Power Performance Test Report

for the

AOC 15/50 Wind Turbine, Test B

in

Golden, Colorado

Conducted for

United States Department of Energy

Conducted by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

R. Jacobson, M. Meadors, E. Jacobson, H. Link

Revision 3

8August 2003

Approval By: Harold F. Link — 1/Oct/2003
Harold F. Link, NREL Certification Test Engineer — Date

Approval By: Harold F. Link — 1/Oct/2003
Harold F. Link, NREL Certification Test Manager — Date

Approval By: C. P. Butterfield — 6/10/03
C. P. Butterfield, NREL Certification Quality Manager — Date

1 Table of Contents

1 TABLE OF CONTENTS 2
2 TABLE OF TABLES 2
3 TABLE OF FIGURES 3
4 DISCLAIMER 3
5 REVISIONS 4
6 TEST SUMMARY 4
7 DESCRIPTION OF WIND TURBINE 6
8 DESCRIPTION OF TEST SITE 8
9 DESCRIPTION OF TEST EQUIPMENT 12
10 DESCRIPTION OF MEASUREMENT AND ANALYSIS PROCEDURES 15
11 POWER CURVE AND AEP AT SEA-LEVEL AIR DENSITY 17
12 POWER CURVE AND AEP AT SITE AVERAGE AIR DENSITY 19
13 ONLINE POWER CURVE AND AEP AT SEA-LEVEL AIR DENSITY 21
14 SUPPLEMENTARY RESULTS 23
15 UNCERTAINTY CALCULATIONS 25
16 DEVIATIONS FROM IEC 61400-12 26
APPENDIX A: PICTURES OF TEST SITE A-1
APPENDIX B: CALIBRATION CERTIFICATES B-1

2 Table of Tables

Table 1. Test Turbine Configuration and Operational Data 6
Table 2. Operating Turbines and Obstructions at Test Site 10
Table 3. Assessment of Test Site Topology 10
Table 4. Results of Site Calibration 11
Table 5. Equipment List 13
Table 6. Test Log 16
Table 7. Performance at Sea-Level Air Density, 1.225 kg/m^3 17
Table 8. Annual Energy Production at Sea-Level Air Density, 1.225 kg/m^3 18
Table 9. Performance at Site Average Air Density, 1.012 kg/m^3 19
Table 10. Annual Energy Production at Site Average Air Density, 1.012 kg/m^3 20
Table 11. Online Performance at Sea-Level Air Density, 1.225 kg/m^3 21
Table 12. Online Annual Energy Production at Sea-Level Air Density, 1.225 kg/m^3 22
Table 13. Type B Uncertainties in Power Performance Measurements 26

3 Table of Figures

Figure 1. Power curve summary. 5
Figure 2. The AOC 15/50 test turbine. 6
Figure 3. Map of test site. 9
Figure 4. Results of site calibration test. 12
Figure 5. Layout of instrumentation. 14
Figure 6. Detail instrumentation at top of meteorological tower. 14
Figure 7. Detail of instrumentation at base of meteorological tower 15
Figure 8. Power curve at sea-level air density, 1.225 kg/m^3 18
Figure 9. Power curve at site average air density, 1.012 kg/m^3. 20
Figure 10. Online power curve at sea-level air density, 1.225 kg/m^3. 22
Figure 11. Scatter plot of power data. 23
Figure 12. Turbulence intensity and mean wind speed versus wind direction. 24
Figure 13. Relationship of secondary anemometer to primary anemometer. 24
Figure 14. Scatter plot of online power data. 25

4 Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States government. The test results documented in this report define the characteristics of the test article as configured and under the conditions tested.

The United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Nor do they assume legal liability or responsibility for the performance of the test article or any similarly named article when tested under other conditions or using different test procedures.

Neither Midwest Research Institute nor the U. S. Government shall be liable for special, consequential or incidental damages. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

The National Renewable Energy Laboratory (NREL) is a National Laboratory of the U. S. Department of Energy, and as an adjunct of the U. S. Government, it cannot certify wind turbines. The information in this report is limited to NREL's knowledge and understanding as of this date.

NREL is accredited by the American Association for Laboratory Accreditation (A2LA). This test was originally conducted in accordance with NREL's terms of accreditation. However, subsequent to this test and prior to this revision of the test report, many A2LA requirements have changed—specifically,

instrument calibration requirements. Therefore, NREL does NOT claim that this test report is in compliance with our A2LA accreditation, nor is the A2LA logo shown.

This report shall not be reproduced, except in full, without the written approval of NREL.

5 Revisions

Revision 1, April 2000

Test data reanalyzed and report rewritten to include site calibration factors from preliminary site calibration test.

Revision 2, May 2003

Test data reanalyzed to include site calibration factors from final site calibration test. Online data analysis also added to report.

Revision 3, August 2003

Corrected Test Summary (Table 1) to correspond with sea level power performance results shown in Figure 7 and Table 8.

Added text to explain the difference between primary results and online results.

6 Test Summary

This report documents the a power performance test of an AOC 15/50 wind turbine installed at NREL's National Wind Technology Center (NWTC), south of Boulder, Colorado. The test was conducted in accordance with the international standard IEC 61400-12, Edition 1, 1998 and NREL's internal quality assurance program as implemented at the time of the test.

Figure 1 summarizes the test results normalized to sea-level air density. Additional results are given in Sections 11 through 14.

Power Performance Test Summary

AOC 15/50, Test B

Power curve results normalized to sea level air density

Report Created: August 14, 2003

Turbine Specifications:

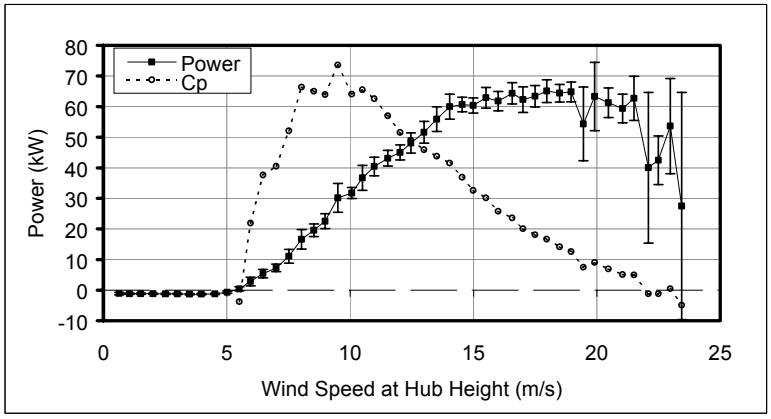
Rated Power:	50	kW
Cut-in Wind Speed:	4.9	m/s
Cut-out Wind Speed:	22.3	m/s
Rated Wind Speed:	12	m/s
Rotor Diameter:	15	m/s
Control Type:	Constant Speed Fixed Pitch	
Pitch Setting:	1.54	deg toward feather

Site Conditions:

Average Air Density:	1.012	kg/m^3
Measurement Sectors:	255-45	deg wrt true north

Test Statistics:

Start Date:	30 December, 1998	
End Date:	28 January, 1999	
Operating Data Collected:	226.7	hours
Highest Bin Filled:	23.4	m/s
Test Completed?	Yes	



Wind Speed (m/s)	Power (kW)	No. of Data Points	Cp
0.64	-1.11	9	
1.06	-1.15	27	
1.51	-1.14	63	
2.01	-1.18	104	
2.51	-1.21	98	
3.00	-1.21	73	
3.49	-1.29	77	
3.97	-1.29	66	
4.52	-1.23	48	
5.01	-0.66	44	
5.50	0.44	59	0.02
5.96	2.84	46	0.12
6.47	5.43	54	0.19
7.00	7.30	56	0.20
7.51	11.08	44	0.24
8.03	16.62	46	0.30
8.53	19.58	49	0.29
8.98	22.55	46	0.29
9.50	30.18	42	0.33
10.06	31.75	51	0.29
10.49	36.70	53	0.29
10.98	40.41	58	0.28
11.52	43.13	52	0.26
12.02	45.02	53	0.24
12.46	48.10	49	0.23
13.00	51.63	37	0.22
13.51	55.89	35	0.21
14.04	59.99	25	0.20
14.54	60.67	37	0.18
14.99	60.37	31	0.17
15.50	62.89	28	0.16
16.00	61.79	32	0.14
16.57	64.34	26	0.13
17.00	62.28	24	0.12
17.50	63.36	21	0.11
17.97	65.07	17	0.10
18.49	64.38	24	0.09
18.96	64.80	18	0.09
19.46	54.32	18	0.07
19.91	63.32	13	0.07
20.47	61.27	10	0.07
21.04	59.34	17	0.06
21.51	62.73	5	0.06
22.09	40.02	8	0.03
22.49	42.47	10	0.03
22.97	53.63	5	0.04
23.44	27.51	3	0.02

Figure 1. Power curve summary.

7 Description of Wind Turbine

The AOC 15/50 test turbine is shown in Figure 2, and its specifications are listed in Table 1. NREL designates the turbine configuration for this test as "AOC B."

Figure 2. The AOC 15/50 test turbine.

Table 1. Test Turbine Configuration and Operational Data

General Configuration:	
Turbine Make	Atlantic Orient Corporation
Turbine Model	AOC 15/50, 60 hertz
Serial Number	None (this was the third AOC 15/50 turbine installed)
Rotation Axis	Horizontal
Orientation	Downwind
Number of Blades	3
Rotor Hub Type	Rigid

Rotor Diameter (m)	15
Rotor Diameter Verification	None
Hub Height (m)	25
Performance:	
Rated Electrical Power (kW)	50
Rated Wind Speed (m/s)	12.0
Cut-In Wind Speed (m/s)	4.9
Cut-In Wind Speed Dead Band (m/s)	3.6
Cut-Out Wind Speed (m/s)	22.3
Extreme Wind Speed (m/s)	59.5 (peak survival)
Rotor:	
Blade Make:	Merrifield Roberts
Blade Type	Wood-Epoxy
Pitch	Fixed
Swept Area (m^2)	177
Online Rotational Speed (rpm)	65
Coning Angle (deg)	6
Tilt Angle (deg)	0
Blade Pitch Angle (deg)	1.54^o toward feather
Power Regulation	stall regulation
Overspeed Control	centrifugal override of tip brake magnets
Drive Train:	
Gearbox Make	Fairfield/AOC
Gearbox Type	2-stage planetary
Gear Ratio	1:28.25
Generator Make	Magnatek
Generator Type	3-phase induction
Generator Speed, Nominal (rpm)	1800
Generator Voltage (VAC)	480
Generator Frequency (hertz)	60
Braking System:	
Mechanical (Parking) Brake: Make, Type, Location	Sterns Series 81,000, on nacelle aft of generator
Aerodynamic Brake: Make, Type, Location	AOC, electromagnetic tip brakes, at the tips of all blades
Electrical Brake: Make, Type, Location	AOC, dynamic brake, connected to the tower droop cable at the base of turbine
Yaw System:	
Wind Direction Sensor	None
Yaw Control Method	Free-yaw
Tower:	
Type	Three-legged steel lattice
Height (m)	24.4

Control/Electrical System:	
Controller: Make, Model	Koyo, DirectLogic 205
Controller Type	Programmable Logic Controller
Software Version	Round Robin 86
Electrical System:	
Power Converter: Make, Model	none
Electrical Output: Voltage, Frequency, Number of Phases	480 VAC, 60 Hz, 3-phases

8 Description of Test Site

The test site for the AOC 15/50 turbine is located at Site 1.1 at the National Wind Technology Center, just south of Boulder, Colorado. The site is at an elevation of 1830 m, with prevailing winds bearing 292° relative to true North. Figure 3 shows the topography and arrangement of the test site during the test period.

