

# Broadband Outdoor Radiometer Calibration Shortwave Shade/Unshade

## BORCAL-SW 2018-02

Generated by



*Radiometer Calibration and Characterization*

### Calibration Facility

#### Solar Radiation Research Laboratory

Latitude: 39.742°N

Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

Calibration date

04/18/2018

Report Date

April 19, 2018



## **NOTICE**

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# Broadband Outdoor Radiometer Calibration Report

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# 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:

- 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.

# Results Summary

**Table 1. Results Summary**

Instrument	Customer	R@45 <sup>1</sup> ( $\mu\text{V}/\text{W}/\text{m}^2$ )	U <sup>2</sup> (%)	Rnet <sup>3</sup> ( $\mu\text{V}/\text{W}/\text{m}^2$ )	Page
2530	NREL-SRRL-BMS	11.017	$\pm 0.77$	N/A	A1-2
2542	NREL-RCC	9.8985	$\pm 0.81$	N/A	A1-4

<sup>1</sup> CF = 1000 / R

<sup>2</sup> See certificate for valid zenith angle range

<sup>3</sup> Instrument's Effective Net IR Response

Note: Environmental Conditions for BORCAL starts on page A1-6.

# **Appendix 1**

## **Instrument Details**

Calibration Certificates: 2 pages for each radiometer (3 including Environmental Conditions)

Environmental Conditions for BORCAL: Last Page of a Calibration Certificate. Note: This appears only once, at the end of Appendix 1.



# National Renewable Energy Laboratory

## Solar Radiation Research Laboratory

### Metrology Laboratory

### Calibration Certificate

**Test Instrument:** Pyranometer  
**Model:** SR25  
**Calibration Date:** 4/18/2018  
**Customer:** NREL-SRRL-BMS  
**Test Dates:** 4/18

**Manufacturer:** Hukseflux  
**Serial Number:** 2530  
**Due Date:** 4/18/2019  
**Environmental Conditions:** see page 3

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

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

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

Table 1. Traceability

Measurement Type	Instrument	Calibration Date	Calibration Due Date
Beam Irradiance †	Eppley Absolute Cavity Radiometer Model HF, S/N 29219	09/25/2017	09/25/2018
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-998	04/12/2017	04/12/2019
Data Acquisition	NREL Data Acquisition System Model RAP-DAQ, S/N 2005-999	04/12/2017	04/12/2019

† Through the World Radiometric Reference (WRR)

**Number of pages of certificate:** 3

**Calibration Procedure:** NREL/TP-1900-68999; <http://www.nrel.gov/docs/fy17osti/68999.pdf>

**Setup:** Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.

**Calibrated by:** RCC

\_\_\_\_\_  
Ibrahim Reda, Technical Manager

\_\_\_\_\_  
Date

For questions or comments, please contact the technical manager at:  
[ibrahim.reda@nrel.gov](mailto:ibrahim.reda@nrel.gov); 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

# Calibration Results

## 2530 Hukseflux SR25

The responsivity ( $R$ ,  $\mu\text{V}/\text{W}/\text{m}^2$ ) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V_u - V_s) / N * \cos(Z)$$

[1]

where,

$V_u$  = radiometer unshaded output voltage (microvolts),

$V_s$  = radiometer shaded output voltage (microvolts),

$N$  = reference direct irradiance ( $\text{W}/\text{m}^2$ ),

$Z$  = zenith angle (degrees).

