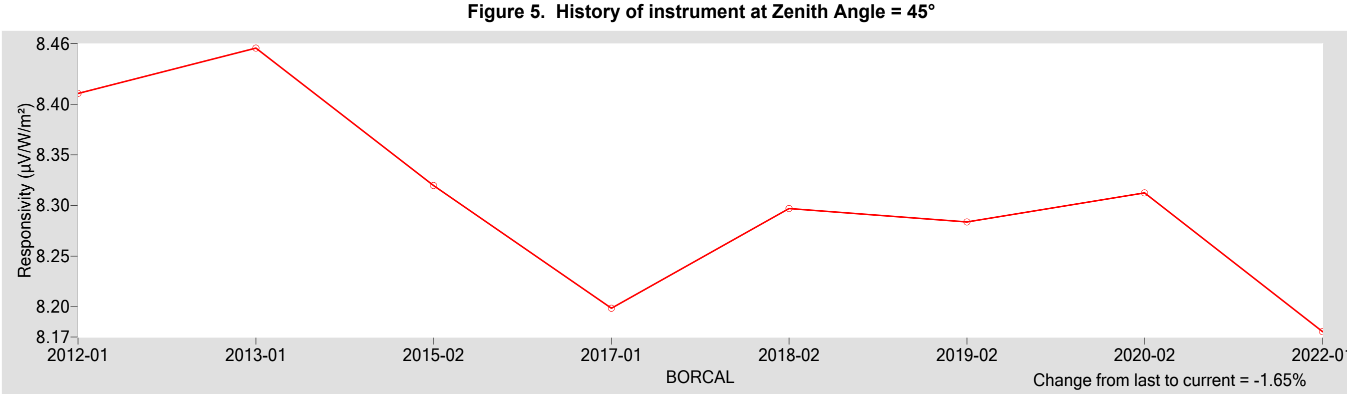
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.1755	0.60000

† Rnet determination date: Estimated

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±1.1
Offset Uncertainty, U(off) (%)	+1.1 / -1.8
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:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	NIP	**Serial Number:**	37361E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	NSA	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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:

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

where,

- V = radiometer output voltage (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

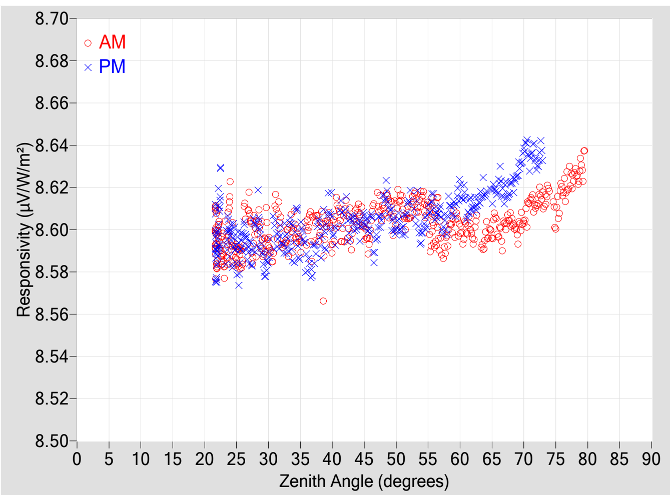


Figure 2. Responsivity vs Local Standard Time

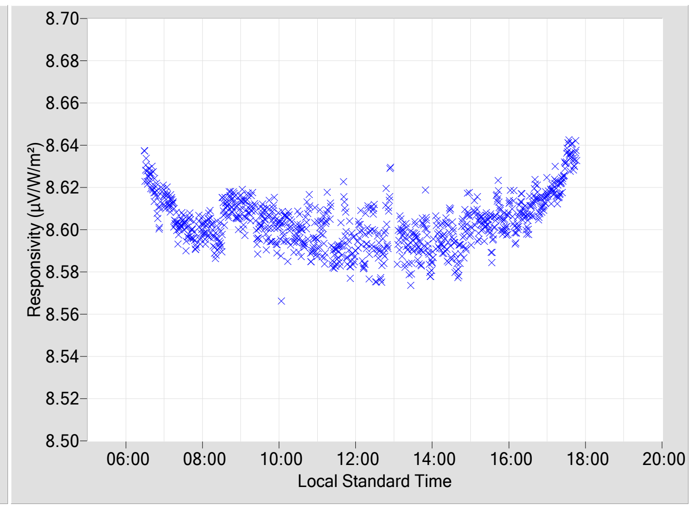


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6003	0.29	105.79	8.6036	0.31	254.34
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6084	0.29	103.84	8.6135	0.30	256.43
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6091	0.29	101.82	8.6005	0.29	258.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6068	0.29	100.00	8.6144	0.31	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6157	0.29	98.25	8.5970	0.29	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6024	0.31	95.29	8.6106	0.29	263.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.5964	0.29	92.07	8.6051	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6000	0.29	90.60	8.6185	0.29	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.5958	0.29	89.09	8.6100	0.30	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.5968	0.30	87.63	8.6169	0.30	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.5981	0.30	86.19	8.6219	0.30	271.29
22	8.5948	0.30	170.77	8.5914	0.30	189.46	68	8.6043	0.30	84.77	8.6217	N/A	272.75
24	8.6042	0.30	151.60	8.5969	0.29	208.48	70	8.6036	N/A	83.37	8.6370	N/A	274.19
26	8.5939	0.30	142.30	8.5972	0.30	217.87	72	8.6114	N/A	81.93	8.6310	N/A	275.63
28	8.5991	0.29	135.57	8.5975	0.29	224.59	74	8.6196	N/A	80.64	N/A	N/A	N/A
30	8.5948	0.31	130.15	8.5869	0.28	229.84	76	8.6190	N/A	79.12	N/A	N/A	N/A
32	8.5989	0.28	125.81	8.5964	0.28	234.40	78	8.6260	N/A	77.68	N/A	N/A	N/A
34	8.5995	0.28	121.81	8.5958	0.31	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6004	0.31	118.53	8.5838	0.30	241.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6000	0.28	115.52	8.5969	0.30	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.5948	0.30	112.70	8.6047	0.30	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6063	0.30	110.24	8.6107	0.31	249.92	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6081	0.29	107.95	8.6023	0.31	252.23	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

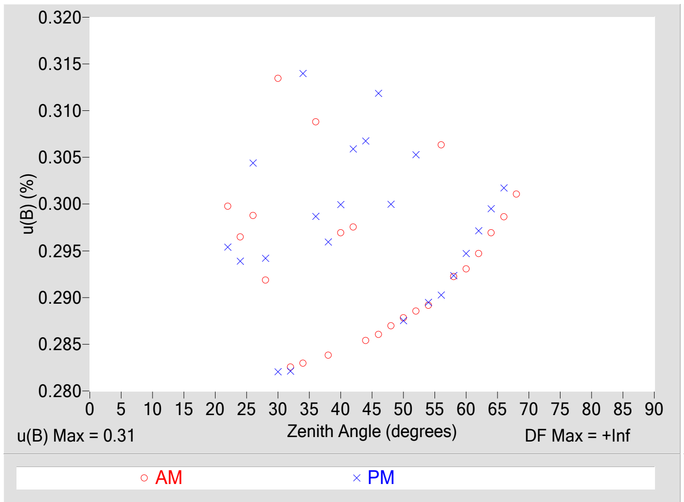


Figure 4. Residuals from Spline Interpolation

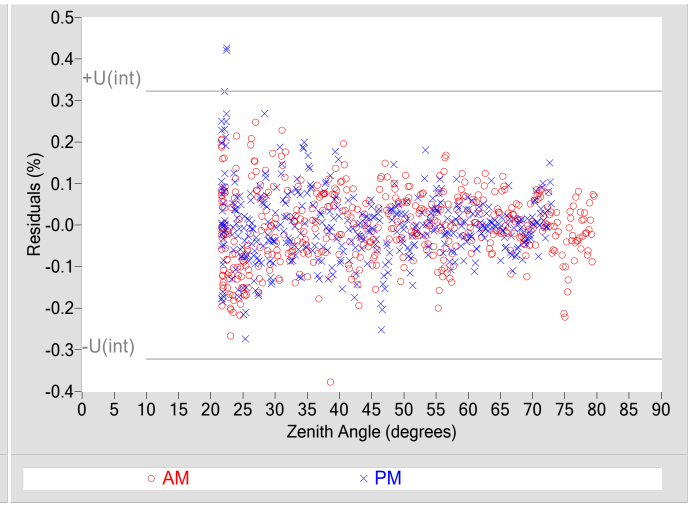


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.16
Combined Standard Uncertainty, u(c) (%)	±0.35
Effective degrees of freedom, DF(c)	18546
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.69
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

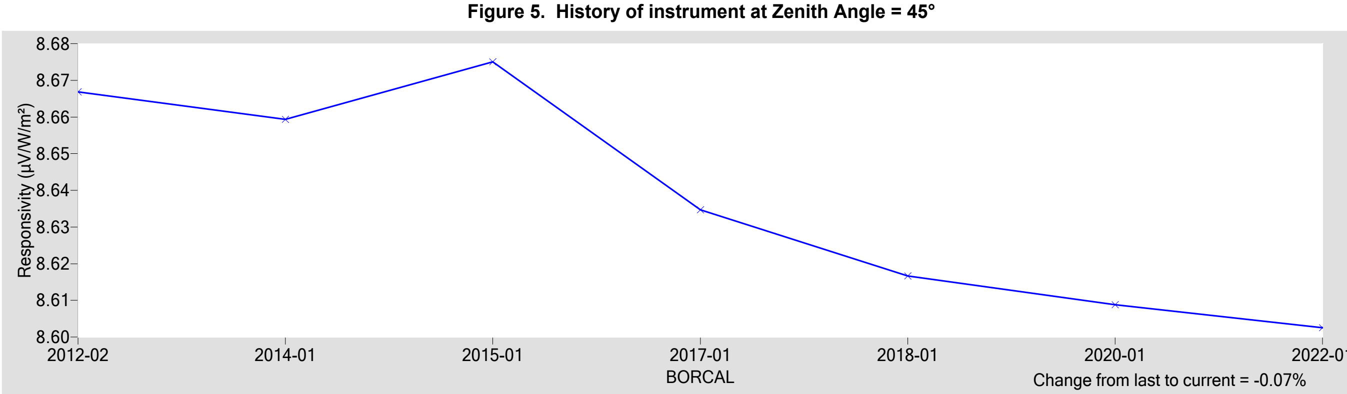
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6025	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.19 / -0.22
Expanded Uncertainty, U (%)	+0.80 / -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: 37392