Prevailing winds are from directions between 260 and 330 degrees true. The meteorological tower for the AOC 15/50 turbine is 37 meters from the turbine position at a bearing of 292° true. This position is in the center of the prevailing wind direction and 2.5 rotor diameters from the turbine.

The test turbine's wake eliminates use of winds from 66° to 158°. In addition, the operation of one nearby turbine at Site 1.3 affects winds at the test turbine and anemometer (Table 2). Other turbines at the NWTC are sufficiently far away that they have a negligible effect at the test turbine.

The site has several obstructions surrounding the test turbine position, as noted in Table 2, but none of these has a significant effect on the anemometer or test turbine.

Based on the prevailing winds, position of the meteorological tower, and position of operating turbines and other obstructions, the preliminary measurement sector is defined as westerly and northerly winds from 223° to 66°. The preliminary measurement sector is used as the basis to assess the topology.

The site has relatively flat terrain close to the turbine and passes the slope and variation requirements out to 4L (four times the distance from the meteorological tower to the turbine) as shown in Table 3. However, a small hillock 200 m southwest of the turbine and a drainage beginning about 300 m northwest of the turbine cause the site to fail the requirements for variation in the preliminary measurement sector between 4L and 8L. Elimination of winds affected by these topological features would not be practical at this test site.

The complexity of the topography between 4L and 8L mandates that a site calibration be conducted at this test site. The calibration was completed in June 1997 and is documented in the revised test report "Site Calibration Test Report for the AOC 15/50 Wind Turbine," dated August 1, 2001. Table 4 and Figure 4 provide the results of the site calibration test.

Figure 4 shows the effect of the small hillock between 230° and 250° and a mild influence from the drainage between 300° and 320°. The hillock effect was strong enough to warrant a reduction in the preliminary measurement sector. In addition, some of the sectors did not have as much data as desired. Therefore, the final measurement sector was reduced to 255° to 45°.

The turbine provides power to the Public Service Company of Colorado utility power grid at a voltage of 480 V ± 5% and a frequency of 60 Hz ± 0.1%.

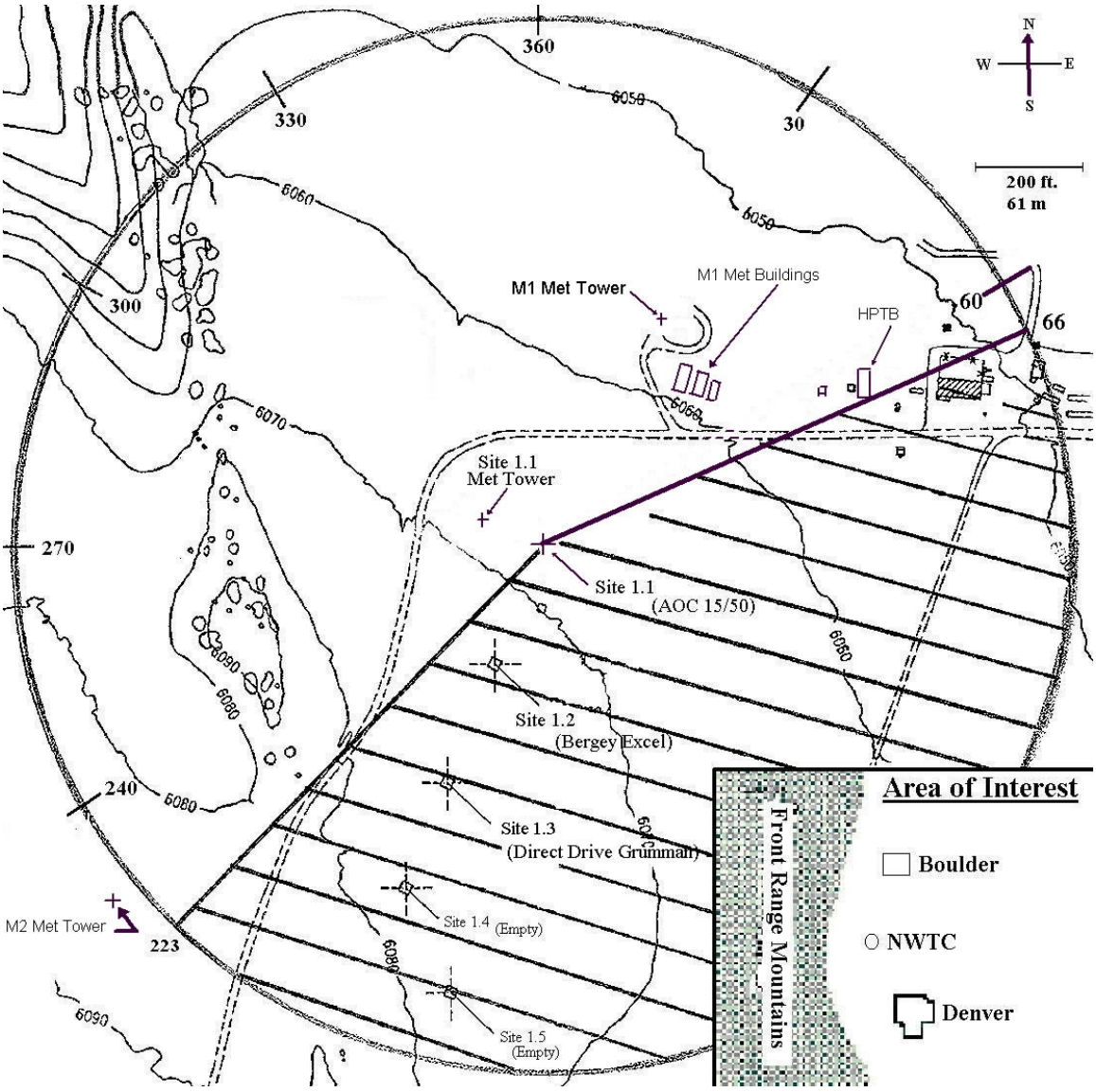


Figure 3. Map of test site.

Table 2. Operating Turbines and Obstructions at Test Site

Description	Bearing from Test Turbine (deg. T)	Distance from Test Turbine (m)	Height (m)	Rotor Dia. or Tower Width (m)	Start of Excluded Region (deg. T)	End of Excluded Region (deg. T)
Site 1.2	202	72	30.5	2.5		
M1 (Tower)	340	108	50.0	1.8		
M1 (Buildings)	46	115	3.0	5.3		
Site 1.3	202	147	24.5	10.0	181	223
HPTB	66	196	5.0	8.9		
M2 (Building)	232	300	3.0	2.4		
M2 (Tower)	232	312	50.0	1.8		
	Bearing from Met Tower (deg. T)	Distance from Met Tower (m)				
Test Turbine	112	37	25.0	15.0	66	158
Site 1.2	174	81	30.5	2.5		
M1 (Tower)	359	87	50.0	1.8		
M1 (Buildings)	58	163	3.0	5.3		
Site 1.3	188	152	24.5	10.0	167	209
HPTB	72	279	5.0	8.9		
M2 (Building)	225	283	3.0	2.4		
M2 (Tower)	226	295	50.0	1.8		

Table 3. Assessment of Test Site Topology

Crit-erion	*Description*	*Distance*	*Sector*	*Test Site Condition*	*Pass/Fail*
1	Maximum slope of best fit plane <3%	<2L[(1)]	360°	1.9%	Pass
2	Max variation from best fit plane < 0.08 D[(3)]	<2L	360°	0.009D	Pass
3	Maximum slope of best fit plane <5%	2-4L	Inside prel. meas. Sector	2.9%	Pass
4	Max variation from best fit plane < 0.15 D	2-4L	Inside prel. meas. Sector	0.063D	Pass
5	Maximum slope of steepest slope <10%	2-4L	Outside prel. meas. Sector	2.0%	Pass
6	Maximum slope of best fit plane <10%	4-8L	Inside prel. meas. Sector	3.1%	Pass
7	Max variation from best fit plane < 0.15 D	4-8L	Inside prel. meas. Sector	0.482D	Fail

Crit-erion	*Description*	*Distance*	*Sector*	*Test Site Condition*	*Pass/Fail*
8	No operating turbines	2Dn[4]	360°	None	Pass
9	Met tower out of test turbine wake	All	59.5° – 164.5°	283°	Pass
10	No obstacles	<8L	Inside prel. meas. Sector	None	Pass

(1) L is the distance for the test turbine to the meteorological tower
(2) Unable to fit a plane to the topography that also passes through turbine base
(3) D is the rotor diameter of the test turbine
(4) Dn is the rotor diameter of a neighboring turbine

Table 4. Results of Site Calibration

Wind Direction Sector (degrees from true north)	Correction Factor	Hours of Data per Bin	Combined Uncertainty
255° - 265°	0.994	27.5	1.10%
265° - 275°	0.996	42.2	1.01%
275° - 285°	0.994	66.0	1.01%
285° - 295°	0.993	116.7	1.04%
295° - 305°	0.987	177.2	1.05%
305° - 315°	0.981	110.2	1.05%
315° - 325°	0.984	51.3	1.10%
325° - 335°	0.993	29.0	1.11%
335° - 345°	1.001	21.3	1.12%
345° - 355°	0.997	21.0	1.10%
355° - 5°	1.003	31.3	1.31%
5° - 15°	1.001	27.0	1.30%
15° - 25°	1.006	23.7	1.06%
25° - 35°	1.000	27.2	1.06%
35° - 45°	0.998	25.7	1.06%