Figure 1. Average Responsivity vs Zenith Angle

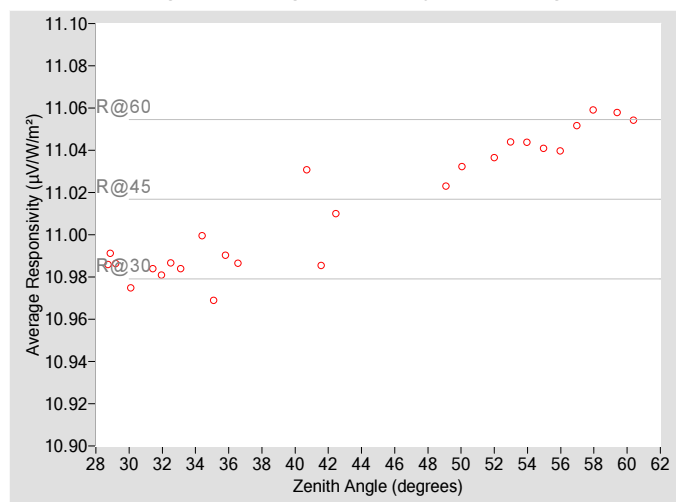


Figure 2. Shaded Voltage Ratio (Test/Control) vs Zenith Angle

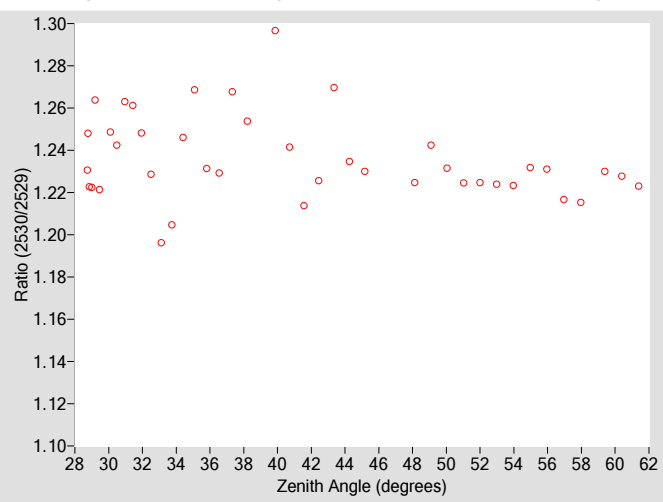
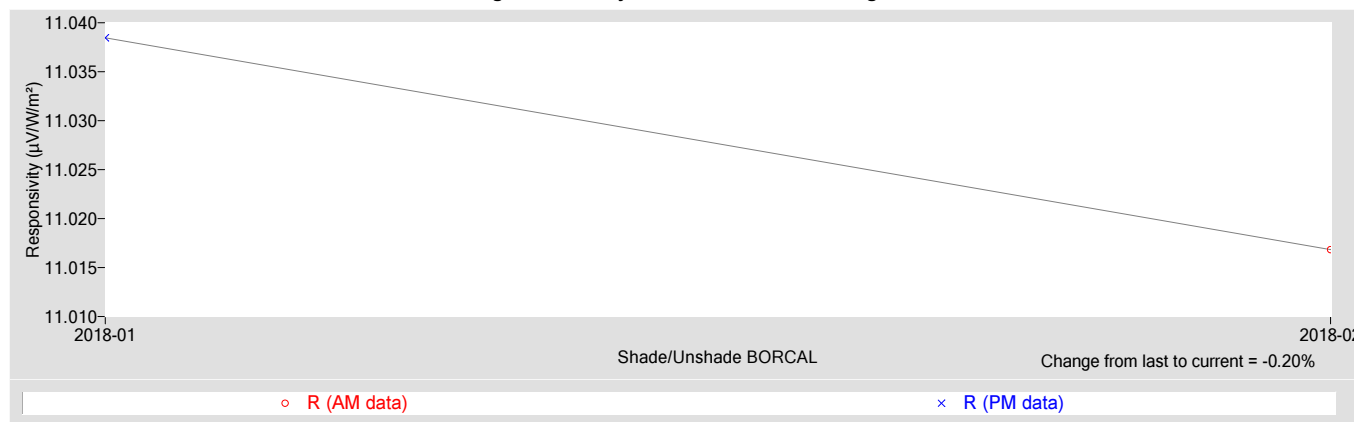


Table 2. Calibration Result and Uncertainty

R @ 45° ( $\mu\text{V}/\text{W}/\text{m}^2$ )	11.017
Type-B Standard Uncertainty, $u(B)$ (%)	$\pm 0.31$
Type-A Standard Uncertainty, $u(A)$ (%)	$\pm 0.090$
Standard Uncertainty of range, $u(R)$ (%)	$\pm 0.20$
Std. Uncertainty of sensor non-linearity, $u(NL)$ (%)	$\pm 0.12$
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, $k$	1.96
Expanded Uncertainty, $U95$ (%)	$\pm 0.77$
Thermal Offset ( $\text{W}/\text{m}^2$ )	0.5
Valid zenith angle range	28.7° to 60.9°

Figure 3. History of instrument at Zenith Angle = 45°



### References:

- [1] Reda, I.; Andreas A. (2017). Calibration Procedure of a Modified Hukseflux SR25 as an Example to Establish the Diffuse Reference for the Broadband Outdoor Radiometer Calibration; NREL/TP-1900-68999; <http://www.nrel.gov/docs/fy17osti/68999.pdf>.
- [2] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5