Calibration Date: 5/7/2022

Due Date: 5/7/2023

Customer: NSA

Environmental Conditions: see page 4

Test Dates: 4/30, 5/7

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

37392 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

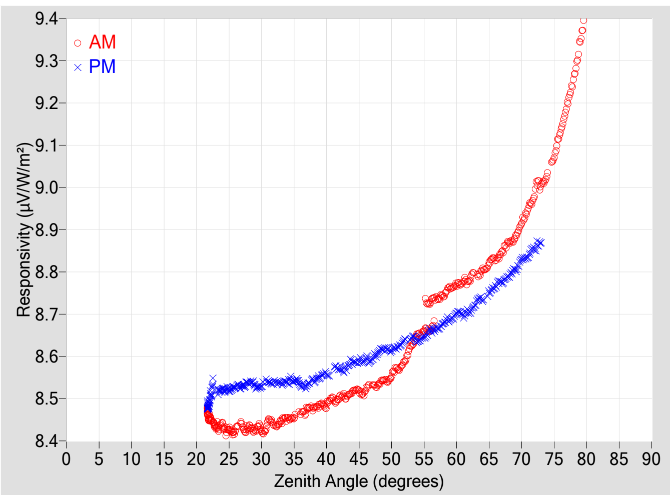


Figure 2. Responsivity vs Local Standard Time

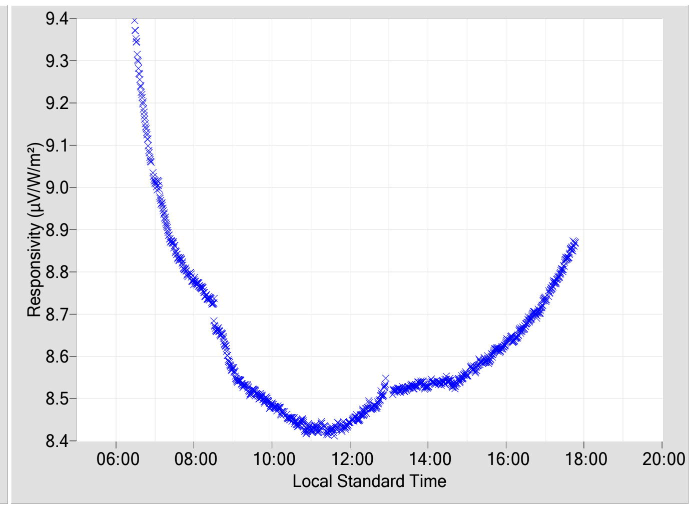


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.5187	0.43	105.77	8.5930	0.40	254.32
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.5325	0.40	103.75	8.6114	0.41	256.41
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.5555	0.41	101.80	8.6136	0.41	258.31
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.5868	0.44	100.04	8.6389	0.41	260.09
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6518	0.43	98.28	8.6355	0.43	261.85
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6922	0.44	95.27	8.6613	0.44	263.57
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.7444	0.47	92.10	8.6790	0.46	265.21
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.7704	0.46	90.58	8.7034	0.48	266.79
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.7803	0.54	89.12	8.7057	0.51	268.32
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.8049	0.50	87.66	8.7351	0.54	269.76
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.8301	0.53	86.17	8.7661	0.57	271.28
22	8.4571	0.37	170.69	8.4907	0.38	189.46	68	8.8703	0.56	84.76	8.7898	N/A	272.73
24	8.4351	0.36	151.24	8.5215	0.36	208.48	70	8.9166	N/A	83.35	8.8290	N/A	274.17
26	8.4251	0.34	142.38	8.5274	0.37	217.57	72	8.9863	N/A	81.96	8.8542	N/A	275.61
28	8.4330	0.36	135.57	8.5373	0.38	224.54	74	9.0265	N/A	80.62	N/A	N/A	N/A
30	8.4242	0.38	130.11	8.5301	0.38	229.93	76	9.1299	N/A	79.15	N/A	N/A	N/A
32	8.4365	0.38	125.60	8.5388	0.35	234.47	78	9.2542	N/A	77.71	N/A	N/A	N/A
34	8.4527	0.37	121.89	8.5388	0.37	238.26	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.4668	0.39	118.51	8.5313	0.43	241.65	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.4771	0.37	115.41	8.5434	0.36	244.65	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.4857	0.39	112.67	8.5578	0.38	247.45	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.5027	0.38	110.22	8.5708	0.37	249.88	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.5161	0.38	107.93	8.5868	0.40	252.25	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

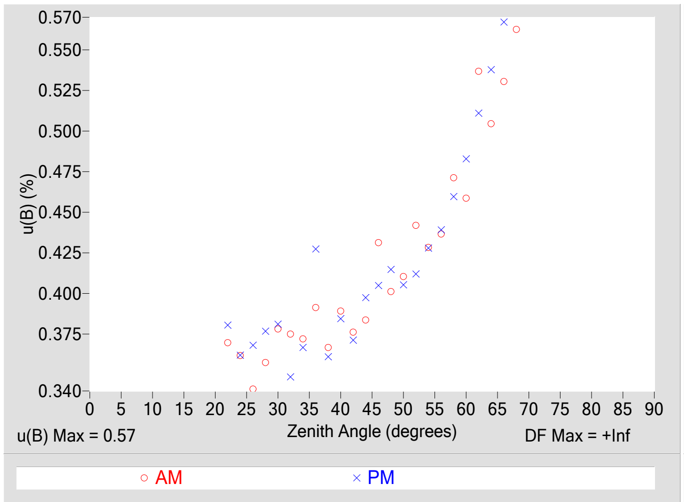


Figure 4. Residuals from Spline Interpolation

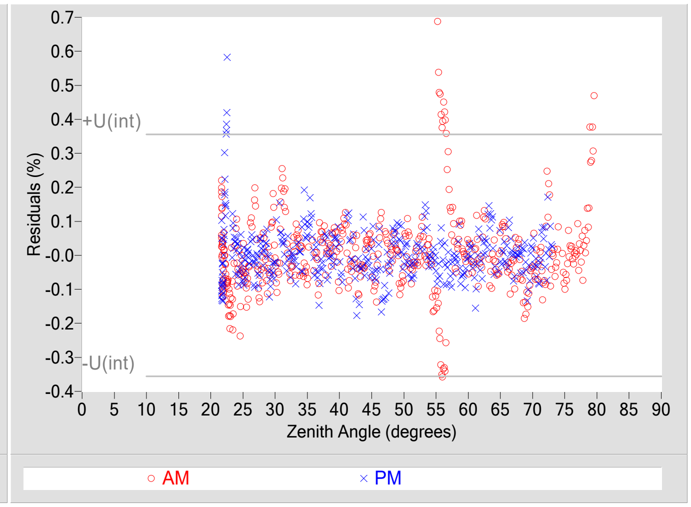


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.57
Type-A Interpolating Function, u(int) (%)	±0.18
Combined Standard Uncertainty, u(c) (%)	±0.59
Effective degrees of freedom, DF(c)	99621
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±1.2
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

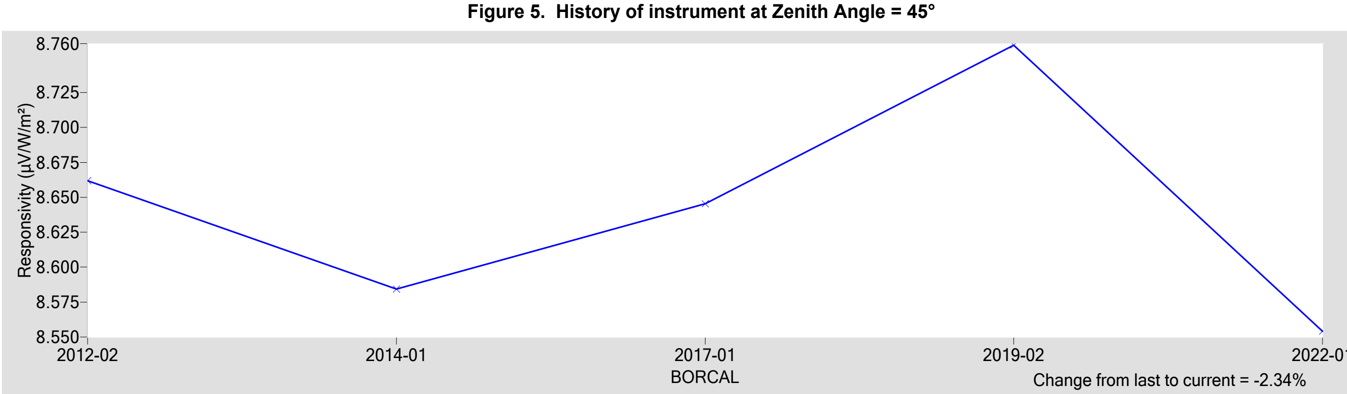
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.5541	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.95
Offset Uncertainty, U(off) (%)	+2.5 / -1.5
Expanded Uncertainty, U (%)	+3.5 / -2.5
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37947E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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

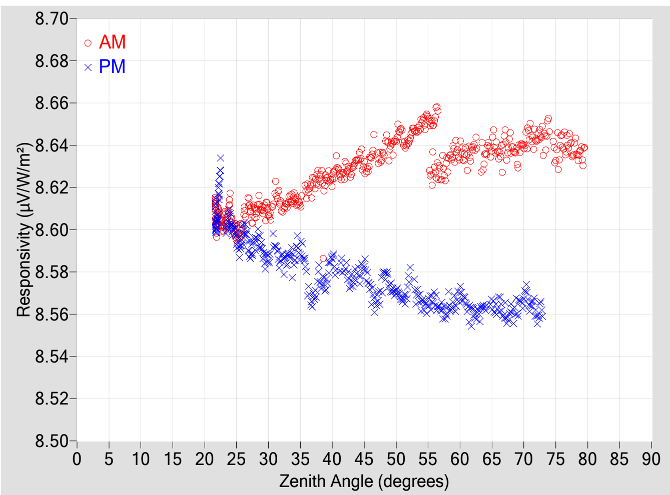


Figure 2. Responsivity vs Local Standard Time

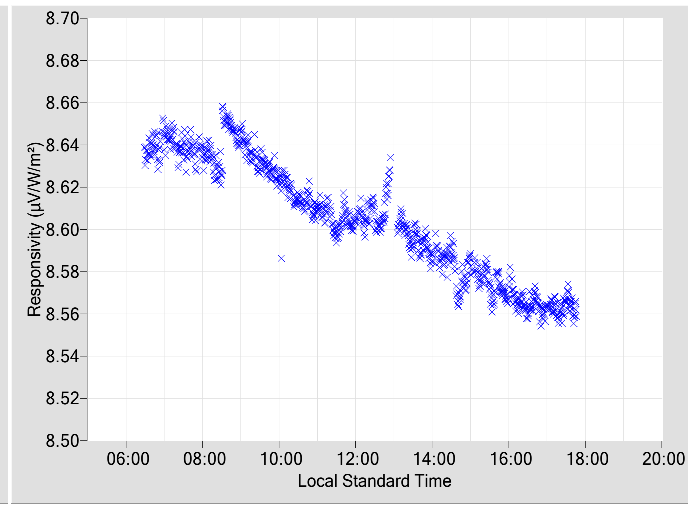


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	8.6336	0.29	105.79	8.5715	0.31	254.34
2	N/A	N/A	N/A	N/A	N/A	N/A	48	8.6352	0.29	103.84	8.5772	0.30	256.43
4	N/A	N/A	N/A	N/A	N/A	N/A	50	8.6440	0.29	101.82	8.5706	0.29	258.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	8.6422	0.29	100.00	8.5771	0.31	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	8.6510	0.29	98.25	8.5659	0.29	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	8.6424	0.31	95.29	8.5669	0.29	263.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	8.6316	0.29	92.07	8.5633	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	8.6365	0.29	90.60	8.5699	0.29	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	8.6391	0.29	89.09	8.5599	0.30	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	8.6356	0.30	87.63	8.5631	0.30	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	8.6361	0.30	86.19	8.5640	0.30	271.29
22	8.6059	0.30	170.77	8.6068	0.30	189.46	68	8.6407	0.30	84.77	8.5619	N/A	272.75
24	8.6097	0.30	151.60	8.6041	0.29	208.48	70	8.6397	N/A	83.37	8.5674	N/A	274.19
26	8.6041	0.30	142.30	8.5978	0.30	217.87	72	8.6431	N/A	81.93	8.5590	N/A	275.63
28	8.6085	0.29	135.57	8.5945	0.29	224.59	74	8.6502	N/A	80.64	N/A	N/A	N/A
30	8.6084	0.31	130.15	8.5865	0.28	229.84	76	8.6417	N/A	79.12	N/A	N/A	N/A
32	8.6112	0.28	125.81	8.5868	0.28	234.40	78	8.6389	N/A	77.68	N/A	N/A	N/A
34	8.6147	0.28	121.81	8.5853	0.31	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	8.6189	0.31	118.53	8.5762	0.30	241.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	8.6244	0.28	115.52	8.5771	0.30	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	8.6239	0.30	112.70	8.5874	0.30	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	8.6285	0.30	110.24	8.5821	0.31	249.92	88	N/A	N/A	N/A	N/A	N/A	N/A
44	8.6336	0.29	107.95	8.5799	0.31	252.23	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