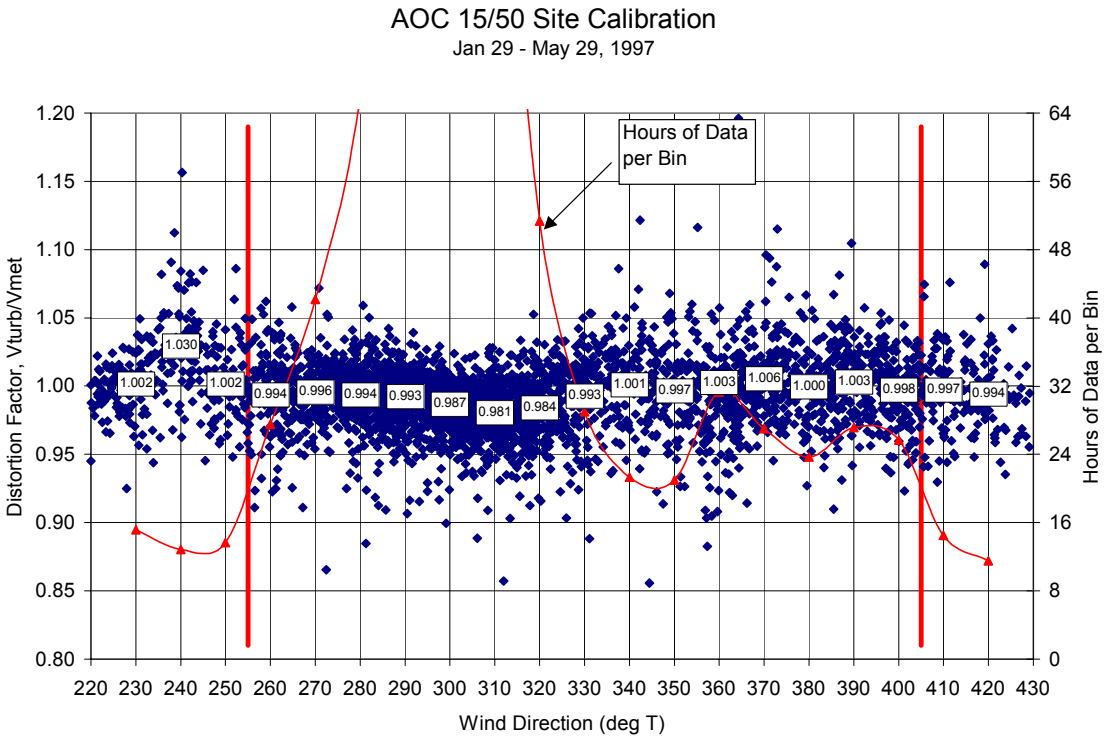


Figure 4. Results of site calibration test.

9 Description of Test Equipment

Table 5 is an equipment list that provides the requirements and specifications for each of the instruments used for performance testing. Figure 5 shows the overall locations of the instrumentation. Figure 6 and Figure 7 show details of the instrument locations at the top and bottom of the met tower, respectively. The second nacelle anemometer was shown to be within tolerance by comparison with the primary anemometer during the first part of the test (see Figure 13).

For this test, one control signal is monitored. It indicates turbine availability and permits application of appropriate data rejection criteria.

Table 5. Equipment List

Power Transducer and CTs	
Make/Model:	OSI, GWV5-008EY05
Serial Number (Transducer/CTs):	8012365 / 8012365
Range with CTs:	-120 to 120 kW
Calibration Due Date:	November 6, 1999
Primary Anemometer (North)	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	T2346
Calibration Due Date:	October 29, 1999
Met Tower Location:	Height AGL: 25.0 m; % of hub height: 100%
Secondary Anemometer (South)	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number.	R1160
Calibration Due Date:	Calibration not required
Met Tower Location:	Height AGL: 25.0 m; % of hub height: 100%
Primary Wind Direction Sensor (North)	
Make/Model:	Met One, 020C with Aluminum Vane
Serial Number:	U1475
Calibration Due Date:	December 18, 1999
Met Tower Location:	Height AGL: 22.6 m; % of hub height: 90.4%
Barometric Pressure Sensor	
Make/Model:	Vaisala, PTB101B
Serial Number:	R4230002
Calibration Due Date:	September 29, 1999
Met Tower Location:	Height AGL: 22 m; % of hub height: 88.0%
Atmospheric Temperature Sensor	
Make/Model:	Met One, T-200 RTD
Serial Number:	544114
Calibration Due Date:	December 18, 1999
Met Tower Location:	Height AGL: 22 m; % of hub height: 88.0%
Precipitation Sensor	
Make/Model:	Campbell Scientific, 237
Serial Number	N/A
Met Tower Location:	Height AGL: 1 m; % of hub height: 4%
Data Logger	
Make/Model:	Campbell Scientific CR23X
Serial Number:	1214
Calibration Due Date:	Dec 2, 1999

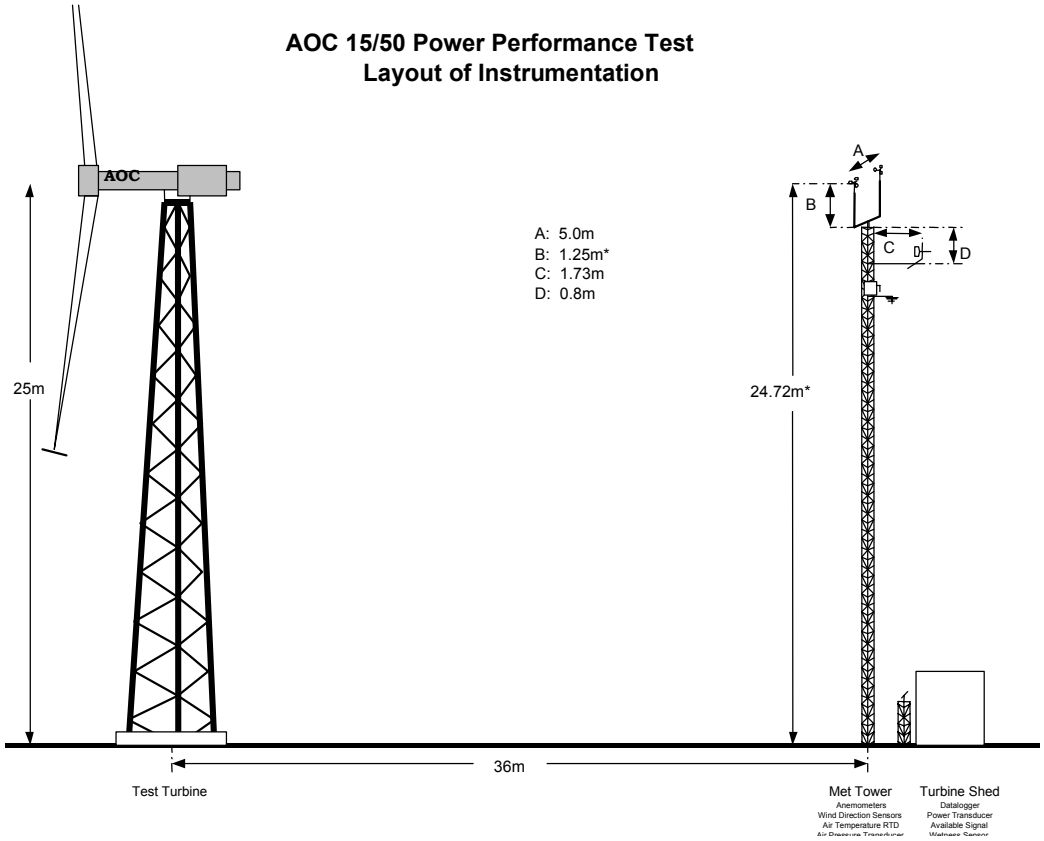


Figure 5. Layout of instrumentation.

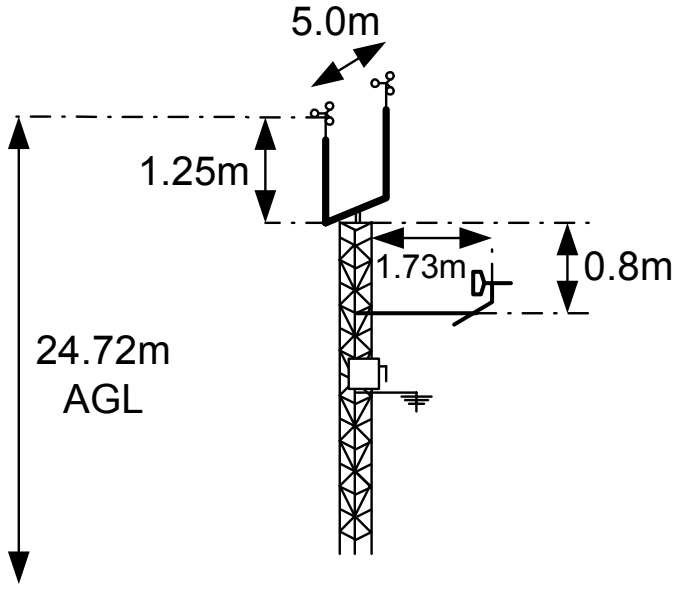


Figure 6. Detail instrumentation at top of meteorological tower.

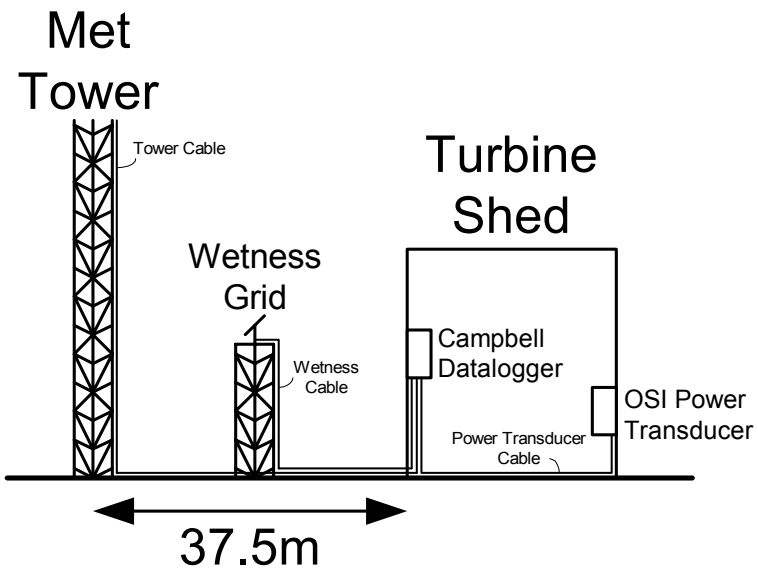


Figure 7. Detail of instrumentation at base of meteorological tower.

10 Description of Measurement and Analysis Procedures

Measurements during the power performance test are obtained automatically by the Campbell data logger. Data are obtained on each channel using a sample rate of 1 hertz. For each 10-minute data set, the data logger records the average, minimum, maximum, and standard deviation of each analog channel. In the case of wind direction, a vector-averaging algorithm is used to ensure that average values close to zero are properly recorded. For channels such as turbine availability, online, and wetness, the data logger records the percentage of the 10-minute period that the signal was "high." The data logger also records power supply voltage for itself, its internal temperature, and the number of seconds in the data set.

On a regular basis during the test, NREL personnel transfer the recorded data from the data logger to office computers and perform data quality checking. NREL quality procedures define the data quality checks that are performed. These include reviewing:

1. Time series plots of each recorded channel
2. Plots of minimums, maximums, and standard deviations
3. Power curve scatter plots, and
4. Comparison of anemometers.

Data are excluded from the power curve if:

1. External conditions other than wind speed are out of the normal range for turbine operation
2. The turbine is faulted
3. The turbine is manually shut down or in maintenance operating mode
4. Any of the instruments fail, malfunction, or operate out of specification
5. The data set is obtained from a record smaller than 10 minutes
6. The wind direction is outside of the final measurement sector.