# National Renewable Energy Laboratory

## Solar Radiation Research Laboratory

### Metrology Laboratory

### Calibration Certificate

**Test Instrument:** Pyranometer  
**Model:** SR25  
**Calibration Date:** 4/18/2018  
**Customer:** NREL-RCC  
**Test Dates:** 4/18

**Manufacturer:** Hukseflux  
**Serial Number:** 2542  
**Due Date:** 4/18/2019  
**Environmental Conditions:** see page 3

This certifies that the above product was calibrated in compliance with procedure listed below. Measurement uncertainties at the time of calibration are consistent with the Guide to the 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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† Through the World Radiometric Reference (WRR)

**Number of pages of certificate:** 3

**Calibration Procedure:** NREL/TP-1900-68999; <http://www.nrel.gov/docs/fy17osti/68999.pdf>

**Setup:** Radiometers are calibrated outdoors, using the sun as the source. Pyranometers and pyrgeometers are installed for horizontal measurements, with their signal connectors oriented north, if their design permits.

**Calibrated by:** RCC

\_\_\_\_\_  
Ibrahim Reda, Technical Manager

\_\_\_\_\_  
Date

For questions or comments, please contact the technical manager at:  
[ibrahim.reda@nrel.gov](mailto:ibrahim.reda@nrel.gov); 303-384-6385; 15013 Denver West Parkway, Golden, CO 80401, USA

# Calibration Results

## 2542 Hukseflux SR25

The responsivity ( $R$ ,  $\mu\text{V}/\text{W}/\text{m}^2$ ) of the test instrument during calibration is calculated using this Measurement Equation:

$$R = (V_u - V_s) / N * \cos(Z)$$

[1]

where,

$V_u$  = radiometer unshaded output voltage (microvolts),

$V_s$  = radiometer shaded output voltage (microvolts),

$N$  = reference direct irradiance ( $\text{W}/\text{m}^2$ ),

$Z$  = zenith angle (degrees).