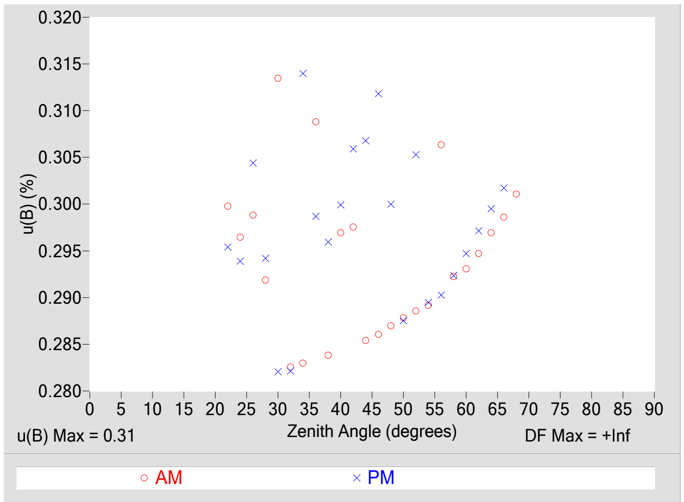


Figure 4. Residuals from Spline Interpolation

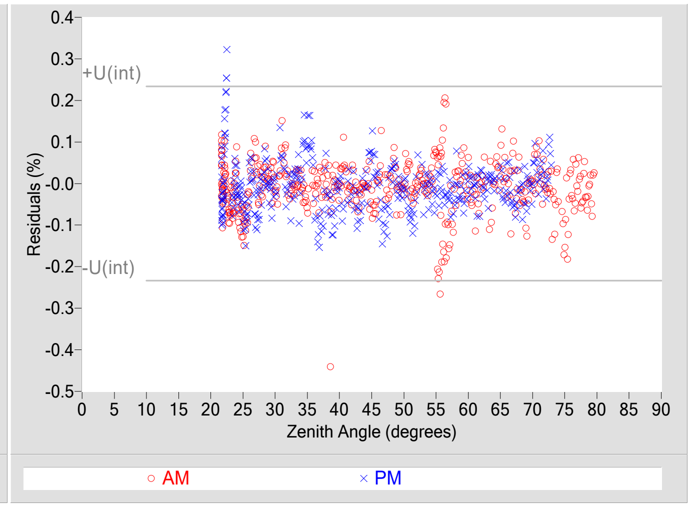


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±0.12
Combined Standard Uncertainty, u(c) (%)	±0.33
Effective degrees of freedom, DF(c)	54662
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±0.66
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

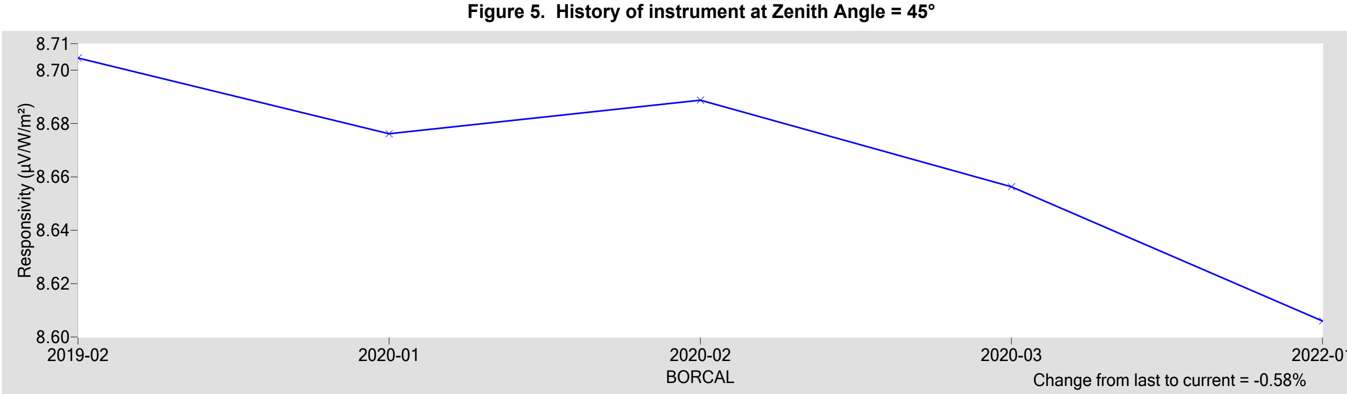
R @ 45° (µV/W/m²)	Rnet (µV/W/m²) †
8.6060	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+0.52 / -0.50
Expanded Uncertainty, U (%)	+1.1 / -1.1
Effective degrees of freedom, DF	+Inf
Coverage factor, k	1.96
Valid zenith angle range	30.0° to 60.0°

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



References:

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

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

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

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

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

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

Southern Great Plains Radiometer Calibration Facility

National Renewable Energy Laboratory

Metrology Laboratory

Calibration Certificate

Test Instrument:	Normal Incidence Pyrheliometer	**Manufacturer:**	Eppley
Model:	sNIP	**Serial Number:**	37959E6
Calibration Date:	5/7/2022	**Due Date:**	5/7/2023
Customer:	SGP	**Environmental Conditions:**	see page 4
Test Dates:	4/30, 5/7		

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	11/29/2021	11/29/2022
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 30495	11/29/2021	11/29/2022
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2549	07/07/2021	07/07/2023
Diffuse Irradiance †	Hukseflux Pyranometer Model SR25-T2, S/N 2550	07/07/2021	07/07/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1206	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1207	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2009-1208	04/26/2022	04/26/2023
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2014-1302	04/26/2022	04/26/2023

† 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* [1]

where,

V = radiometer output voltage (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

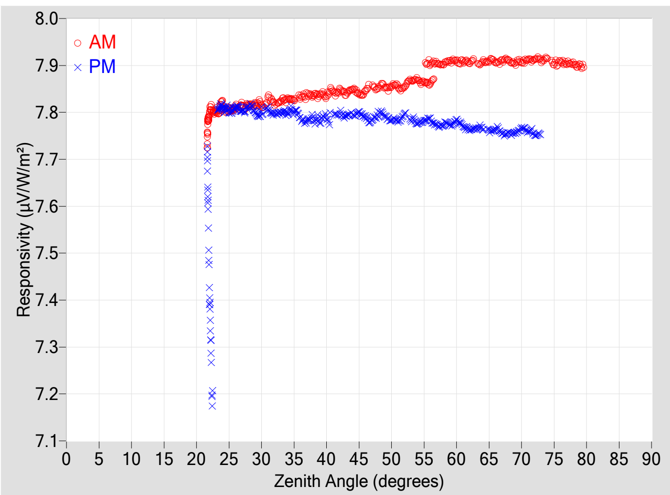


Figure 2. Responsivity vs Local Standard Time

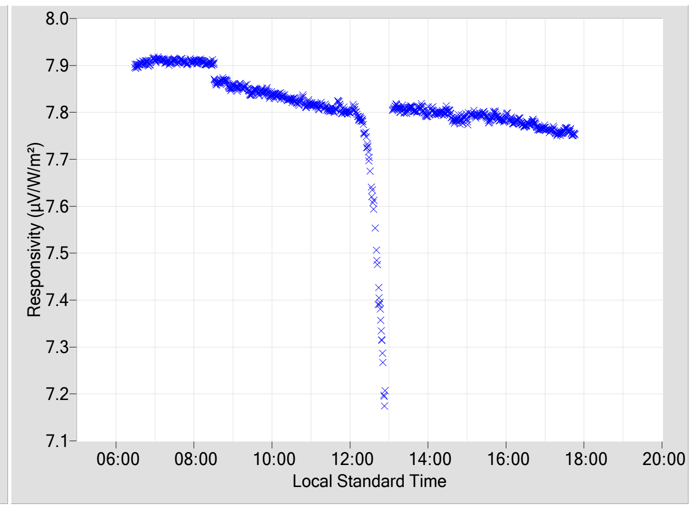


Table 2. Instrument Responsivity (R) and Calibration Type-B Standard Uncertainty, u(B)

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	7.8451	0.29	105.79	7.7901	0.31	254.34
2	N/A	N/A	N/A	N/A	N/A	N/A	48	7.8514	0.29	103.84	7.7971	0.30	256.43
4	N/A	N/A	N/A	N/A	N/A	N/A	50	7.8560	0.29	101.82	7.7832	0.29	258.27
6	N/A	N/A	N/A	N/A	N/A	N/A	52	7.8543	0.29	100.00	7.7965	0.31	260.11
8	N/A	N/A	N/A	N/A	N/A	N/A	54	7.8697	0.29	98.25	7.7765	0.29	261.87
10	N/A	N/A	N/A	N/A	N/A	N/A	56	7.8813	0.31	95.29	7.7840	0.29	263.53
12	N/A	N/A	N/A	N/A	N/A	N/A	58	7.9030	0.29	92.07	7.7734	0.29	265.17
14	N/A	N/A	N/A	N/A	N/A	N/A	60	7.9099	0.29	90.60	7.7827	0.29	266.75
16	N/A	N/A	N/A	N/A	N/A	N/A	62	7.9059	0.29	89.09	7.7630	0.30	268.28
18	N/A	N/A	N/A	N/A	N/A	N/A	64	7.9074	0.30	87.63	7.7655	0.30	269.78
20	N/A	N/A	N/A	N/A	N/A	N/A	66	7.9064	0.30	86.19	7.7640	0.30	271.29
22	7.7905	0.30	170.77	7.4542	0.30	189.84	68	7.9108	0.30	84.77	7.7561	N/A	272.75
24	7.8164	0.30	151.60	7.8108	0.29	208.48	70	7.9066	N/A	83.37	7.7650	N/A	274.19
26	7.8102	0.30	142.30	7.8107	0.30	217.87	72	7.9127	N/A	81.93	7.7523	N/A	275.63
28	7.8160	0.29	135.57	7.8096	0.29	224.59	74	7.9158	N/A	80.64	N/A	N/A	N/A
30	7.8153	0.31	130.15	7.7984	0.28	229.84	76	7.9080	N/A	79.12	N/A	N/A	N/A
32	7.8196	0.28	125.81	7.7972	0.28	234.40	78	7.9031	N/A	77.68	N/A	N/A	N/A
34	7.8271	0.28	121.81	7.7988	0.31	238.29	80	N/A	N/A	N/A	N/A	N/A	N/A
36	7.8332	0.31	118.53	7.7853	0.30	241.68	82	N/A	N/A	N/A	N/A	N/A	N/A
38	7.8358	0.28	115.52	7.7848	0.30	244.68	84	N/A	N/A	N/A	N/A	N/A	N/A
40	7.8353	0.30	112.70	7.7901	0.30	247.39	86	N/A	N/A	N/A	N/A	N/A	N/A
42	7.8464	0.30	110.24	7.7983	0.31	249.92	88	N/A	N/A	N/A	N/A	N/A	N/A
44	7.8490	0.29	107.95	7.7960	0.31	252.23	90	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not Available