In this test, wind speed measurements are corrected to account for terrain effects based on the results of a site calibration test. Corrected wind speed is determined by multiplying measured wind speed by the appropriate site calibration factor as determined from measured wind direction and Table 4.

In this test, air pressure is measured within 3 m of hub height. Therefore, no correction was applied to this measurement.

Data are normalized to two air densities, sea level (1.225 kg/m^3) and site average (reported in Section 12), using the method specified in IEC 61400-12. Since the test turbine is stall-regulated with constant pitch and constant rotational speed, normalization is applied to the power measurements.

After normalization, data are binned in accordance with IEC 61400-12. The results are shown in Sections 11 and 12. Annual energy production is estimated in accordance with IEC 61400-12. Those estimates are also shown in Sections 11 and 12. Finally, the coefficient of performance, Cp, is determined as a function of wind speed using the swept area of the rotor.

In addition to the normal power curve measurements, NREL also evaluated the online performance of the AOC 15/50. "Online" designates that the turbine was connected to the utility grid for the entire ten-minute pre-averaging period. Because no online signal was available, NREL used data in which power was greater than zero as the first indication of online power. In addition, NREL eliminated 73 points in which mean power was considerably lower than during normal operation. Most of these were attributable to start-up or yaw misalignment. Figure 14 shows online data relative to all valid data.

Table 6. Test Log

Date	Event
9/16/98	Site assessment completed
12/15/98	In-lab end-to-end instrumentation check completed
12/15/98	Data logger power supply check completed
12/23/98	In-field end-to-end instrumentation check completed
12/31/98	AOCr28.csi Replaced primary anemometer, R1161, with T2346 due to loss of cupset
12/31/98	AOCr28.csi Replaced cupset on secondary anemometer, R1160
12/31/98	AOCr28.csi Fixed wiring problem with power transducer
1/11/99	Disconnected secondary anemometer and secondary wind vane and connected them to SOMAT data acquisition for loads test
1/14/99	AOCr48.csi Connected secondary anemometer, secondary wind vane, real and reactive power signals to data logger l AND to SOMAT data acquisition for loads test
1/28/99	Data collection ended
2/12/99	Test debriefing completed
2/22/99	Original test report completed with no site calibration factors applied
4/11/00	First revision of test report completed with application of preliminary site calibration factors
5/22/03	Analysis completed for second revision with application of final site calibration factors and online performance

11 Power Curve and AEP at Sea-Level Air Density

Table 7. Performance at Sea-Level Air Density, 1.225 kg/m^3

Bin Number	Hub-Height Wind Speed m/s	Power Output KW	Number 10-Min Sets	Category A Standard Uncertainty KW	Category B Standard Uncertainty KW	Combined Standard Uncertainty kW
1	0.64	-1.11	9	0.09	0.39	0.40
2	1.06	-1.15	27	0.04	0.18	0.19
3	1.51	-1.14	63	0.03	0.18	0.19
4	2.01	-1.18	104	0.02	0.18	0.19
5	2.51	-1.21	98	0.02	0.18	0.19
6	3.00	-1.21	73	0.03	0.18	0.19
7	3.49	-1.29	77	0.08	0.19	0.20
8	3.97	-1.29	66	0.06	0.18	0.19
9	4.52	-1.23	48	0.11	0.19	0.21
10	5.01	-0.66	44	0.16	0.32	0.36
11	5.50	0.44	59	0.26	0.57	0.62
12	5.96	2.84	46	0.43	1.32	1.38
13	6.47	5.43	54	0.53	1.30	1.40
14	7.00	7.30	56	0.74	0.96	1.21
15	7.51	11.08	44	0.96	2.04	2.25
16	8.03	16.62	46	0.97	3.05	3.20
17	8.53	19.58	49	1.07	1.78	2.07
18	8.98	22.55	46	1.31	2.03	2.41
19	9.50	30.18	42	1.04	4.58	4.70
20	10.06	31.75	51	1.36	1.18	1.80
21	10.49	36.70	53	1.28	3.86	4.07
22	10.98	40.41	58	1.33	2.74	3.05
23	11.52	43.13	52	1.56	2.02	2.56
24	12.02	45.02	53	1.72	1.72	2.44
25	12.46	48.10	49	1.70	2.82	3.29
26	13.00	51.63	37	2.19	2.79	3.55
27	13.51	55.89	35	1.97	3.49	4.00
28	14.04	59.99	25	2.24	3.45	4.11
29	14.54	60.67	37	1.85	1.54	2.41
30	14.99	60.37	31	2.02	1.45	2.49
31	15.50	62.89	28	2.17	2.60	3.39
32	16.00	61.79	32	2.60	1.75	3.14
33	16.57	64.34	26	2.31	2.56	3.45
34	17.00	62.28	24	3.26	2.66	4.20
35	17.50	63.36	21	2.97	1.83	3.49
36	17.97	65.07	17	2.87	2.36	3.72
37	18.49	64.38	24	2.38	1.65	2.90
38	18.96	64.80	18	2.83	1.60	3.25
39	19.46	54.32	18	4.77	11.07	12.06
40	19.91	63.32	13	3.24	10.70	11.18
41	20.47	61.27	10	4.12	2.49	4.81
42	21.04	59.34	17	4.07	2.34	4.69
43	21.51	62.73	5	5.71	4.42	7.22
44	22.09	40.02	8	9.21	22.82	24.60
45	22.49	42.47	10	7.01	3.75	7.95
46	22.97	53.63	5	6.47	14.15	15.56
47	23.44	27.51	3	13.29	34.63	37.09

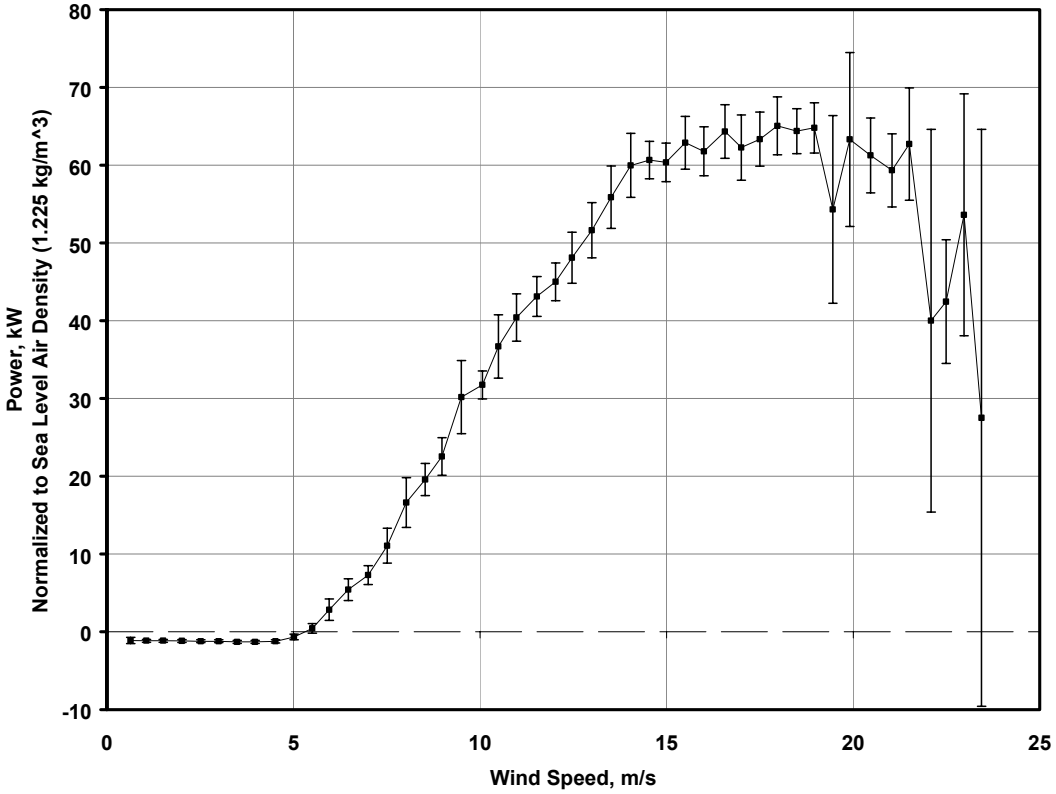


Figure 8. Power curve at sea-level air density, 1.225 kg/m^3.

Table 8. Annual Energy Production at Sea-Level Air Density, 1.225 kg/m^3

Estimated Annual Energy Production			
Reference air density:	1.225	kg/m^3	
Cut-out wind speed:	22.3	m/s	

Hub-Height Annual Average Wind Speed (Rayleigh)	**AEP-Measured** (from measured power and zero from last bin to cut-out)	**Standard Uncertainty in AEP-Measured**		**AEP-Extrapolated** (from measured power and constant power from last bin to cut-out)
m/s	MWh	MWh	%	MWh
4	11	5	44%	11
5	42	8	19%	42
6	83	10	13%	83
7	128	13	10%	128
8	172	14	8%	172
9	211	15	7%	211
10	243	15	6%	243
11	268	15	6%	268

12 Power Curve and AEP at Site Average Air Density

Table 9. Performance at Site Average Air Density, 1.012 kg/m^3

Bin Number	Hub-Height Wind Speed m/s	Power Output KW	Number 10-Min Sets	Category A Standard Uncertainty KW	Category B Standard Uncertainty KW	Combined Standard Uncertainty kW
1	0.64	-0.93	9	0.09	0.39	0.40
2	1.06	-0.96	27	0.04	0.18	0.19
3	1.51	-0.95	63	0.03	0.18	0.19
4	2.01	-0.98	104	0.02	0.18	0.19
5	2.51	-1.01	98	0.02	0.18	0.19
6	3.00	-1.01	73	0.03	0.18	0.19
7	3.49	-1.07	77	0.08	0.19	0.20
8	3.97	-1.07	66	0.06	0.18	0.19
9	4.52	-1.02	48	0.11	0.19	0.21
10	5.01	-0.55	44	0.16	0.32	0.36
11	5.50	0.37	59	0.26	0.57	0.62
12	5.96	2.36	46	0.43	1.32	1.38
13	6.47	4.50	54	0.53	1.30	1.40
14	7.00	6.05	56	0.74	0.96	1.21
15	7.51	9.17	44	0.96	2.04	2.25
16	8.03	13.77	46	0.97	3.05	3.20
17	8.53	16.20	49	1.07	1.78	2.07
18	8.98	18.65	46	1.31	2.03	2.41
19	9.50	24.97	42	1.04	4.58	4.70
20	10.06	26.28	51	1.36	1.18	1.80
21	10.49	30.34	53	1.28	3.86	4.07
22	10.98	33.43	58	1.33	2.74	3.05
23	11.52	35.68	52	1.56	2.02	2.56
24	12.02	37.21	53	1.72	1.72	2.44
25	12.46	39.79	49	1.70	2.82	3.29
26	13.00	42.72	37	2.19	2.79	3.55
27	13.51	46.18	35	1.97	3.49	4.00
28	14.04	49.59	25	2.24	3.45	4.11
29	14.54	50.16	37	1.85	1.54	2.41
30	14.99	49.88	31	2.02	1.45	2.49
31	15.50	51.96	28	2.17	2.60	3.39
32	16.00	51.05	32	2.60	1.75	3.14
33	16.57	53.18	26	2.31	2.56	3.45
34	17.00	51.48	24	3.26	2.66	4.20
35	17.50	52.34	21	2.97	1.83	3.49
36	17.97	53.76	17	2.87	2.36	3.72
37	18.49	53.19	24	2.38	1.65	2.90
38	18.96	53.54	18	2.83	1.60	3.25
39	19.46	44.87	18	4.77	11.07	12.06
40	19.91	52.31	13	3.24	10.70	11.18
41	20.47	50.62	10	4.12	2.49	4.81
42	21.04	49.03	17	4.07	2.34	4.69
43	21.51	51.82	5	5.71	4.42	7.22
44	22.09	33.06	8	9.21	22.82	24.60
45	22.49	35.09	10	7.01	3.75	7.95
46	22.97	44.31	5	6.47	14.15	15.56
47	23.44	22.73	3	13.29	34.63	37.09