Figure 1. Average Responsivity vs Zenith Angle

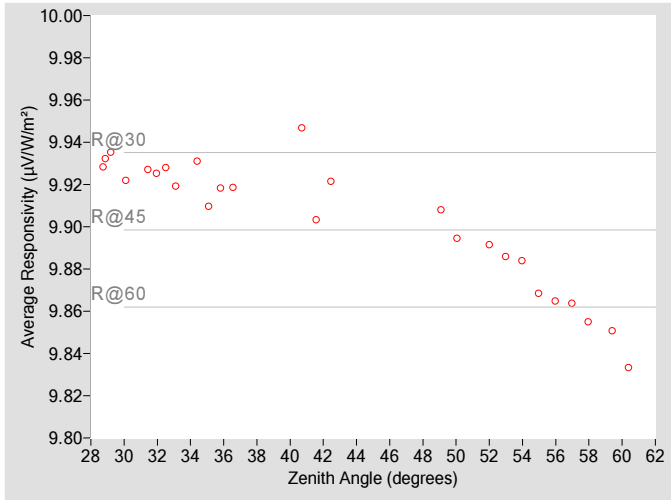


Figure 2. Shaded Voltage Ratio (Test/Control) vs Zenith Angle

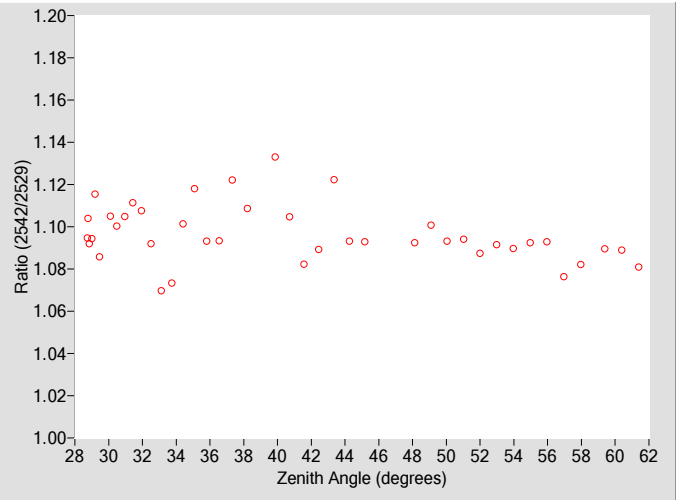
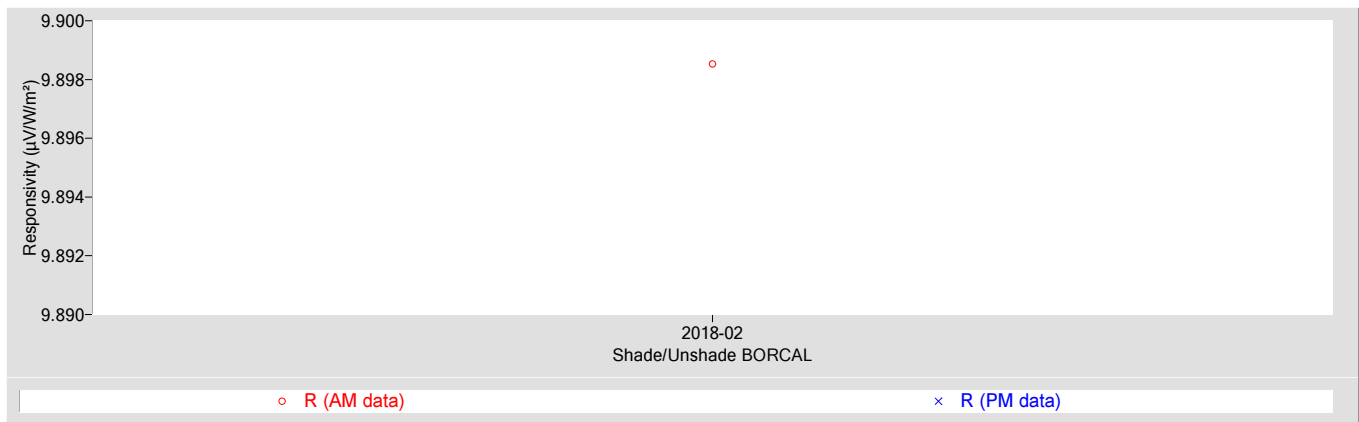


Table 2. Calibration Result and Uncertainty

R @ 45° ( $\mu\text{V}/\text{W}/\text{m}^2$ )	9.8985
Type-B Standard Uncertainty, $u(B)$ (%)	$\pm 0.31$
Type-A Standard Uncertainty, $u(A)$ (%)	$\pm 0.13$
Standard Uncertainty of range, $u(R)$ (%)	$\pm 0.21$
Std. Uncertainty of sensor non-linearity, $u(NL)$ (%)	$\pm 0.12$
Effective degrees of freedom, $DF(c)$	+Inf
Coverage factor, $k$	1.96
Expanded Uncertainty, $U95$ (%)	$\pm 0.81$
Thermal Offset ( $\text{W}/\text{m}^2$ )	0.5
Valid zenith angle range	28.7° to 60.9°

Figure 3. History of instrument at Zenith Angle = 45°



### References:

- [1] Reda, I.; Andreas A. (2017). Calibration Procedure of a Modified Hukseflux SR25 as an Example to Establish the Diffuse Reference for the Broadband Outdoor Radiometer Calibration; NREL/TP-1900-68999; <http://www.nrel.gov/docs/fy17osti/68999.pdf>.
- [2] Reda, I.; Stoffel, T.; Myers, D. (2003). "Method to Calibrate a Solar Pyranometer for Measuring Reference Diffuse Irradiance." Solar Energy. Vol. 74, 2003; pp. 103-112; NREL Report No. JA-560-35025. doi:10.1016/S0038-092X(03)00124-5