Figure 3. Type-B Standard Uncertainty vs Zenith Angle

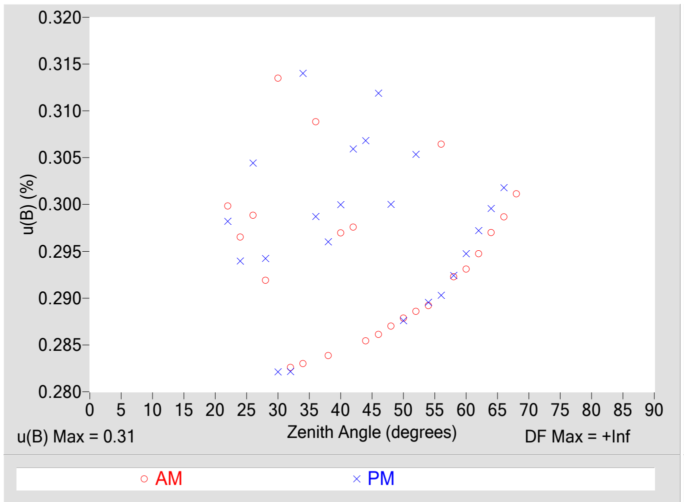


Figure 4. Residuals from Spline Interpolation

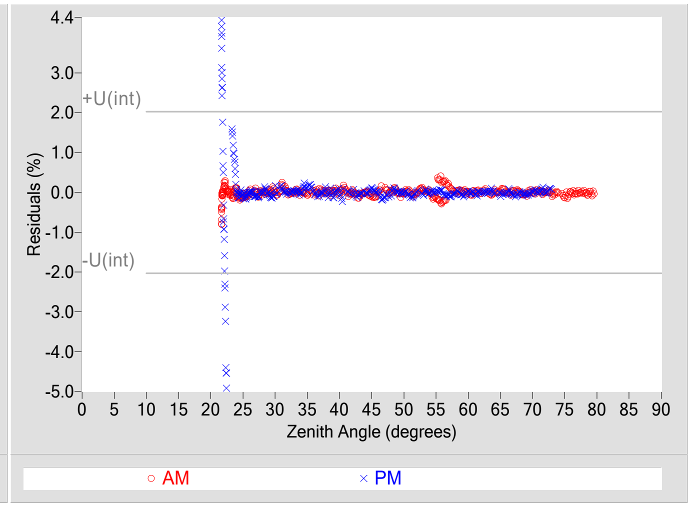


Table 3. Uncertainty using Spline Interpolation ‡

Type-B Standard Uncertainty, u(B) (%)	±0.31
Type-A Interpolating Function, u(int) (%)	±1.0
Combined Standard Uncertainty, u(c) (%)	±1.1
Effective degrees of freedom, DF(c)	961
Coverage factor, k	1.96
Expanded Uncertainty, U95 (%)	±2.1
AM Valid zenith angle range	22° to 68°
PM Valid zenith angle range	22° to 66°

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

Table 4. Calibration Label Values

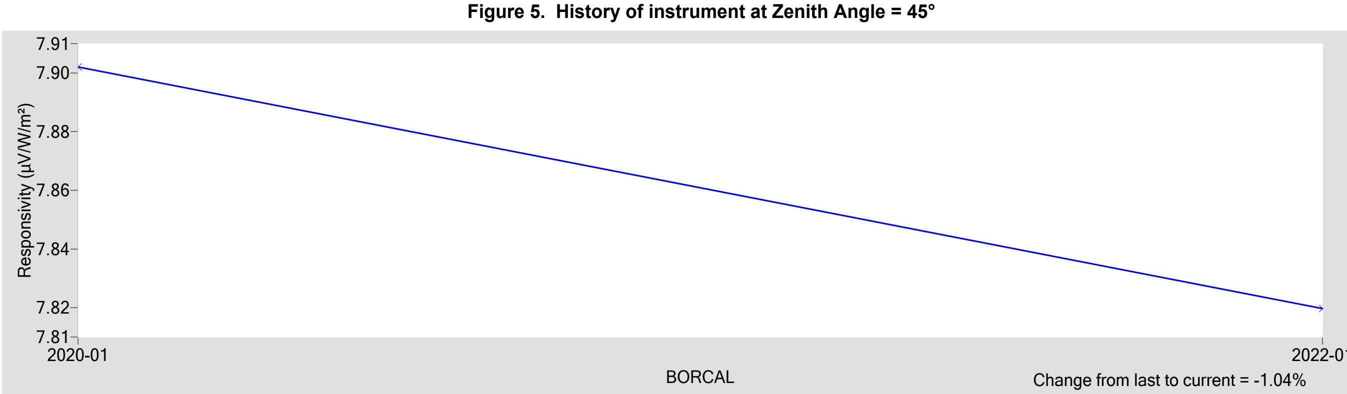
R @ 45° (μV/W/m²)	Rnet (μV/W/m²) †
7.8197	0

† Rnet determination date: N/A

Table 5. Uncertainty using R @ 45°

Type-B Expanded Uncertainty, U(B) (%)	±0.62
Offset Uncertainty, U(off) (%)	+1.2 / -0.59
Expanded Uncertainty, U (%)	+1.8 / -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).

Environmental and Sky Conditions for BORCAL-SW 2022-01

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

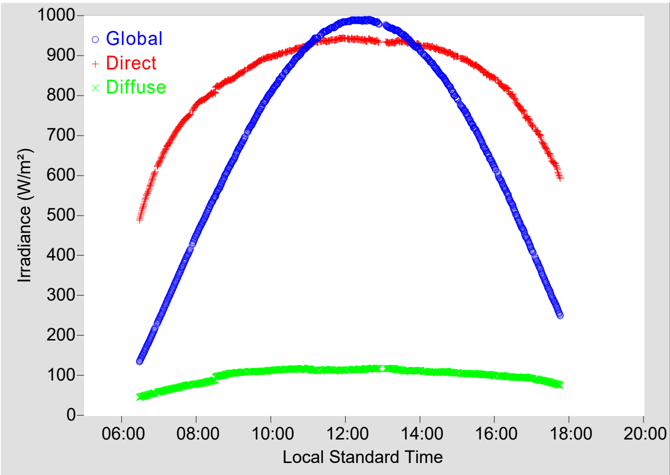
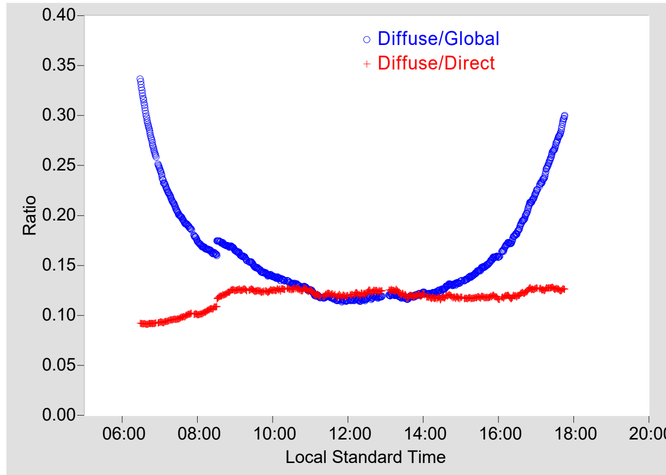


Figure 7. Diffuse Ratios



Meteorological Observations:

Figure 8. Temperature

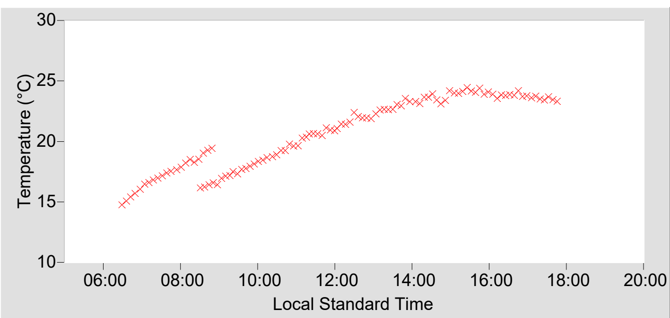


Figure 9. Humidity

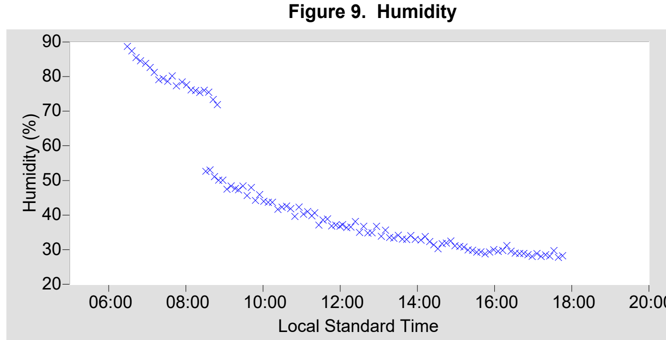


Figure 10. Pressure

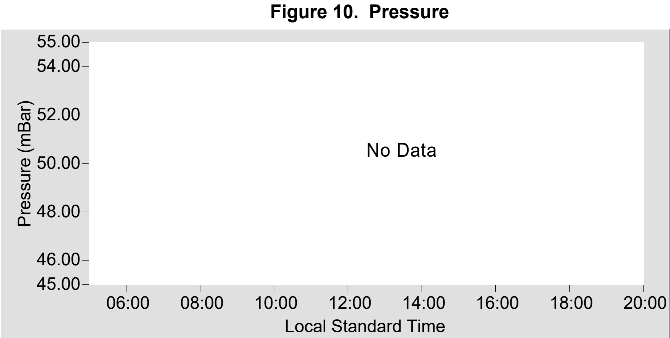


Figure 11. Effective Net Infrared

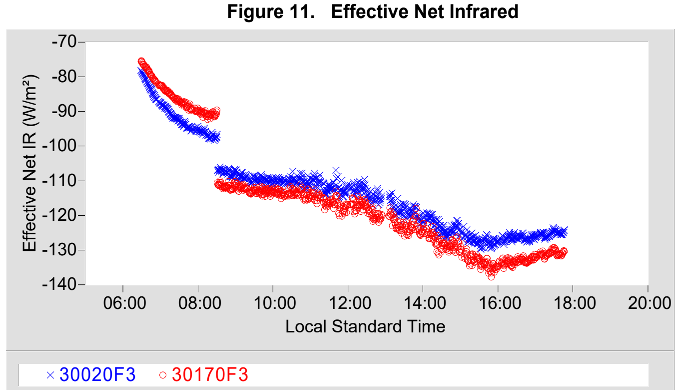


Figure 12. Estimated Broadband Aerosol Optical Depth

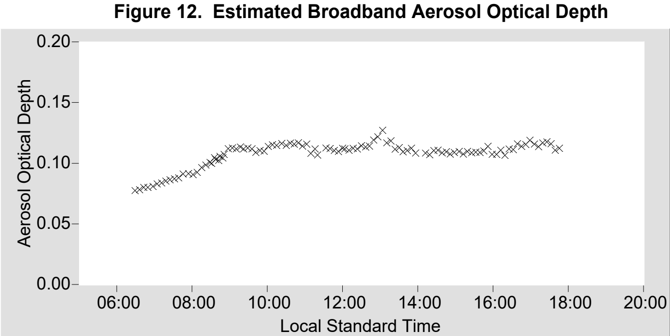


Table 6. Meteorological Observations

Observations	Mean	Min	Max
Temperature (°C)	20.64	14.74	24.46
Humidity (%)	44.95	27.81	88.72
Pressure (mBar)	N/A	N/A	N/A
Est. Aerosol Optical Depth (BB)	0.107	0.077	0.127

For other information about the calibration facility visit: https://www.arm.gov/capabilities/observatories/sgp

Appendix 2
BORCAL Notes

Instrument, Configuration, and Session Notes for the BORCAL

BORCAL Notes

Facility: Southern Great Plains
Comments:
Avg. Station Pressure and Temperature is for Tulsa, OK, which is used for the Solar Position Algorithm (SPA).