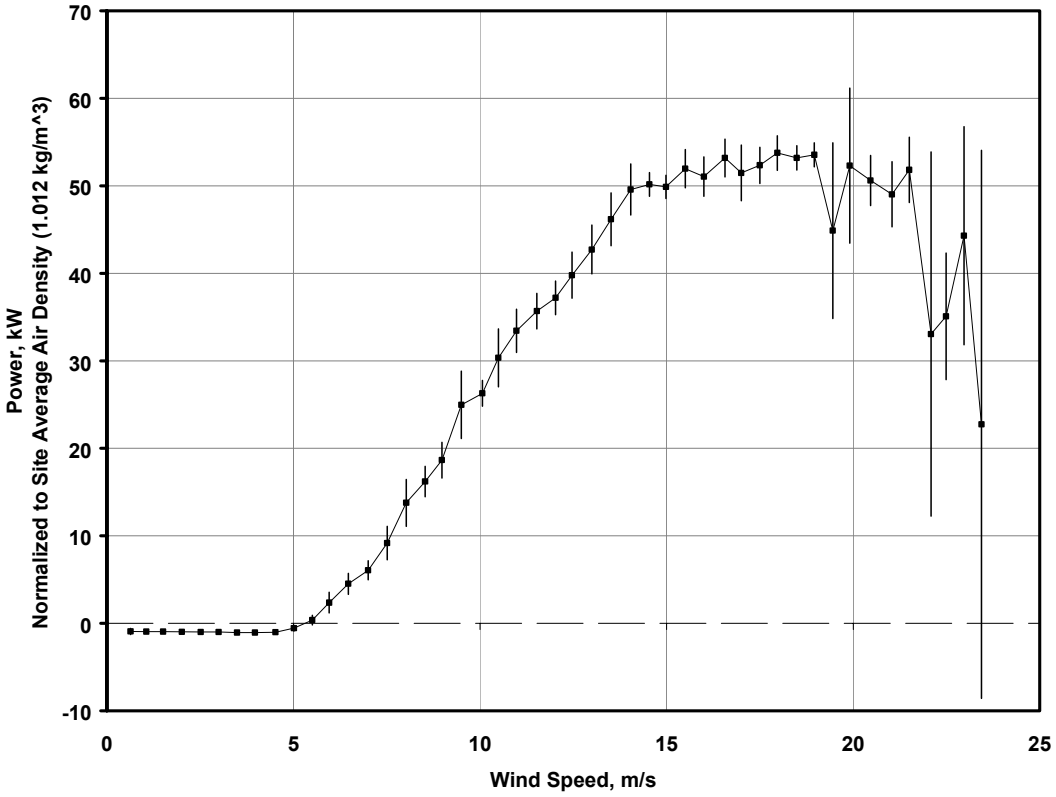


Figure 9. Power curve at site average air density, 1.012 kg/m^3.

Table 10. Annual Energy Production at Site Average Air Density, 1.012 kg/m^3

Estimated Annual Energy Production				
	Reference air density:	1.012	kg/m^3	
	Cut-out wind speed:	22.3	m/s	
Hub-Height Annual Average Wind Speed (Rayleigh)	**AEP-Measured** (from measured power and zero from last bin to cut-out)	**Standard Uncertainty in AEP-Measured**		**AEP-Extrapolated** (from measured power and constant power from last bin to cut-out)
m/s	MWh	MWh	%	MWh
4	9	5	54%	9
5	35	8	22%	35
6	69	10	15%	69
7	106	13	12%	106
8	142	14	10%	142
9	175	15	8%	175
10	201	15	7%	201
11	221	15	7%	221

13 Online Power Curve and AEP at Sea-Level Air Density

The online power curve indicates performance achieved by the turbine using data obtained only when it is connected to the grid for the entire 10-minute preaveraging period.

Table 11. Online Performance at Sea-Level Air Density, 1.225 kg/m^3

Bin Number	Hub-Height Wind Speed m/s	Power Output KW	Number 10-Min Sets	Category A Standard Uncertainty KW	Category B Standard Uncertainty KW	Combined Standard Uncertainty kW
1	4.57	0.80	3	0.35	0.19	0.40
2	5.04	1.51	9	0.42	0.39	0.58
3	5.52	2.94	24	0.33	0.74	0.81
4	5.96	4.77	31	0.40	1.05	1.13
5	6.48	7.95	39	0.38	1.56	1.61
6	7.04	11.52	37	0.54	1.71	1.79
7	7.50	15.33	32	0.59	2.28	2.36
8	8.04	19.01	40	0.71	1.99	2.11
9	8.52	22.82	41	0.71	2.35	2.46
10	8.98	26.33	39	0.82	2.36	2.49
11	9.50	31.07	40	0.90	2.92	3.05
12	10.05	35.05	44	0.97	2.46	2.64
13	10.49	38.19	51	1.01	2.48	2.68
14	10.98	42.27	55	1.04	2.99	3.16
15	11.52	45.99	47	1.24	2.64	2.92
16	12.02	48.79	47	1.36	2.33	2.70
17	12.46	50.19	46	1.42	1.66	2.18
18	13.00	54.41	34	1.75	3.24	3.68
19	13.52	56.98	34	1.81	2.36	2.97
20	14.04	59.99	25	2.24	2.74	3.54
21	14.55	61.16	35	1.89	1.73	2.56
22	14.99	60.78	30	2.03	1.48	2.51
23	15.50	62.89	28	2.17	2.33	3.18
24	16.00	63.83	31	2.09	1.72	2.71
25	16.57	64.34	26	2.31	1.57	2.79
26	17.00	65.04	23	2.49	1.71	3.02
27	17.51	65.11	20	2.78	1.54	3.18
28	17.97	65.07	17	2.87	1.53	3.26
29	18.49	64.38	24	2.38	1.65	2.90
30	18.96	64.80	18	2.83	1.60	3.25
31	19.48	63.50	15	3.08	1.99	3.67
32	19.91	63.32	13	3.24	1.50	3.57
33	20.45	63.71	9	4.02	1.55	4.31
34	21.06	63.14	16	2.84	1.57	3.25
35	21.51	62.73	5	5.71	1.57	5.92
36	22.07	61.54	5	5.59	1.90	5.90
37	22.49	60.49	5	5.43	2.07	5.81
38	23.02	61.56	3	7.67	1.89	7.90

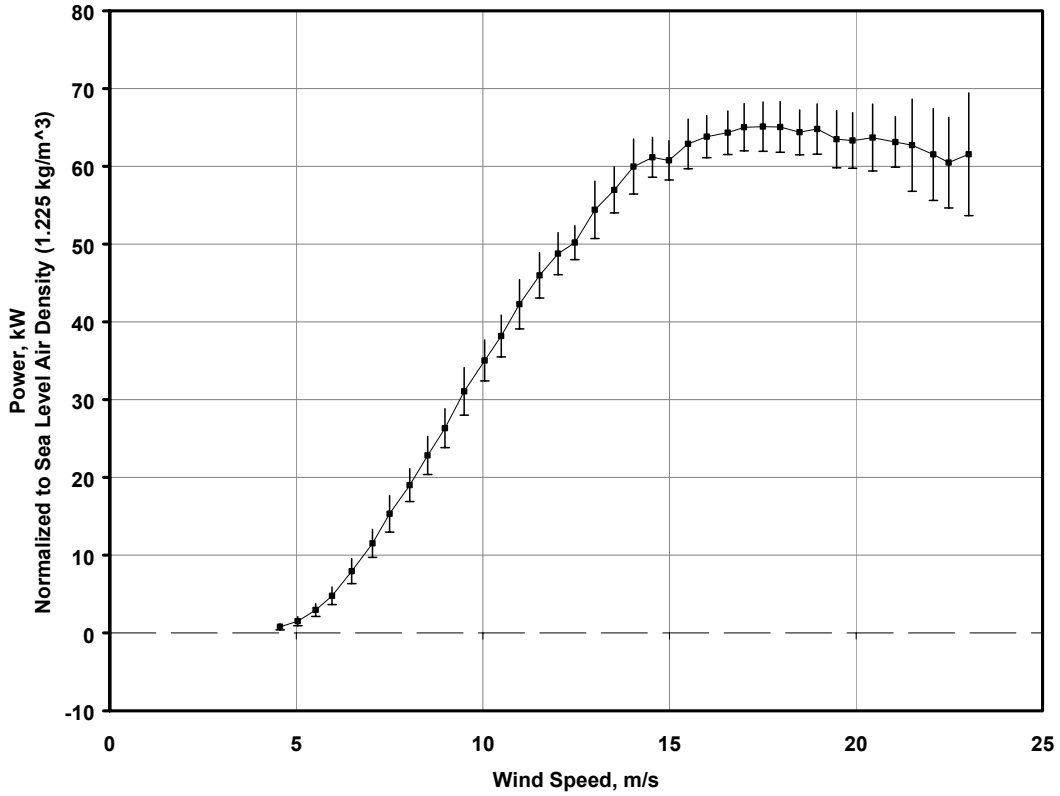


Figure 10. Online power curve at sea-level air density, 1.225 kg/m^3.

Table 12. Online Annual Energy Production at Sea-Level Air Density, 1.225 kg/m^3

Estimated Annual Energy Production				
	Reference air density:	1.225	kg/m^3	
	Cut-out wind speed:	22.3	m/s	
Hub-Height Annual Average Wind Speed (Rayleigh)	**AEP-Measured** (from measured power and zero from last bin to cut-out)	**Standard Uncertainty in AEP-Measured**		**AEP-Extrapolated** (from measured power and constant power from last bin to cut-out)
m/s	MWh	MWh	%	MWh
4	26	5	20%	26
5	60	8	13%	60
6	102	11	10%	102
7	147	12	9%	147
8	191	14	7%	191
9	230	14	7%	230
10	262	14	6%	262
11	285	14	6%	285

14 Supplementary Results

The below scatter plot shows the mean powers for both cases when the turbine is wet (the wetness sensor shows wet for the entire 10-minute data set) and when the turbine is dry.