# Environmental and Sky Conditions for BORCAL-SW 2018-02

**Calibration Facility:** Solar Radiation Research Laboratory

Latitude: 39.742°N

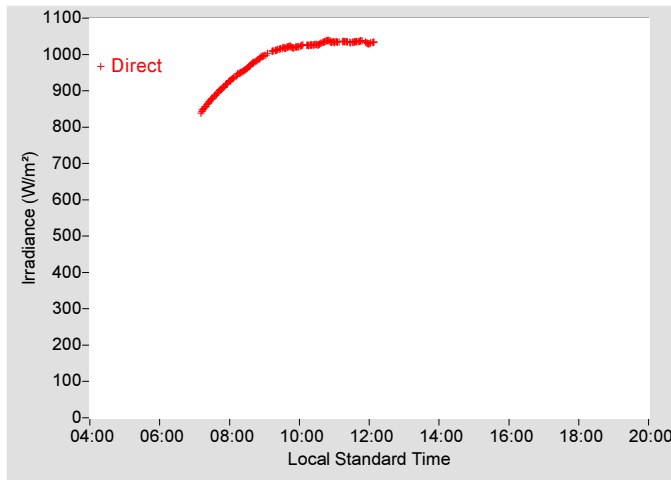
Longitude: 105.180°W

Elevation: 1828.8 meters AMSL

Time Zone: -7.0

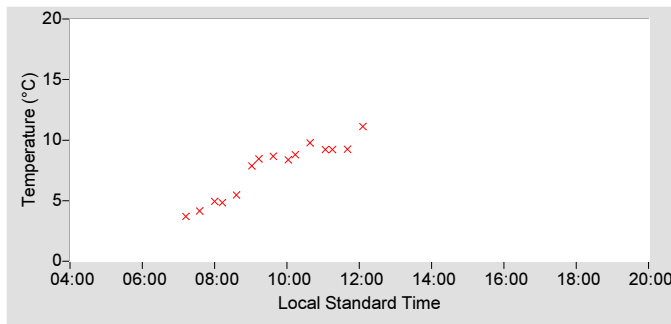
## Reference Irradiance:

**Figure 4. Reference Irradiance**

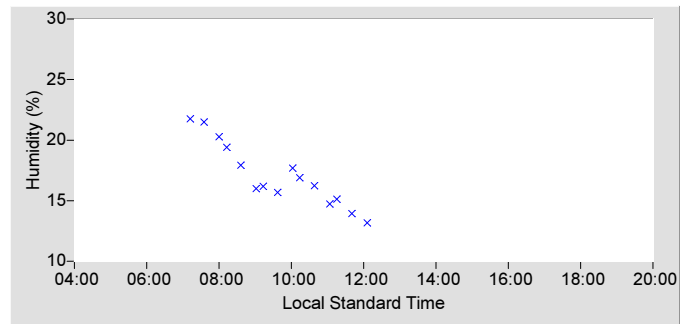


## Meteorological Observations:

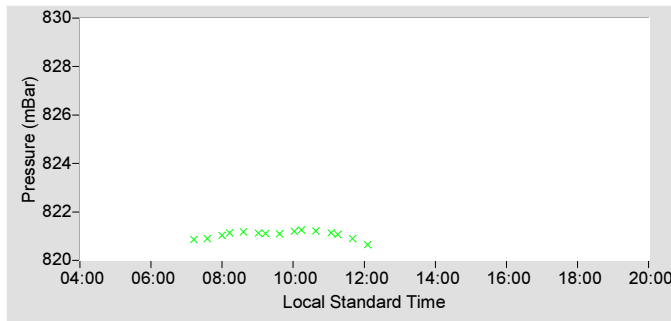
**Figure 5. Temperature**



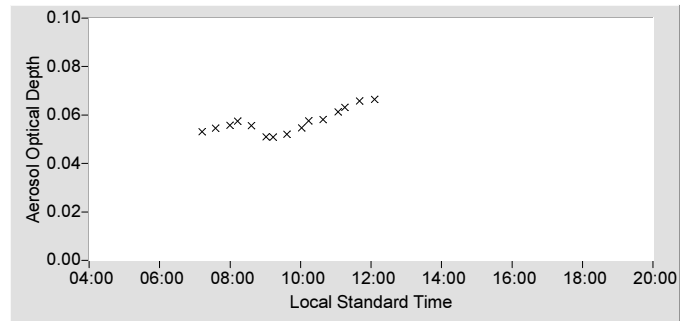
**Figure 6. Humidity**



**Figure 7. Pressure**



**Figure 8. Estimated Broadband Aerosol Optical Depth**



**Table 3. Meteorological Observations**

Observations	Mean	Min	Max
Temperature (°C)	7.59	3.69	11.13
Humidity (%)	17.10	13.17	21.77
Pressure (mBar)	821.1	820.6	821.3
Est. Aerosol Optical Depth (BB)	0.057	0.051	0.066

For other information about the calibration facility visit: [http://www.nrel.gov/solar\\_radiation/](http://www.nrel.gov/solar_radiation/)

## **Appendix 2**

# **BORCAL Notes**

Instrument, Configuration, and Session Notes for the BORCAL

# BORCAL Notes

---

Facility: Solar Radiation Research Laboratory

Comments:

Avg. Station Pressure & Temperature is for Denver, CO, which is used for the Solar Position Algorithm (SPA).