29011E6 Eppley NIP
Comments:
Instrument repaired 6/1/09 and new factory cal of 8.33 uV/W/m^2 applied. Replaces old cal of 9.25.

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)

29935E6 Eppley NIP
Comments:
Instrument repaired 6/30/09. New factory cal of 8.04 uV/W/m^2. Replaces old cal of 8.580

30895F3 Eppley PSP
Comments:
Factory cal was 9.040 but the cal sheet from Eppley Inc. was 9.050.

31746E6 Eppley NIP
Comments:
Instrument repaired June 2011. New factory cal of 8.515 assigned. Old cal 7.98

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 2022-01 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	-0.100

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	69.284

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
Temperature: E0710025T Vaisala HMP155 T			
239		AT	AT
		Scale 100	Offset -40
Humidity: E0710025H Vaisala HMP155 H			
255		RH	RH
		Scale 100	Offset 0
Pressure: None			
		Scale 0	Offset 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 3	2014-1302 NREL RAP-DAQ	SG42000596 Agilent 34420A
Unit 0	2009-1206 NREL RAP-DAQ	MY42002863 Agilent 34420A
Unit 2	2009-1208 NREL RAP-DAQ	MY42002866 Agilent 34420A

	Unit 1	Unit 3	Unit 0	Unit 2
Cal Date	04/26/2022	04/26/2022	04/26/2022	04/26/2022
Cal Due Date	04/26/2023	04/26/2023	04/26/2023	04/26/2023
System Offsets: Volts DC (µV)	0.95	0.95	0.95	0.95
2-Wire Res. (mOhms)	2826.00	2826.00	2826.00	2826.00
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	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
DMM	2	GPIB	23	0	0	0	0
Relay	2	GPIB	26	1	0	0	0

CAVITIES, CONTROL UNITS, AND DIGITAL MULTI METERS

	Cavity 1	Cavity 2
Unwindowed WRR	1.000000	1.000000
Windowed WRR	1.058780	1.055710
Unwindowed Uncert (%)	0.00	0.00
Windowed Uncert (%)	0.38	0.38
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	11/29/2021	11/29/2021
Cal Due Date	11/29/2022	11/29/2022

	Unit 1	Unit 2
Cavity Head	29222 Eppley HF	30495 Eppley HF
Control Unit	US37037985 NREL Reda	MY58006669 NREL Reda
Digital Multi Meter	US37037985 Hewlett Packard 34970A	MY58006669 Hewlett Packard 34970A
Cavity Location	T2-A	T5

	Control Unit 1	Control Unit 2
Current Shunt	1.000	1.000
Circuit Resist	3.700	2.600
Cal Date	09/09/2021	09/09/2021
Cal Due Date	09/09/2022	09/09/2022

Calibration Waits (Seconds)

	Cavity 1	Cavity 2
TP-solar	0	0
TP-heated	45	45
TP-zero	60	60
Dwell	15	15
Active	✔	✔
Window in Use	✔	✔

Communications

	Type	Port	Bd.	Parity	Stop bits	Data bits
Control Unit 1	GPIB	10	0	0	0	0
DMM 1		0	0	0	0	0
Control Unit 2	GPIB	9	0	0	0	0
DMM 2		0	0	0	0	0

BORCAL 2022-01 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: 2549 Hukseflux SR25-T2														
9.064	07/07/2021	07/07/2023	6.2	70.0	5.1	2.30	0.5	50	176		T3	T3	☐	✔
Diffuse 1: Case NONE Temperature									n/a	n/a	n/a			
Diffuse 1: Dome NONE Temperature									n/a	n/a	n/a			
Diffuse 2: 2550 Hukseflux SR25-T2														
8.700	07/07/2021	07/07/2023	6.2	70.0	5.1	1.90	0.5	50	177		T4	T4	☐	✔
Diffuse 2: Case NONE Temperature									n/a	n/a	n/a			
Diffuse 2: Dome NONE Temperature									n/a	n/a	n/a			

PYRGEOMETER INSTRUMENTS

Cal Date	Cal Due Date	K0	K1	K2	K3	Kr	Uncert. (W/m^2)	Max Out (mV)	Channel	J Box	Cable	Location	Active
		Calibration Coefficients											
Pyrgeometer 1: 30170F3 Eppley PIR													
04/09/2021	04/09/2023	0.00000	0.23628	1.00580	-3.39000	7.04400E-4	2.60	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)													
04/09/2021	04/09/2023	0.00000	0.24455	0.99530	-3.44000	7.04400E-4	2.70	9	232		83	83	✔
Pyrgeometer 2: Case 10K Temperature									240		83		
Pyrgeometer 2: Dome 10K Temperature									248		83		

BORCAL 2022-01 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	10
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	4
			Eppley sNIP			3
6	Direct	20	Kipp & Zonen CHP1	Kipp & Zonen CHP1	none	1
7	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
8	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
9	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	10
10	Global	50	Eppley PSP	Eppley PSP	30020F3 Eppley PIR-V	1
11	Global	50	Kipp & Zonen CMP22	Kipp & Zonen CM22	30020F3 Eppley PIR-V	2
12	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	10
13	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	10
14	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	10
15	Global	50	Eppley PSP	Eppley PSP	30170F3 Eppley PIR	4
Total						115

BORCAL 2022-01 Session Configuration Audit Report

INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
13011F3 ©	PSP	TWP	12	1	13		26	No	Yes	No	TOT	26	12
18289F3 ©	PSP	Nels Laulainen	12	2	4		22	No	Yes	No	TOT	22	12
18637E6	NIP	TWP	3	1	193		T22	No	No	No	DIR	T22	12
20018F3 ©	PSP	TWP	12	3	97		32	No	Yes	No	TOT	32	12
200692 ©	CMP22	SGP	11	1	114		56	No	Yes	Yes	TOT	56	12
		(Case 10K Temperature)			122								
200693 ©	CMP22	SGP	11	2	128		57	No	Yes	Yes	TOT	57	12
		(Case 10K Temperature)			136								
200804	CHP1	SGP	6	1	222		T33	No	Yes	No	DIR	T33	12
20620F3 ©	PSP	TWP	12	4	109		33	No	Yes	No	TOT	33	12
29010E6	NIP	SGP	3	2	250		T31	No	Yes	No	DIR	T31	12
29011E6	NIP	SGP	3	3	237		T24	No	Yes	No	DIR	T24	12
29278F3 ©	PSP	SGP	12	5	16		16	No	Yes	No	TOT	16	12
29541E6	NIP	SGP	3	4	244		T18	No	Yes	No	DIR	T18	12
29608F3 ©	PSP	SGP	12	6	2		6	No	Yes	No	TOT	6	12
29609F3 ©	PSP	SGP	7	1	126		49	No	Yes	Yes	TOT	49	12
29738E6	NIP	SGP	3	5	236		T17	No	Yes	No	DIR	T17	12
29848E6	NIP	SGP	3	6	234		T20	No	Yes	No	DIR	T20	12
29911F3 ©	PSP	SGP	7	2	118		42	No	Yes	Yes	TOT	42	12
29917F3 ©	PSP	TWP	7	3	144		65	No	Yes	Yes	TOT	65	12
29935E6	NIP	SGP	3	7	238		T25	No	Yes	No	DIR	T25	12
29937E6	NIP	TWP	3	8	214		T11	No	Yes	No	DIR	T11	12
30584E6	NIP	SGP	3	9	245		T26	No	Yes	No	DIR	T26	12
30615F3 ©	PSP	SGP	12	7	14		27	No	Yes	No	TOT	27	12
30666F3 ©	PSP	SGP	7	4	149		67	No	Yes	Yes	TOT	67	12
30667F3 ©	PSP	SGP	12	8	8		7	No	Yes	No	TOT	7	12
30674F3 ©	PSP	SGP	12	9	1		5	No	Yes	No	TOT	5	12
30720E6	NIP	SGP	3	10	205		T23	No	Yes	No	DIR	T23	12
30797F3 ©	PSP	SGP	12	10	17		17	No	Yes	No	TOT	17	12
30811F3 ©	PSP	SGP	7	5	116		40	No	Yes	Yes	TOT	40	12
30887F3 ©	PSP	SGP	13	1	64		12	No	Yes	No	TOT	12	12
30890F3 ©	PSP	SGP	7	6	150		68	No	Yes	Yes	TOT	68	12
30894F3 ©	PSP	SGP	7	7	166		78	No	Yes	Yes	TOT	78	12
30895F3 ©	PSP	SGP	13	2	9		8	No	Yes	No	TOT	8	12
30897F3 ©	PSP	SGP	13	3	10		9	No	Yes	No	TOT	9	12
30899F3 ©	PSP	SGP	7	8	156		66	No	Yes	Yes	TOT	66	12
30901F3 ©	PSP	SGP	13	4	22		36	No	Yes	No	TOT	36	12
30903F3 ©	PSP	SGP	7	9	132		50	No	Yes	Yes	TOT	50	12
30929F3 ©	PSP	SGP	7	10	110		38	No	Yes	Yes	TOT	38	12
30934F3 ©	PSP	SGP	8	1	158		75	No	Yes	Yes	TOT	75	12
30940F3 ©	PSP	SGP	8	2	165		77	No	Yes	Yes	TOT	77	12
30944F3 ©	PSP	SGP	8	3	164		76	No	Yes	Yes	TOT	76	12
30945F3 ©	PSP	SGP	13	5	78		15	No	Yes	No	TOT	15	12
30946F3 ©	PSP	SGP	8	4	108		39	No	Yes	Yes	TOT	39	12
30947F3 ©	PSP	SGP	13	6	65		13	No	Yes	No	TOT	13	12
30951F3 ©	PSP	SGP	13	7	0		4	No	Yes	No	TOT	4	12
30952F3 ©	PSP	SGP	13	8	66		14	No	Yes	No	TOT	14	12
30954F3 ©	PSP	SGP	13	9	20		34	No	Yes	No	TOT	34	12
30958F3 ©	PSP	SGP	13	10	61		3	No	Yes	No	TOT	3	12