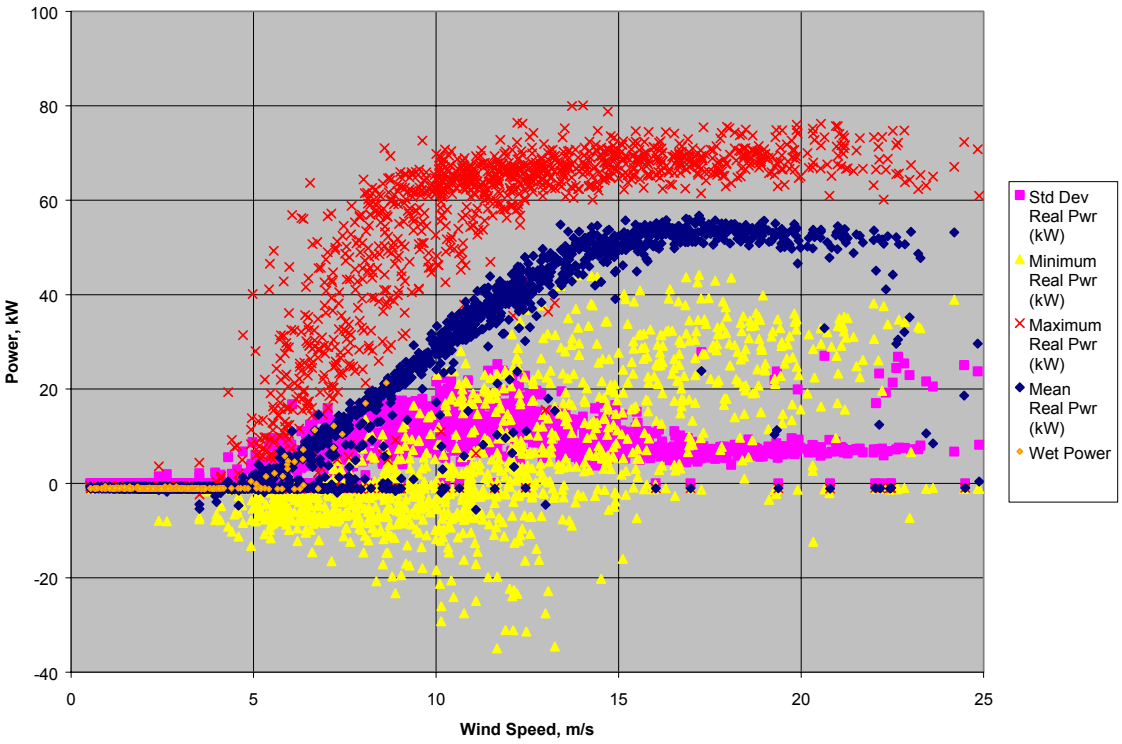


Figure 11. Scatter plot of power data.

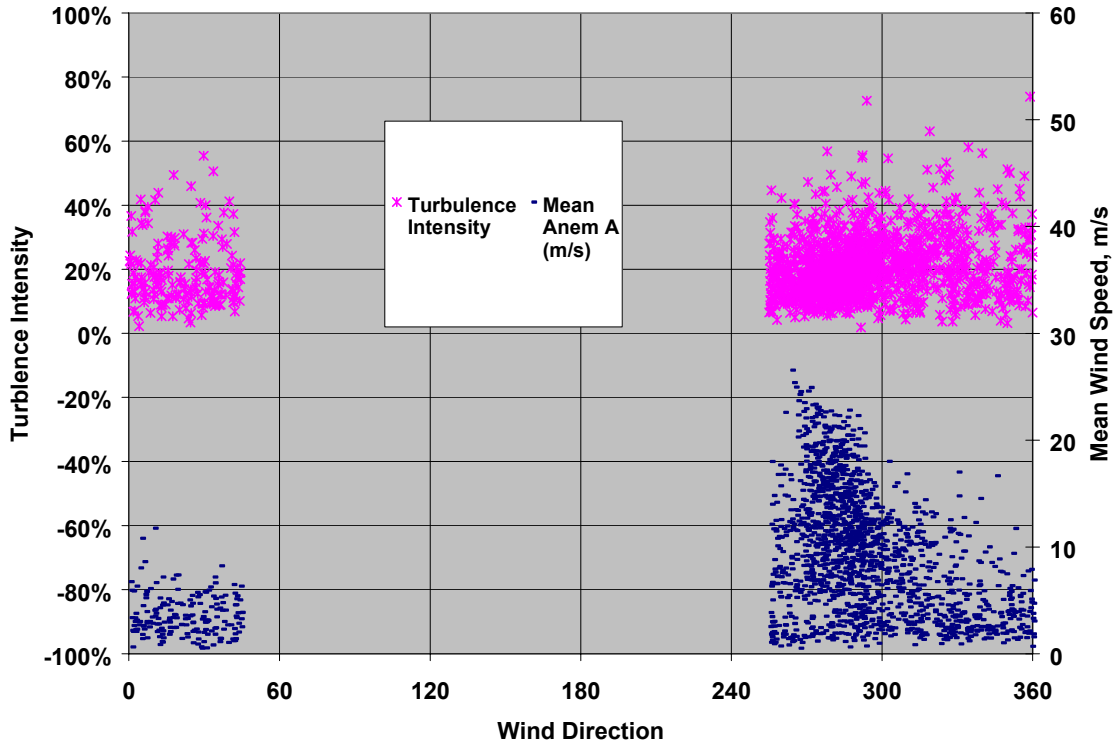


Figure 12. Turbulence intensity and mean wind speed versus wind direction.

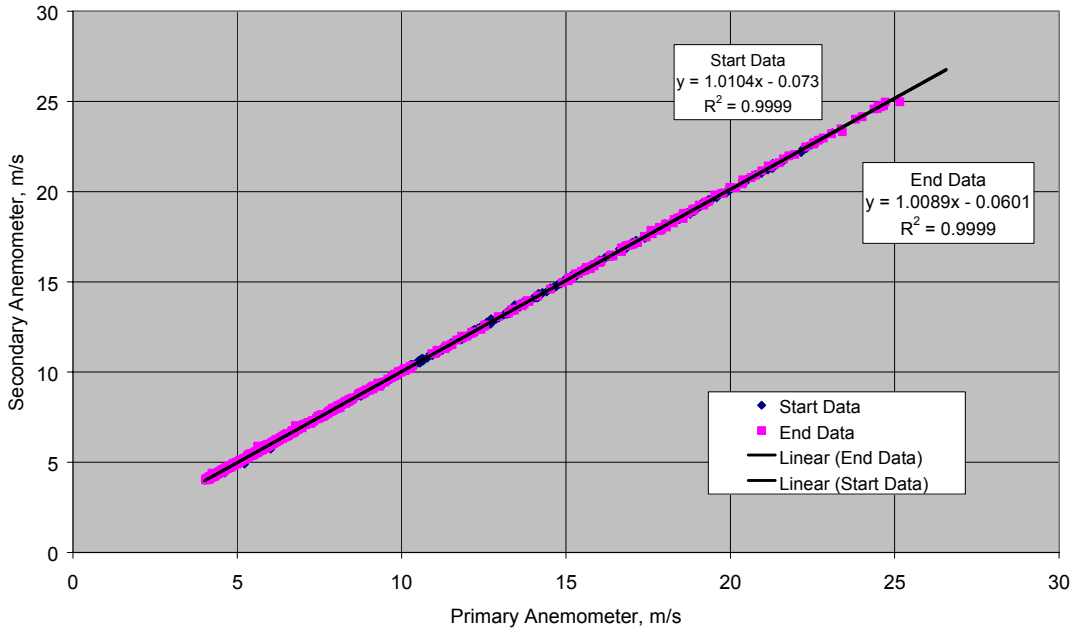


Figure 13. Relationship of secondary anemometer to primary anemometer.

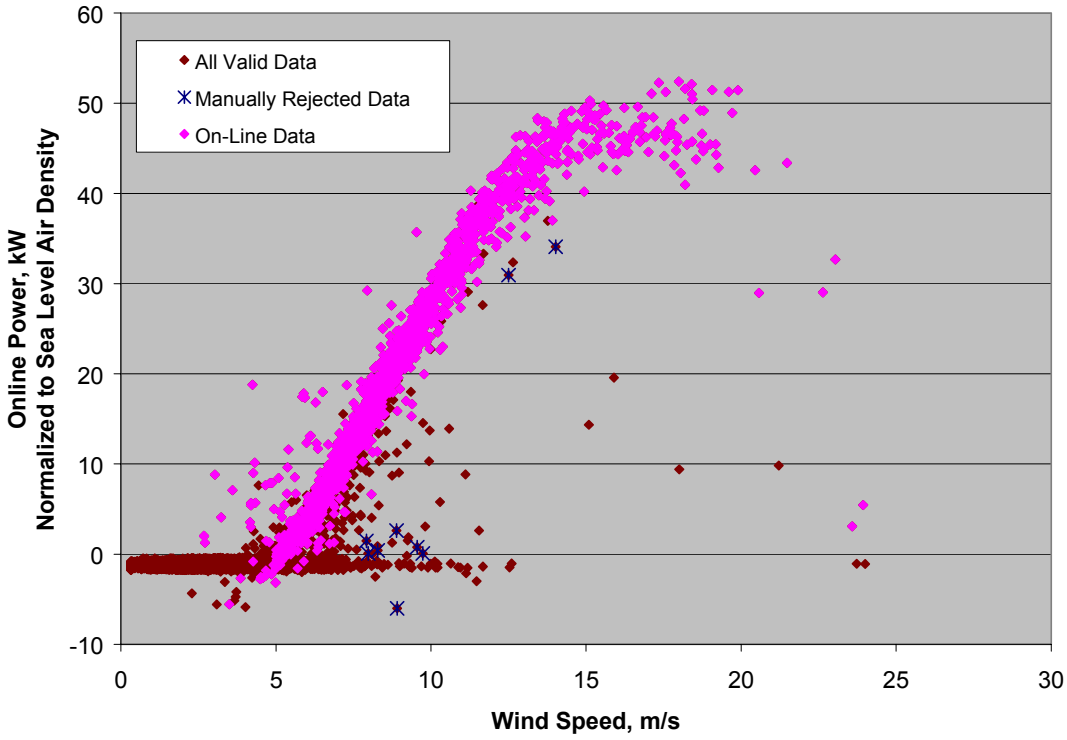


Figure 14. Scatter plot of online power data.

15 Uncertainty Calculations

NREL uses the procedure defined in IEC 61400-12 to define measurement uncertainty for power curves, AEP, and site calibration. Uncertainty is expressed in terms of a "standard uncertainty," which corresponds to a coverage factor of 1 and a level of confidence of approximately 68%. Standard uncertainty is the root sum squared of Type A (determined by statistical means) and Type B (determined by other than statistical means) uncertainty components.