---

Operator: RCC

Comments:

Un-attended with no operator

# **Appendix 3**

## **Session Configuration Audit Report**

Latest Session Configuration Audit Report for the BORCAL

DATALOGGER													
Logger/Relay				DMM		Communications							
Unit 0	2005-998 NREL RAP-DAQ	SG42000600 Agilent 34420A			Unit	Type	Addr.	Board	Parity	Stop	Data		
Unit 1	2005-999 NREL RAP-DAQ	SG42000530 Agilent 34420A			DMM	0	GPIOB	21	0	0	0	0	
Unit 0	None	None			Relay	0	GPIOB	24	1	0	0	0	
Unit 0	None	None			DMM	1	GPIOB	22	0	0	0	0	
		Unit 0	Unit 1	Unit 0	Unit 0	Relay	1	GPIOB	25	1	0	0	0
	Cal Date	04/12/2017	04/12/2017				-1	0	0	0	0	0	0
	Cal Due Date	04/12/2019	04/12/2019				-1	0	0	0	0	0	0
System Offsets:		Volts DC (μV)	2.44	2.44	0.00	0.00		-1	0	0	0	0	0
	2-Wire Res. (mOhms)	3640.00	3640.00	0.00	0.00			-1	0	0	0	0	0
	4-Wire Res. (mOhms)	0.06	0.06	0.00	0.00								

A3-2

## BORCAL 2018-02 Session Configuration Audit Report

## DIFFUSE REFERENCE INSTRUMENTS

Responsivity	Cal Date	Cal Due Date	Shading Disk			Uncertainty			Max Out (mV)	Channel	J Box	Cable	Location	Tilt	Active
			Diameter (cm)	Arm Length (cm)	Subtended Angle	Percent	Offset (W/m^2)								
Diffuse 1: 2529 Hukseflux SR25															
9.253	05/04/2017	05/04/2018	6.2	70.3	5.0	1.50	0.0	25	116	15-08	04-07	BMS Tracker	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
Diffuse 1: Case 10K Temperature										n/a	n/a	n/a			
Diffuse 1: Dome 10K Temperature										n/a	n/a	n/a			

## PYRGEOMETER INSTRUMENTS

Cal Date	Cal Due Date	K0	Calibration Coefficients				K <sub>r</sub>	Uncert. (W/m^2)	Max Out (mV)	Channel	J Box	Cable	Location	Active
			K1	K2	K3									
Pyrgometer 1: None														
		0.00000	0.00000	0.00000	0.00000	0.00000E+0	0.00	0						<input type="checkbox"/>
Pyrgometer 1: Case Thermistor										n/a	n/a	n/a		
Pyrgometer 1: Dome Thermistor										n/a	n/a	n/a		



**BORCAL 2018-02 Session Configuration Audit Report****INSTRUMENT GROUPS**

Group	Calib. Type	Out (mV)	Instrument Type	Instrument Grouping Type	Correcting Pyrgometer	Count
1	Global	25	Hukseflux SR25	Hukseflux SR25	none	2
Total						2

**BORCAL 2018-02 Session Configuration Audit Report****INSTRUMENTS**

Serial Number	Model	Customer	Grp	Idx	Ch	Box	Cbl	ISO	AIM	Vent	Use	Location	Due
2530	SR25	NREL-SRRL-BMS	1	1	14	07-02		Yes	Yes	No	TOT	Tkr-07-	12
2542	SR25	NREL-RCC	1	2	15	07-03		Yes	Yes	No	TOT	Tkr-07-	12

# **Appendix 4**

## **Operator Session Logs**

Operator session logs for the BORCAL

## BORCAL 2018-02 Operator Session Log

=====  
Session: 1

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	07:15:26	08:16:00	29219	0:00	957.0	960.5

Observations: [None]  
=====

Session: 2

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	08:16:00	09:16:17	29219	0:00	960.5	961.4

Observations: [None]  
=====

Session: 3

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	09:16:17	10:17:21	29219	0:00	961.4	961.6

Observations: [None]  
=====

Session: 4

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	10:17:21	11:18:49	29219	0:00	961.6	960.9