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INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
31099F3 ‡©	PSP	Calibration System	8	5	130		64	No	Yes	Yes	TOT	64	12
		(Case 10K Temperature)			138		64						
31100F3 ‡©	PSP	Calibration System	8	6	145		73	No	Yes	Yes	TOT	73	12
		(Case 10K Temperature)			153		73						
31101F3 ‡©	PSP	Calibration System	8	7	160		82	No	Yes	Yes	TOT	82	12
		(Case 10K Temperature)			168		82						
31120E6 ‡	NIP	Calibration System	4	1	242		T29	No	Yes	No	DIR	T29	12
31121E6 ‡	NIP	Calibration System	4	2	210		T32	No	Yes	No	DIR	T32	12
		(Case NONE Temperature)			218								
31146F3 ‡©	PSP	Calibration System	8	8	98		37	No	Yes	Yes	TOT	37	12
		(Case 10K Temperature)			106		37						
31147F3 ‡©	PSP	Calibration System	8	9	112		46	No	Yes	Yes	TOT	46	12
		(Case 10K Temperature)			120		46						
31148F3 ‡©	PSP	Calibration System	8	10	113		55	No	Yes	Yes	TOT	55	12
		(Case 10K Temperature)			121		55						
31152F3 ‡©	PSP	Calibration System	14	1	80		19	No	Yes	No	TOT	19	12
		(Case 10K Temperature)			88		19						
31153F3 ‡©	PSP	Calibration System	14	2	81		28	No	Yes	No	TOT	28	12
		(Case 10K Temperature)			89		28						
31154F3 ‡©	PSP	Calibration System	14	3	82		29	No	Yes	No	TOT	29	12
		(Case 10K Temperature)			90		29						
31155F3 ‡©	PSP	Calibration System	14	4	48		1	No	Yes	No	TOT	1	12
		(Case 10K Temperature)			56		1						
31156F3 ‡©	PSP	Calibration System	14	5	49		10	No	Yes	No	TOT	10	12
		(Case 10K Temperature)			57		10						
31157F3 ‡©	PSP	Calibration System	14	6	50		11	No	Yes	No	TOT	11	12
		(Case 10K Temperature)			58		11						
31275F3 ©	PSP	TWP	14	7	5		23	No	Yes	No	TOT	23	12
31277F3 ©	PSP	TWP	9	1	124		47	No	Yes	Yes	TOT	47	12
31280F3 ©	PSP	TWP	14	8	6		24	No	Yes	No	TOT	24	12
31281F3 ©	PSP	TWP	9	2	174		86	No	Yes	Yes	TOT	86	12
31287F3 ©	PSP	TWP	14	9	96		31	No	Yes	No	TOT	31	12
31288F3 ©	PSP	TWP	14	10	18		18	No	Yes	No	TOT	18	12
31344E6	NIP	NSA	4	3	229		T8	No	Yes	No	DIR	T8	12
31627F3 ©	PSP	SGP	9	3	133		51	No	Yes	Yes	TOT	51	12
31631F3 ©	PSP	SGP	15	1	21		35	No	Yes	No	TOT	35	12
31632F3 ©	PSP	SGP	9	4	157		69	No	Yes	Yes	TOT	69	12
31635F3 ©	PSP	SGP	9	5	146		74	No	Yes	Yes	TOT	74	12
31746E6	NIP	SGP	4	4	194		T27	No	Yes	No	DIR	T27	12
31759E6	NIP	NSA	4	5	225		T7	No	Yes	No	DIR	T7	12
31866E6	NIP	TWP	4	6	253		T35	No	Yes	No	DIR	T35	12
32015F3 ©	PSP	NSA	9	6	161		84	No	Yes	Yes	TOT	84	12
32017F3 ©	PSP	NSA	9	7	162		85	No	Yes	Yes	TOT	85	12
32018F3 ©	PSP	NSA	9	8	125		48	No	Yes	Yes	TOT	48	12
33237	8-48	SGP	1	1	28		70	No	Yes	Yes	TOT	70	12
33239	8-48	SGP	1	2	26		45	No	Yes	Yes	TOT	45	12
33242	8-48	SGP	1	3	29		71	No	Yes	Yes	TOT	71	12
33243	8-48	TWP	1	4	38		81	No	Yes	Yes	TOT	81	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

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INSTRUMENTS

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
33269	8-48	SGP	1	7	37		80	No	Yes	Yes	TOT	80	12
33271	8-48	TWP	1	8	44		88	No	Yes	Yes	TOT	88	12
33274	8-48	SGP	1	9	32		52	No	Yes	Yes	TOT	52	12
33277	8-48	SGP	1	10	33		53	No	Yes	Yes	TOT	53	12
33282	8-48	TWP	2	1	36		79	No	Yes	Yes	TOT	79	12
33376	8-48	TWP	2	2	41		62	No	Yes	Yes	TOT	62	12
33379	8-48	TWP	2	3	142		60	No	Yes	Yes	TOT	60	12
33551E6	NIP	TWP	4	7	233		T19	No	Yes	No	DIR	T19	12
33784	8-48	SGP	2	4	34		54	No	Yes	Yes	TOT	54	12
33785	8-48	SGP	2	5	25		44	No	Yes	Yes	TOT	44	12
33787	8-48	SGP	-	-	28		70	No	Yes	No	TOT	70	12
33860E6	NIP	AMF	4	8	212		T9	No	Yes	No	DIR	T9	12
34066	8-48	AMF	2	6	173		87	No	Yes	Yes	TOT	87	12
34504E6	NIP	SGP	4	9	230		T16	No	Yes	No	DIR	T16	12
34505E6	NIP	SGP	4	10	226		T15	No	Yes	No	DIR	T15	12
34506E6	NIP	SGP	5	1	241		T21	No	Yes	No	DIR	T21	12
34580	8-48	SGP	2	7	24		43	No	Yes	Yes	TOT	43	12
35751	8-48	AMF#2	2	8	42		63	No	Yes	Yes	TOT	63	12
35834F3 ©	PSP	AMF#2	9	9	117		41	No	Yes	Yes	TOT	41	12
37166	8-48	NSA	2	9	46		90	No	Yes	Yes	TOT	90	12
37285E6	NIP	AMF	5	2	246		T34	No	Yes	No	DIR	T34	12
37298F3 ©	PSP	NSA	9	10	129		58	No	Yes	Yes	TOT	58	12
37299F3 ©	PSP	NSA	10	1	141		59	No	Yes	Yes	TOT	59	12
37303F3 ©	PSP	AMF	15	2	92		20	No	Yes	No	TOT	20	12
37317F3 ©	PSP	AMF	15	3	93		21	No	Yes	No	TOT	21	12
37319F3 ©	PSP	AMF	15	4	12		25	No	Yes	No	TOT	25	12
37360E6	NIP	AMF	5	3	213		T10	No	Yes	No	DIR	T10	12
37361E6	NIP	NSA	5	4	254		T36	No	Yes	No	DIR	T36	12
37392	8-48	NSA	2	10	45		89	No	Yes	Yes	TOT	89	12
37945E6 ‡	sNIP	SGP	5	5	178		T12	No	Yes	No	DIR	T12	12
		(Case NONE Temperature)			186		T12						
37947E6 ‡	sNIP	SGP	5	6	209		T28	No	Yes	No	DIR	T28	12
		(Case NONE Temperature)			217								
37959E6	sNIP	SGP	5	7	204		T14	No	Yes	No	DIR	T14	12

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Effective Net IR Corrected Instruments

Instrument	Vent	Correcting Pyrgeometer	Inst. RSnet	RSnet uncert.	RSnet Date
13011F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
18289F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	05/18/2019
20018F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
200692 Kipp & Zonen CMP22	Yes	30020F3 Eppley PIR-V	0.0870	20.0000	Estimated
200693 Kipp & Zonen CMP22	Yes	30020F3 Eppley PIR-V	0.0870	20.0000	Estimated
20620F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
29278F3 Eppley PSP	No	30170F3 Eppley PIR	0.5680	10.0000	04/05/2006
29608F3 Eppley PSP	No	30170F3 Eppley PIR	0.5710	10.0000	04/06/2006
29609F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6360	10.0000	04/20/2006
29911F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5975	10.0000	04/24/2007
29917F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5800	10.0000	06/28/2005
30615F3 Eppley PSP	No	30170F3 Eppley PIR	0.6853	10.0000	04/25/2007
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
30674F3 Eppley PSP	No	30170F3 Eppley PIR	0.6149	10.0000	04/26/2007
30797F3 Eppley PSP	No	30170F3 Eppley PIR	0.5891	10.0000	04/25/2007
30811F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5550	10.0000	04/05/2006
30887F3 Eppley PSP	No	30170F3 Eppley PIR	0.6436	10.0000	04/06/2006
30890F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5945	10.0000	06/07/2006
30894F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6467	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
30901F3 Eppley PSP	No	30170F3 Eppley PIR	0.5230	10.0000	06/29/2005
30903F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5865	10.0000	04/18/2006
30929F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6304	10.0000	06/07/2006
30934F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5300	10.0000	04/18/2006
30940F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6187	10.0000	06/07/2006
30944F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5669	10.0000	04/18/2006
30945F3 Eppley PSP	No	30170F3 Eppley PIR	0.5340	10.0000	07/10/2006
30946F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6625	10.0000	04/24/2007
30947F3 Eppley PSP	No	30170F3 Eppley PIR	0.5490	10.0000	04/06/2006
30951F3 Eppley PSP	No	30170F3 Eppley PIR	0.6427	10.0000	07/06/2006
30952F3 Eppley PSP	No	30170F3 Eppley PIR	0.5867	10.0000	04/05/2006
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
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
31275F3 Eppley PSP	No	30170F3 Eppley PIR	0.5915	10.0000	07/03/2008
31277F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5040	10.0000	04/03/2006

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Effective Net IR Corrected Instruments

Instrument	Vent	Correcting Pyrgeometer	Inst. RSnet	RSnet uncert.	RSnet Date
31280F3 Eppley PSP	No	30170F3 Eppley PIR	0.4970	10.0000	03/30/2006
31281F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5410	10.0000	06/29/2005
31287F3 Eppley PSP	No	30170F3 Eppley PIR	0.6241	10.0000	04/26/2007
31288F3 Eppley PSP	No	30170F3 Eppley PIR	0.5780	10.0000	03/30/2006
31627F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6180	10.0000	06/29/2005
31631F3 Eppley PSP	No	30170F3 Eppley PIR	0.6599	10.0000	04/25/2007
31632F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	06/24/2013
31635F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6137	10.0000	06/06/2006
32015F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.4221	10.0000	03/25/2009
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
35834F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.5492	10.0000	08/05/2009
37298F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
37299F3 Eppley PSP	Yes	30020F3 Eppley PIR-V	0.6000	20.0000	Estimated
37303F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
37317F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated
37319F3 Eppley PSP	No	30170F3 Eppley PIR	0.6000	20.0000	Estimated

Appendix 4
Operator Session Logs

Operator session logs for the BORCAL

BORCAL 2022-01 Operator Session Log

Session: 1

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	06:22:20	06:23:26	29222	0:00	971.2	971.2
			30495	0:00	956.8	956.8

Observations: [None]

Session: 2

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	06:26:25	06:26:41	29222	0:00	970.2	970.2
			30495	0:00	956.8	956.8

Observations: [None]

Session: 3

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	06:40:34	07:39:37	29222	06:10:0:00	970.1	971.9
			30495	0:00	956.4	957.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:00:49	74.49	Blue	626.5	26.4	Craig Webb

Comments:
several alarms, keep getting a reference alarms. temp 13 C, hum 95%, hpa 973, wnd dir 240 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:20:54	70.50	Blue	676.8	24.3	Craig Webb

Comments:
still getting reference alarms and a few std alarms, temp 13.5C, hum 65% hpa 973, wnd 230 @ 7 mph.

Session: 4

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	07:45:08	08:25:20	29222	06:10:0:00	971.8	971.7
			30495	0:00	957.6	957.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:05:20	61.59	Blue	784.0	19.1	Craig Webb

Comments:
Bird on shade arm for diffused. refference alarm, temp 15C, hum 56%, hpa 974, wnd dir 250@ 9 mph.