For power curve measurements, Type A is calculated for each wind speed bin as the standard deviation of the 10-minute mean power values divided by the square root of the number of data sets. Type B uncertainty is determined from the uncertainty components listed in Table 13. Because all components are assumed to be uncorrelated, they are combined using the root-sum-squared method. Sensitivity factors are used to express all uncertainty in terms of measured power. The sensitivity factor for wind speed is the local slope of the power versus wind speed curve. The sensitivity for air pressure at sea-level air density is bin average power divided by sea-level barometric pressure (101.3 kPa) or bin average power divided by site average air density. The sensitivity for air temperature is bin average power divided by 288.15° K.

Uncertainty for site calibration is calculated for each wind direction bin using the following components:

- Anemometer calibration as a percentage at a nominal average wind speed of 10 m/s
- Data acquisition for both anemometers
- Wind direction times the local slope of the correction factor plotted against wind direction, and

- Type A as calculated by the standard deviation of the correction factor divided by the number of points.

To simplify the power performance analysis, the uncertainties for individual correction factors were not weight averaged by the number of data points in each wind direction bin. Instead, the worst-case uncertainty, 1.31%, was applied to all wind speed measurements (as shown in Table 13).

Table 13. Type B Uncertainties in Power Performance Measurements

Measurement	Component	Uncertainty		Source
Power	power transducer (>37.5 kW)*	0.075	kW	calibration
	power transducer (>=37.5 kW)*	0.20%		calibration
	data acquisition	0.165	kW	manual
	resistor	1.00%		measured
Wind Speed	anemometer	0.20	m/s	calibration
	operational characteristics	2.00%		assumption
	mounting effects	0.03%		assumption
	terrain effects	1.31%		site calibration
	data acquisition	0.00	m/s	manual
Air Temperature	temperature sensor	0.05%		specifications
	radiation shielding	2.00	K	assumption
	mounting effects	1.16	K	assumption
	algorithm	0.00	K	DAS manual
	data acquisition	0.02%		manual
Air Pressure	pressure sensor	2.00	hPa	calibration
	mounting effects	0.41	hPa	10% of correction
	data acquisition	0.03	hPa	manual
* Power transducer uncertainty includes uncertainty in current transformer.				

16 Deviations from IEC 61400-12

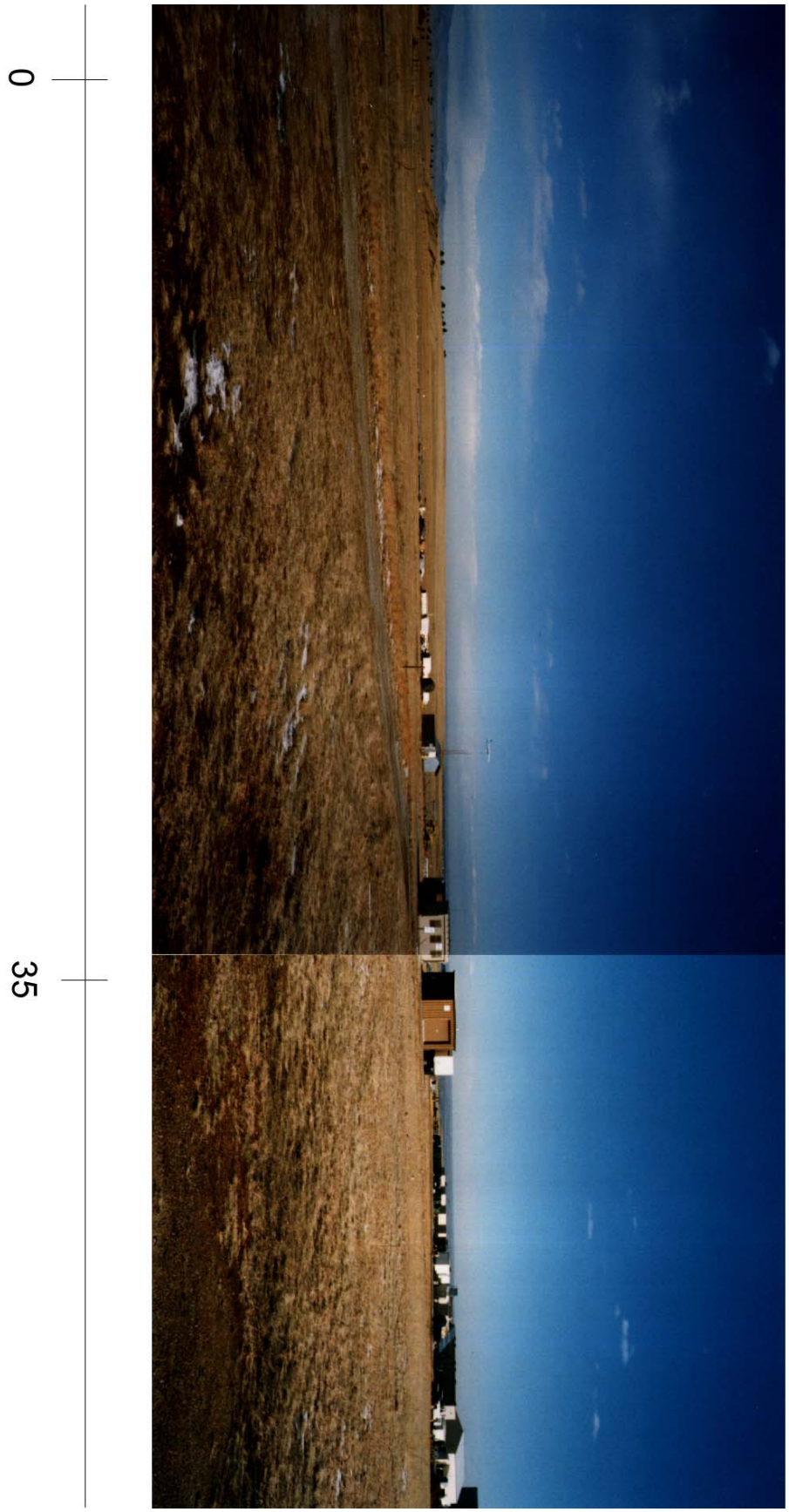
Power performance instrumentation deviates from the IEC standard as follows:

1. The power transducer was not tested for compliance with IEC 688.

2. The current transformers were not tested for compliance with IEC 185.

Appendix A: Pictures of Test Site

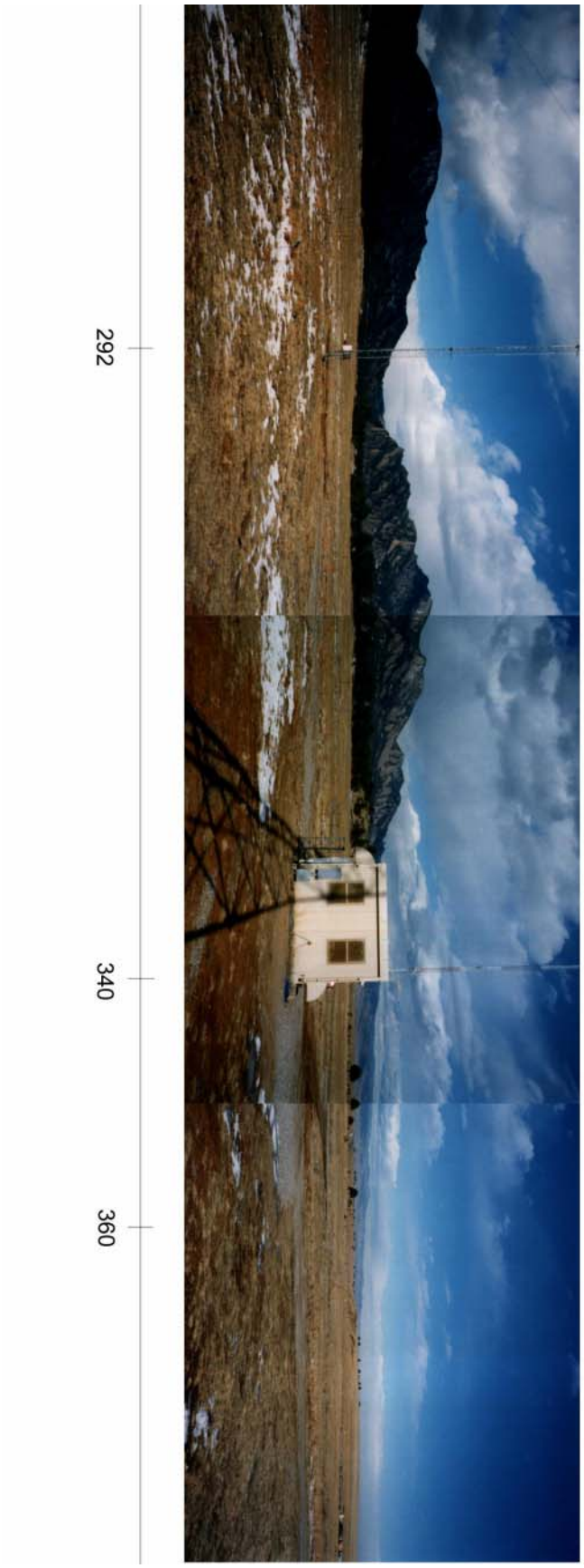
The bearings given in these pictures are relative to true north and correspond to the map in Figure 3.