Observations: [None]  
=====

Session: 5

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	11:18:49	12:20:40	29219	0:00	960.9	960.4

Observations: [None]  
=====

Session: 6

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	12:20:40	13:22:23	29219	0:00	960.4	960.3

Observations: [None]  
=====

Session: 7

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	13:22:23	14:23:26	29219	0:00	960.3	959.8

Observations: [None]  
=====

Session: 8

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	14:23:26	15:23:59	29219	0:00	959.8	959.8

Observations: [None]  
=====

Session: 9

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	15:23:59	16:25:01	29219	0:00	959.8	959.9

Observations: [None]  
=====

Session: 10

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-14-2018	16:25:01	17:18:22	29219	0:00	959.9	959.5

## BORCAL 2018-02 Operator Session Log

Observations: [None]

Session: 11

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	06:48:25	07:48:30	29219	0:00	965.5	964.3

Observations: [None]

Session: 12

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	07:48:30	08:49:43	29219	0:00	964.3	963.0

Observations: [None]

Session: 13

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	08:49:43	09:50:25	29219	0:00	963.0	961.9

Observations: [None]

Session: 14

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	09:50:25	10:51:35	29219	0:00	961.9	960.7

Observations: [None]

Session: 15

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	10:51:35	11:53:23	29219	0:00	960.7	960.1

Observations: [None]

Session: 16

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	11:53:23	12:55:18	29219	0:00	960.1	959.2

Observations: [None]

Session: 17

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	12:55:18	13:56:44	29219	0:00	959.2	959.1

Observations: [None]

Session: 18

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	13:56:44	14:57:44	29219	0:00	959.1	959.0

Observations: [None]

Session: 19

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	14:57:44	15:59:16	29219	0:00	959.0	959.1

Observations: [None]

Session: 20

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	15:59:16	16:59:40	29219	0:00	959.1	959.0

## BORCAL 2018-02 Operator Session Log

Observations: [None]

Session: 21

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-15-2018	16:59:40	17:19:28	29219	0:00	959.0	959.5

Observations: [None]

Session: 22

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-16-2018	06:47:01	07:10:47	29219	0:00	965.1	965.1

Observations: [None]

Session: 23

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-17-2018	07:11:41	08:12:16	29219	0:00	960.2	959.1

Observations: [None]

Session: 24

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-17-2018	08:12:16	09:12:33	29219	0:00	959.1	958.5

Observations: [None]

Session: 25

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-17-2018	09:12:33	10:13:38	29219	0:00	958.5	958.0

Observations: [None]

Session: 26

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-17-2018	10:13:38	11:15:09	29219	0:00	958.0	957.5

Observations: [None]

Session: 27

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-17-2018	11:15:09	12:17:09	29219	0:00	957.5	957.9

Observations: [None]

Session: 28

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-17-2018	12:17:09	12:34:37	29219	0:00	957.9	957.1

Observations: [None]

Session: 29

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	07:10:21	08:10:55	29219	0:00	958.7	960.7

Observations: [None]

Session: 30

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	08:10:55	09:11:11	29219	0:00	960.7	961.4

## BORCAL 2018-02 Operator Session Log

Observations: [None]

Session: 31

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	09:11:11	10:12:19	29219	0:00	961.4	961.4

Observations: [None]

Session: 32

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	10:12:19	11:13:51	29219	0:00	961.4	960.9

Observations: [None]

Session: 33

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	11:13:51	12:15:52	29219	0:00	960.9	960.4

Observations: [None]

Session: 34

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	12:15:52	13:17:48	29219	0:00	960.4	960.3

Observations: [None]

Session: 35

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	13:17:48	14:19:00	29219	0:00	960.3	960.0

Observations: [None]

Session: 36

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	14:19:00	15:19:43	29219	0:00	960.0	959.7

Observations: [None]

Session: 37

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	15:19:43	16:20:55	29219	0:00	959.7	959.6

Observations: [None]

Session: 38

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-18-2018	16:20:55	16:55:01	29219	0:00	959.6	959.7

Observations: [None]

Session: 39

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-19-2018	07:09:03	07:35:12	29219	0:00	965.6	965.0

Observations: [None]

Session: 40

Date	Start Time	End Time	Cavity S/N	Setup	M (beg)	M (end)
04-19-2018	07:35:40	07:35:50	29219	0:00	965.0	965.0

## **BORCAL 2018-02 Operator Session Log**

Observations: [None]