Session: 5

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	08:30:14	09:21:14	29222	06:10	971.9	971.5
			30495	06:10	957.8	957.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:57:05	51.29	Blue	840.7	16.7	Craig Webb

Comments:

reference responsitivy corrected and refernce alarm cleared. temp 16C, hum 50%, hum 974, wnd dir 250 @ 13 mph. clear.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:17:14	47.33	Blue	862.4	15.5	Craig Webb

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Comments:
31353F3 keeps alarming. clear temp 17 C, hum 48%, hpa 974, wnd dir 180 @ 12 mph

Session: 6

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	09:21:14	10:22:16	29222	06:10	971.5	971.1
			30495	06:10	957.2	956.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:43:25	42.31	Blue	889.1	14.3	Craig Webb

Comments:
clear temp 18C, hum 48%, hpa 974, wnd dir 300 @ 17 mph. getting alarm on control 31153F3.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:07:09	37.91	Blue	900.0	13.8	Craig Webb

Comments:
birds flying in area, clear temp 18C, hum 45%, hpa 974. wnd dir 255 @ 15 mph.

Session: 7

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	10:22:16	11:19:20	29222	06:10	971.1	970.8
			30495	06:10	956.8	956.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:33:55	33.23	Blue	913.1	13.0	Craig Webb

Comments:
clear, temp 19C, hum 42%, hpa 974, wnd dir 240 @ 16 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:54:04	29.99	Blue	923.6	12.6	Craig Webb

Comments:
clouds forming to the east and south, otherwise it is clear, temp 19C, hum 40%, hpa 974, wnd dir 255 @ 14 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:16:32	26.78	Blue	934.7	11.7	Craig Webb

Comments:
clear with clouds to temp 20C, hum 40%, hpa 974, wnd dir 260 @ 18 mph.

Session: 8

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	11:19:20	12:02:45	29222	06:10	970.8	970.3
			30495	06:10	956.5	956.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:36:47	24.41	Brown	941.2	11.6	Craig Webb

Comments:
no change in sky conditions, temp 20C, hum 47%, hpa 974, wnd dir 260 @ 21 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:56:55	22.69	Blue	946.0	11.4	Craig Webb

Comments:
going to calibrate early getting ready for solar noon, temp 21C, hum 37%, hpa 974, wnd dir 240 @ 7 mph.

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Session: 9

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	12:02:45	13:02:48	29222	06:10	970.3	969.6
			30495	06:10	956.1	955.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:17:18	21.78	Green	941.1	11.5	Craig Webb

Comments:
solar noon, temp 21C, hum 36%, hpa 974, wnd dir 260 @ 20 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:37:25	21.78	Blue	943.0	11.5	Craig Webb

Comments:
getting a std alarm checked for bugs found none, temp 22C, hum 36%, hpa 974, wnd dir 248 @ 17 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:40:01	21.85	Blue	941.2	11.7	Craig Webb

Comments:
light haze starting to form thru out the sky.

Session: 10

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	13:02:48	14:04:50	29222	06:10	969.6	969.2
			30495	06:10	955.8	955.6

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:06:39	23.37	Green	933.4	11.9	Craig Webb

Comments:
clear with a light haze, temp 22C, hum 34%, hpa 974, wnd dir 280 @ 16 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:26:49	25.40	Blue	936.3	11.8	Craig Webb

Comments:
no change in sky conditions, temp 22C, hum 33%, hpa 974, wnd dir 260 @ 12 mph,

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:47:05	28.01	Blue	929.9	11.9	Craig Webb

Comments:
no change, temp 23C, hum 33%, hpa 974, wnd dir 290 @ 16 mph.

Session: 11

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	14:04:50	15:04:51	29222	06:10	969.2	968.9
			30495	06:10	955.6	955.1

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:07:13	31.04	Blue	924.2	12.1	Craig Webb

Comments:
some small clouds to the east and south and a light haze, temp23C, hum 33%, hpa 974, wnd dir 235 @ 19 mph.

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Time	Zenith	ASR	Direct	% Diffuse	Operator
14:27:22	34.36	Blue	922.1	12.2	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
14:47:43	37.97	Blue	909.4	12.9	Craig Webb

Comments:
light haze, temp 23C, hum 32%, hpa 974, wnd dir 250 @ 15 mph.

Session: 12

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	15:04:51	16:04:54	29222	06:10	968.9	968.9
			30495	06:10	955.1	955.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:07:52	41.69	Blue	893.0	13.5	Craig Webb

Comments:
some small clouds forming through the area, temp 24C, hum 31%, hpa 974, wnd dir 275 @ 18 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:28:09	45.54	Blue	874.8	14.4	Craig Webb

Comments:
no change,

Time	Zenith	ASR	Direct	% Diffuse	Operator
15:48:17	49.46	Blue	853.9	15.4	Craig Webb

Comments:
some small clouds in area, temp 24C, hum 39%, hpa 974, wnd dir 249 @ 18 mph.

Session: 13

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-30-2022	16:04:54	17:04:55	29222	06:10	968.9	968.7
			30495	06:10	955.0	955.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:08:23	53.41	Blue	831.1	16.3	Craig Webb

Comments:
clouds moved to the east, temp 24C, hum 30%, hpa 974, wnd dir 255 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:28:45	57.48	Blue	803.6	17.9	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:48:49	61.49	Blue	750.4	20.9	Craig Webb

Comments:
clear, temp 24C, hum 29%, hpa 974, wnd dir 243 @ 13 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
16:51:31	62.03	Blue	747.4	21.2	Craig Webb

Comments:
bird hit on 31631F3, cleaned.

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==========================================================================================
Session: 14
-------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
04-30-2022    17:04:55      17:49:09      29222         06:10          968.7         968.6
                                          30495         06:10          955.4         955.0
-------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
17:11:36       66.06        Blue           703.3             23.5     Craig Webb
------------------------------------------------------------------------------
Comments:
there is a haze on the horzin, temp 23C, hum 29%, hpa 974, wnd dir 270 @ 8 mph.
------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
17:31:43       70.08        Blue           638.4             27.0     Craig Webb
------------------------------------------------------------------------------
Comments:
no change.
------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
17:45:38       72.85        Blue           594.5             29.8     Craig Webb
------------------------------------------------------------------------------
Comments:
quiting for the day, temp 23C, hum 28%, hpa 974, wnd dir 243 @ 6 mph.
==========================================================================================
Session: 15
-------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
05-07-2022    06:28:08      06:56:34      29222         06:10          970.4         970.9
                                          30495         06:10          957.7         958.7
-------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
06:48:18       75.70        Blue           586.8             27.1     Craig Webb
------------------------------------------------------------------------------
Comments:
bug stuck in fan of 29609F3, spider web on 31146F3, clear sky some haze on horizon, temp 16C, hum 85%, hpm
973, wnd dir 090 @ 3 mph.
==========================================================================================
Session: 16
-------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
05-07-2022    06:56:34      07:53:36      29222         06:10          970.9         971.5
                                          30495         06:10          958.7         958.3
-------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
07:08:26       71.71        Blue           659.6             23.0     Craig Webb
------------------------------------------------------------------------------
Comments:
calibnrated early for solar noon, clear sky, temp 16C, hum 83%, hpa 973, wnd dir 110 @ 4 mph.
------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
07:35:35       66.30        Blue           728.4             19.7     Craig Webb
------------------------------------------------------------------------------
Comments:
a few alarms, but sky is clear, temp 17C, hum 79%, hpa 973, wnd dir 105 @ 4 mph.
==========================================================================================
Session: 17
-------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
05-07-2022    07:53:36      08:53:36      29222         06:10          971.5         971.3
                                          30495         06:10          958.3         957.7
-------------------------------------------------------------------------------------
```

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Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
07:55:40	62.29	Blue	766.5	17.9	Craig Webb

Comments:
clear, temp 18C, hum 78%, hpa 974, wnd dir 108 @ 2 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:17:41	57.88	Blue	797.7	16.6	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:37:55	53.82	Blue	816.4	15.7	Craig Webb

Comments:
clear temp 19C, hum 75%, hpa 974, wnd dir 155 @ 3 mph.

Session: 18

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-07-2022	08:53:36	09:53:40	29222	06:10	971.3	970.4
			30495	06:10	957.7	956.8

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:58:13	49.77	Blue	835.4	14.9	Craig Webb

Comments:
clear sky, temp 20C, hum 71%, hpa 974, wnd dir 096 @ 8 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:18:24	45.81	Blue	845.7	14.7	Craig Webb

Comments:
no change in conditions.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:38:39	41.86	Blue	847.4	15.2	Craig Webb

Comments:
clear. yemp 21C, hum 66% hpa 974, wnd dir 090 @ 2 mph.

Session: 19

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-07-2022	09:53:40	10:52:41	29222	06:10	970.4	970.1
			30495	06:10	956.8	956.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:58:47	38.04	Blue	853.3	14.9	Craig Webb

Comments:
some small thin clouds moving in from the S/E, temp 21C, hum 66%, hpa 974, wnd dir 200 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:19:05	34.30	Blue	858.1	15.8	Craig Webb

Comments:
clouds pass through the area, temp 22C, hum 65%, hpa 974, wnd dir 110 @ 6 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:39:11	30.79	Blue	854.4	16.7	Craig Webb

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```
Comments:
light cirrus clouds in area, temp 23C, hum 63%, hpa 974, wnd dir 140 @ 7 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
10:43:32        30.06         Green           849.3              17.5      Craig Webb
------------------------------------------------------------------------------------------
Comments: [None]
==================================================================================================
Session: 20
------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-07-2022     10:52:41       11:52:44       29222          06:10            970.1          969.0
                                             30495          06:10            956.2          955.4
------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
11:03:38        26.86         Blue            891.4              13.0      Craig Webb
------------------------------------------------------------------------------------------
Comments:
cloud moved to the N/E, temp 23C, hum 60%, hpa 973, wnd dir 120 @ 8 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
11:24:13        24.00         Blue            909.1              12.1      Craig Webb
------------------------------------------------------------------------------------------
Comments:
clouds clearing out, temp 24C, hum 59%, hpa 973, wnd dir 148 @ 9 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
11:44:23        21.75         Blue            918.0              11.7      Craig Webb
------------------------------------------------------------------------------------------
Comments:
clouds are moving to the north and east, temp 24C, hum 57%, hpa 973, wnd dir 114 @ 8 mph.  soloar noon
will be the next session.
==================================================================================================
Session: 21
------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-07-2022     11:52:44       12:52:44       29222          06:10            969.0          969.0
                                             30495          06:10            955.4          955.3
------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
12:04:34        20.24         Blue            896.0              14.3      Craig Webb
------------------------------------------------------------------------------------------
Comments:
clouds cleared off, temp 24C, hum 59%, hpa 973, wnd dir 211 @ 5 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
12:24:39        19.64         Red             873.0              24.2      Craig Webb
------------------------------------------------------------------------------------------
Comments:
more clouds moving in from the south, temp 25C, hum 58%, hpa 973, wnd dir 130 @ 7 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
12:44:52        20.05         Blue            889.9              13.3      Craig Webb
------------------------------------------------------------------------------------------
Comments:
clouds still coming into the area, temp 25C, hum 55%, hpa 973, wnd dir 114 @ 8 mph.
==================================================================================================
Session: 22
------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-07-2022     12:52:44       13:52:47       29222          06:10            969.0          968.3
                                             30495          06:10            955.3          954.9
------------------------------------------------------------------------------------------------
```

```
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
13:05:06        21.40         Blue            909.8              12.1      Craig Webb
------------------------------------------------------------------------------------------
Comments:
some lught cirrus in area, temp 26C, hum 55%, hpa 973, wnd dir 075 @ 5 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
13:25:15        23.53         Blue            903.7              12.3      Craig Webb
------------------------------------------------------------------------------------------
Comments:
no change in conditions.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
13:45:24        26.24         Blue            900.0              12.8      Craig Webb
------------------------------------------------------------------------------------------
Comments:
some light cirrus in area, temp 26 C, hum 54%, hpa 973, wnd dir 110 @ 9 mph.


==========================================================================================================
Session: 23
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-07-2022     13:52:47       14:50:50       29222          06:10            968.3          968.2
                                             30495          06:10            954.9          954.6
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:05:38        29.39         Blue            878.0              13.9      Craig Webb
------------------------------------------------------------------------------------------
Comments:
some std alarms, temp 26C, hum 54%, hpa 973, wnd dir 090 @ 6 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:25:45        32.80         Blue            879.1              13.6      Craig Webb
------------------------------------------------------------------------------------------
Comments:
no change in conditions.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:45:59        36.46         Blue            865.6              14.3      Craig Webb
------------------------------------------------------------------------------------------
Comments:
clear and a few std alarms. temp 26C, hum 57%, hpa 973, wnd dir 136
 5 mph.
==========================================================================================================
Session: 24
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-07-2022     14:50:50       15:50:54       29222          06:10            968.2          967.8
                                             30495          06:10            954.6          954.4
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
15:06:10        40.25         Blue            856.3              14.3      Craig Webb
------------------------------------------------------------------------------------------
Comments:
std alarms, temp 27C, hum 55%, hpa973, wnd dir 140 @ 4 mph
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
15:26:19        44.12         Green           855.2              14.6      Craig Webb
------------------------------------------------------------------------------------------
Comments:
no change.
```

```
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
15:46:26       48.07        Blue           836.7             15.1     Craig Webb
-------------------------------------------------------------------------------------------
Comments:
temp 27C, hum 56%, hpa 973, wnd dir 123 @ 10 mph.
=========================================================================================================
Session: 25
---------------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
05-07-2022    15:50:54      16:50:56      29222         06:10           967.8         967.8
                                          30495         06:10           954.4         954.5
---------------------------------------------------------------------------------------------------
Observations:
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
16:06:34       52.06        Blue           818.7             16.5     Craig Webb
-------------------------------------------------------------------------------------------
Comments:
clear,,temp 27C, hum 56 %, hpa-973, wnd dir 128 @ 18 mph.
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
16:26:39       56.06        Blue           761.8             20.1     Craig Webb
-------------------------------------------------------------------------------------------
Comments:
no change.
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
16:47:49       60.31        Blue           609.7             28.0     Craig Webb
-------------------------------------------------------------------------------------------
Comments:
light cirrus forming to the west, temp 26C, hum 56%, hpa 973,
=========================================================================================================
Session: 26
---------------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
05-07-2022    16:50:56      17:31:43      29222         06:10           967.8         967.7
                                          30495         06:10           954.5         954.6
---------------------------------------------------------------------------------------------------
Observations:
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
17:07:59       64.35        Blue           623.1             30.9     Craig Webb
-------------------------------------------------------------------------------------------
Comments:
cirrus to the west, temp 26C, hum 58%, hpa 973, wnd dir 106 @ 10 mph.
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
17:27:51       68.29        Green          457.3             37.9     Craig Webb
-------------------------------------------------------------------------------------------
Comments:
quiting due to clouds on west horizon, temp 26C, hum 57%, hpa973, wnd dir 108 @ 15 mph.
=========================================================================================================
Session: 27
---------------------------------------------------------------------------------------------------
Date          Start Time    End Time      Cavity S/N    Setup         M (beg)       M (end)
05-09-2022    07:28:35      08:29:37      29222         07:10           969.2         968.5
                                          30495         07:10           955.5         954.9
---------------------------------------------------------------------------------------------------
Observations:
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
07:48:50       63.34        Green          622.1             30.0     Craig Webb
-------------------------------------------------------------------------------------------
Comments:
some haze through the sky, temp 27C, hum 71%, hpa 974, wnd dir 142 @ 17 mph.
-------------------------------------------------------------------------------------------
Time          Zenith        ASR           Direct        % Diffuse     Operator
08:09:12       59.26        Blue           677.3             26.7     Craig Webb
-------------------------------------------------------------------------------------------
```

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Comments:
no change in sky conditions.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:15:23	58.01	Blue	691.8	25.8	Craig Webb

Comments: [None]

Session: 28

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-09-2022	08:29:37	09:29:40	29222	07:10	968.5	967.8
			30495	07:10	954.9	954.4

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:35:34	53.97	Blue	736.3	23.0	Craig Webb

Comments:
light cirrus starting to move into the area, temp 28C, hum 68%, hpa 974, wnd dir 160 @ 23 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
08:55:48	49.93	Green	763.1	21.5	Craig Webb

Comments:
no change.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:16:08	45.92	Green	785.8	20.2	Craig Webb

Comments:
temp 28C, hum 69%, hpa 974, wnd dir 167 @ 20 mph.

Session: 29

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-09-2022	09:29:40	09:56:36	29222	07:10	967.8	967.5
			30495	07:10	954.4	954.2

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:36:19	41.98	Blue	808.0	19.0	Craig Webb

Comments:
will calibrate early for solar noon, temp 29C, hum 64%, hoa 974, wnd dir 170 @ 14 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
09:53:41	38.65	Green	814.9	18.7	Craig Webb

Comments:
calibrating now .

Session: 30

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-09-2022	09:56:36	10:57:36	29222	07:10	967.5	967.1
			30495	07:10	954.2	953.9

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
10:13:48	34.89	Blue	848.8	16.8	Craig Webb

Comments:
light cirrus haze through the sky, temp 30C, hum 64%, hpa 974, wnd dir 173 @ 16 mph.

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Time	Zenith	ASR	Direct	% Diffuse	Operator
10:33:58	31.30	Blue	858.3	16.1	Craig Webb

Comments:
no change in conditions

Session: 31

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-09-2022	10:57:36	11:53:40	29222	07:10	967.1	966.6
			30495	07:10	953.9	953.5

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:00:08	26.97	Blue	879.6	15.2	Craig Webb

Comments:
temp 30C, hum 61%, hpa 974, wnd dir 168 @ 21 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:20:26	24.04	Blue	861.4	16.1	Craig Webb

Comments:
no change

Time	Zenith	ASR	Direct	% Diffuse	Operator
11:40:32	21.62	Green	864.9	15.8	Craig Webb

Comments:
temp 31C, hum 60%, hpa 974, wnd dir 155 @ 23 mph.

Session: 32

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-09-2022	11:53:40	12:46:41	29222	07:10	966.6	966.5
			30495	07:10	953.5	953.3

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:00:38	19.94	Blue	874.9	15.3	Craig Webb

Comments:
temp 31C, hum 57%, hpa 974, wnd dir 155 @ 17 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:20:49	19.14	Blue	857.8	16.2	Craig Webb

Comments:
almost solar noon, temp 32C, hum 57%, hpa 975, wnd dir 147 @ 12 mph.

Time	Zenith	ASR	Direct	% Diffuse	Operator
12:40:59	19.36	Blue	871.4	14.9	Craig Webb

Comments:
solar noon is past, temp 32C, hum 56%, hpa 975, wnd dir 160 @ 18 mph.

Session: 33

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
05-09-2022	12:46:41	13:42:44	29222	07:10	966.5	966.2
			30495	07:10	953.3	953.0

Observations:

Time	Zenith	ASR	Direct	% Diffuse	Operator
13:01:10	20.58	Brown	896.6	13.9	Craig Webb

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```
Comments:
haze in sky, temp 32C, hum 50%, hpa 975, w2nd dir 150 @ 17 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
13:21:26        22.62         Brown           874.1              15.2      Craig Webb
------------------------------------------------------------------------------------------
Comments:
temp 33C, hum 49%, hpa 975, wnd dir 145 @ 19 mph.
=========================================================================================================
Session: 34
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-09-2022     13:42:44       14:42:46       29222          07:10            966.2          965.8
                                             30495          07:10            953.0          952.8
-------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
13:45:48        25.89         Blue            884.5              14.5      Craig Webb
------------------------------------------------------------------------------------------
Comments:
windy, temp 33C, hum 51%, hpa 975, wnd dir 148 @ 24 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:06:00        29.07         Blue            849.3              16.2      Craig Webb
------------------------------------------------------------------------------------------
Comments:
31152F3 keeps alarming, temp 33C, hum 47%, hpa 975, wnd dir 128 @ 17 m-ph
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:26:20        32.57         Green           828.5              17.2      Craig Webb
------------------------------------------------------------------------------------------
Comments:
temp 33C, hum 49%, hpa 975, wnd dir 136 @ 17 mph.
=========================================================================================================
Session: 35
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-09-2022     14:42:46       15:42:48       29222          07:10            965.8          965.5
                                             30495          07:10            952.8          952.5
-------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
14:47:52        36.49         Blue            836.2              17.0      Craig Webb
------------------------------------------------------------------------------------------
Comments:
clrar, temp 33C, hum 48%, hpa 975, wnd dir 143 @ 12 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
15:10:40        40.80         Blue            798.4              19.0      Craig Webb
------------------------------------------------------------------------------------------
Comments:
no change,
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
15:33:12        45.18         Blue            761.8              20.8      Craig Webb
------------------------------------------------------------------------------------------
Comments:
temp 33C, hum 48%, hpa 975, wnd dir 191 @ m16 mph.
=========================================================================================================
Session: 36
-------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-09-2022     15:42:48       16:42:53       29222          07:10            965.5          965.5
                                             30495          07:10            952.5          952.0
-------------------------------------------------------------------------------------------------
```

BORCAL 2022-01 Operator Session Log

```
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
15:53:22        49.16         Blue            742.7              21.6      Craig Webb
------------------------------------------------------------------------------------------
Comments:
clear haze on hoszsin, temp 33C, hum 54%, hpa 975, wnd dir 130 @ 12 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
16:13:43        53.19         Blue            710.8              23.5      Craig Webb
------------------------------------------------------------------------------------------
Comments:
no change.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
16:33:54        57.25         Blue            666.5              26.4      Craig Webb
------------------------------------------------------------------------------------------
Comments:
temp 32C, hum 52%, hpa 975, wnd dir 126 @ 12 mph.
==========================================================================================================
Session: 37
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-09-2022     16:42:53       17:42:54       29222          07:10            965.5          965.7
                                             30495          07:10            952.0          952.7
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
16:54:03        61.28         Blue            617.5              29.3      Craig Webb
------------------------------------------------------------------------------------------
Comments:
some haze forming, temp 32C, hum 54%, hpa 975, wnd dir 159 @ 15 mph.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
17:14:29        65.38         Blue            541.5              34.4      Craig Webb
------------------------------------------------------------------------------------------
Comments:
no change.
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
17:42:24        70.52         Blue            430.9              42.9      Craig Webb
------------------------------------------------------------------------------------------
Comments:
quiting for the day almost 400 watt
==========================================================================================================
Session: 38
--------------------------------------------------------------------------------------------------
Date           Start Time     End Time       Cavity S/N     Setup          M (beg)        M (end)
05-09-2022     17:42:54       17:43:21       29222          07:10            965.7          965.7
                                             30495          07:10            952.7          952.7
--------------------------------------------------------------------------------------------------
Observations:
------------------------------------------------------------------------------------------
Time           Zenith         ASR            Direct         % Diffuse      Operator
17:42:55        70.52         Blue            430.9              42.9      Craig Webb
------------------------------------------------------------------------------------------
Comments: [None]
```