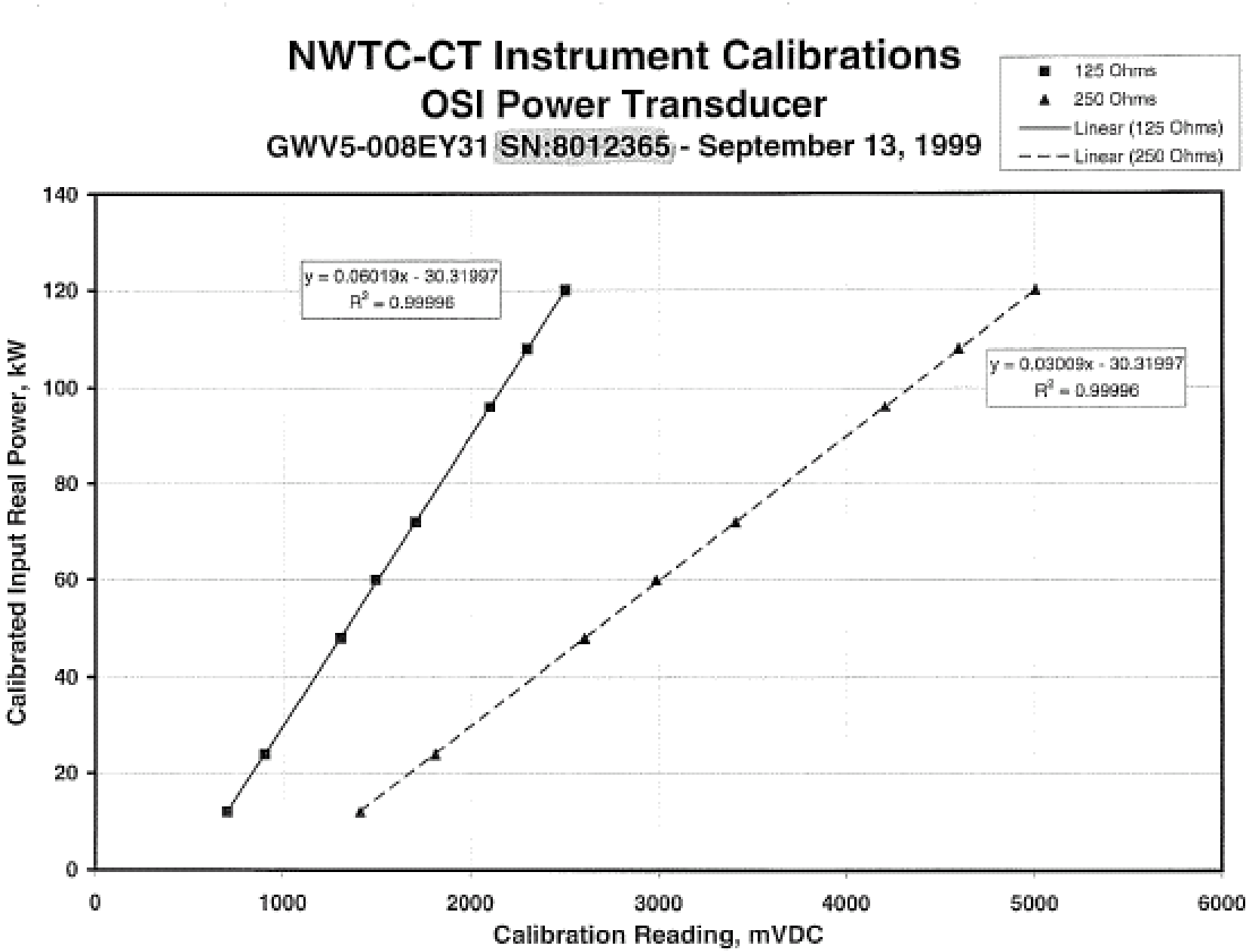
A-2


80
120
160


180
202
232


292
340
360

Appendix B: Calibration Certificates


NWTC-CT Instrument Calibrations
OSI Power Transducer
GWV5-008EY31 SN:8012365 - September 13, 1999
125 Ohms
250 Ohms
Linear (125 Ohms)
Linear (250 Ohms)
y = 0.06019x - 30.31997
R² = 0.99996
y = 0.03009x - 30.31997
R² = 0.99996
Calibrated Input Real Power, kW
Calibration Reading, mVDC
0
20
40
60
80
100
120
140
0
1000
2000
3000
4000
5000
6000

OHIO SEMITRONICS, INC.

4242 REYNOLDS DRIVE • HILLIARD, OHIO 43026
Telephone (614) 777-1005 FAX (614) 777-4511

CERTIFICATE OF COMPLIANCE

MODEL GWV5-008EY31 COMPANY NREL

SERIAL NO. 8012365 PO# 4486-8600-0005-883 OSI PO# NA RMA# 11556

DATE 9-13-99

It is hereby certified, that all articles in the quantities as called for on the above order are in conformance with all applicable requirements and specifications as outlined in that order and any negotiated changes related thereto.

Accuracy has been established by comparison with standards traceable to the National Institute of Standards and Technology.

EQUIPMENT USED:

MFG	MODEL	S/N	CAL. DATE	DUE DATE
ROTEK	811A	717	5-13-99	5-13-00
HEWLETT PACKARD	34401A	3146A58151	6-16-99	12-16-99

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	811A	717	5-13-99	5-13-00	20835
ROTEK	710	115	7-12-99	11-12-99	20883

TEMP. 72°F

HUM. 68%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Page 1 of 6

CALIBRATION DATA

Dwg.# A-7003-15

Ohio Semitronics, Inc.
4242 Reynolds Drive
Hilliard, OH 43026

CUSTOMER NREL

CUSTOMER NO. 4486-8600-0005-863 DATE 9-13-99

OSI NO. RMA 11556 Watts [X] VARS [ ] Amps [ ] PF [ ]

Model No. GWV-008EY31 Serial No. 8012365 Data taken by D EWING

Specified Accuracy CAL FOR BEST ACCURACY Output Load 0-500 Ω Data Certified By

Input at Rated Output 0-120 kWac INPUT @ 60 Hz=4-20 mAdc OUTPUT Title QUALITY ASSURANCE

INPUT				OUTPUT					
Volts	Amps	PF	Watts IN kW	Nominal Reading In mAdc WATTS	Nominal Reading In mAdc VARS	Actual Reading In mAdc WATTS	VARS PF	ACTUAL READING IN mAdc LEAD(-)	ACTUAL READING IN mAdc LAG (+)
240	166.7	1	120	20.000		20.000			
240	133.3	1	96	16.800		16.808			
240	100.0	1	72	13.600		13.616			
240	66.7	1	48	10.400		10.428			
240	33.3	1	24	7.200		7.232			
240	16.7	1	12	5.600		5.636			
240	166.7	.5 LAG	120	12.000		11.932			
240	166.7	.9 LAG	120	16.400		16.368			

Remarks (AFTER CALIBRATION) PAGE 1 OF 5

CALIBRATION DATA

Dwg.# A-7003-15

Ohio Semitronics, Inc.
4242 Reynolds Drive
Hilliard, OH 43026

CUSTOMER NREL

CUSTOMER NO. 4486-8600-0005-863 DATE 9-13-99

OSI NO. RMA 11556 Watts [ ] VARS [X] Amps [ ] PF [ ]

Model No. GWV5-008EY31 Serial No. 8012365 Data taken by D EWING

Specified Accuracy CAL FOR BEST ACCURACY Output Load 0-500 Ω Data Certified By

Input at Rated Output 0-120 kvar ac INPUT @ 60 Hz=4-12-20 mAdc OUTPUT Title QUALITY ASSURANCE

INPUT				OUTPUT					
Volts	Amps	PF	Watts IN KW	Nominal Reading In mAdc WATTS	Nominal Reading In mAdc VARS	Actual Reading In mAdc WATTS	VARS PF	ACTUAL READING IN mAdc LEAD(-)	ACTUAL READING IN mAdc LAG (+)
240	166.7	.9	120		15.486		.9		15.486
240	166.7	.7	120		17.712		.7		17.724
240	166.7	.5	120		18.926		.5		18.940
240	166.7	.3	120		19.630		.3		19.640
240	166.7	.1	120		19.958		.1		19.964
240	166.7	0	120		20.000		0		20.000

Remarks (AFTER CALIBRATION) FORWARD POWER LAG PF PAGE 2 OF 5

CALIBRATION DATA

Dwg.# A-7003-15

Ohio Semitronics, Inc.
4242 Reynolds Drive
Hilliard, OH 43026

CUSTOMER NREL

CUSTOMER NO. 4486-8600-0005-863 DATE 9-13-99

OSI NO. RMA 11556 Watts ☐ VARS ☒ Amps ☐ PF ☐

Model No. GWVS-008EY31 Serial No. 8012385 Data taken by D EWING

Specified Accuracy CAL FOR BEST ACCURACY Output Load 0-500 Ω Data Certified By

Input at Rated Output 0-120 kvar ac INPUT @ 60 Hz=4-12-20 mAdc Title QUALITY ASSURANCE

INPUT				OUTPUT					
Volts	Amps	PF	Watts IN kW	Nominal Reading in mAdc WATTS	Nominal Reading in mAdc VARS	Actual Reading in mAdc WATTS	VARS PF	ACTUAL READING IN mAdc LEAD(-)	ACTUAL READING IN mAdc LAG (+)
240	166.7	.9	120		15.486		.9	15.492	
240	166.7	.7	120		17.712		.7	17.716	
240	166.7	.5	120		18.926		.5	18.932	
240	166.7	.3	120		19.630		.3	19.636	
240	166.7	.1	120		19.958		.1	19.968	
240	166.7	0	120		20.000		0	20.000	

Remarks (AFTER CALIBRATION) REVERSE POWER LEAD PF PAGE 3OF5

CALIBRATION DATA

Dwg.# A-7003-15

Ohio Semitronics, Inc.
4242 Reynolds Drive
Hilliard, OH 43026

CUSTOMER NREL

CUSTOMER NO. 4486-8600-0005-863 DATE 9-13-99

OSI NO. RMA 11556 Watts [ ] VARS [X] Amps [ ] PF [ ]

Model No. GWV5-008EY31 Serial No. 8012385 Data taken by D EWING

Specified Accuracy CAL FOR BEST ACCURACY Output Load 0-500 Ω Data Certified By

Input at Rated Output 0-120 kvar ac INPUT @ 60 Hz=4-12-20 mAdc OUTPUT Title QUALITY ASSURANCE

INPUT				OUTPUT					
Volts	Amps	PF	Watts In kW	Nominal Reading in mAdc WATTS	Nominal Reading in mAdc VARS	Actual Reading in mAdc WATTS	VARS PF	ACTUAL READING IN mAdc LEAD(-)	ACTUAL READING IN mAdc LAG (+)
240	166.7	.9	120		8.513		.9		8.524
240	166.7	.7	120		6.287		.7		6.296
240	166.7	.5	120		5.072		.5		5.080
240	166.7	.3	120		4.369		.3		4.376
240	166.7	.1	120		4.041		.1		4.052
240	166.7	0	120		4.000		0		4.008

Remarks (AFTER CALIBRATION) REVERSE POWER LAG PF PAGE 4OF5

CALIBRATION DATA

Dwg.# A-7003-15

Ohio Semitronics, Inc.
4242 Reynolds Drive
Hilliard, OH 43026

CUSTOMER NREL

CUSTOMER NO. 4486-8600-0005-863 DATE 9-13-99

OSI NO. RMA 11556 Watts [ ] VARS [X] Amps [ ] PF [ ]

Model No. GWV5-008EY31 Serial No. 8012385 Data taken by D EWING

Specified Accuracy CAL FOR BEST ACCURACY Output Load 0-500 Ω Data Certified By

Input at Rated Output 0-120 kvar ac INPUT @ 60 Hz=4-12-20 mAdc OUTPUT Title QUALITY ASSURANCE

INPUT				OUTPUT					
Volts	Amps	PF	Watts IN KW	Nominal Reading in mAdc WATTS	Nominal Reading in mAdc VARS	Actual Reading in mAdc WATTS	VARS PF	ACTUAL READING IN mAdc LEAD(-)	ACTUAL READING IN mAdc LAG (+)
240	166.7	.9	120		8.513		.9	8.524	
240	166.7	.7	120		6.287		.7	6.304	
240	166.7	.5	120		5.072		.5	5.084	
240	166.7	.3	120		4.369		.3	4.380	
240	166.7	.1	120		4.041		.1	4.048	
240	166.7	0	120		4.000		0	4.008	

Remarks (AFTER CALIBRATION) FORWARD POWER LEAD PF PAGE 5 OF5

Annemometer Calibration Report

Calibration Laboratory:
National Wind Technology Center - Cert. Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Calibration Location:
National Wind Technology Center
Side-by-Side Anemometer Calibration Facility

Report Number: CR-anno-98-4-T3

Page: 1 of 1

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	T2346
Cup Material	Aluminum
Condition	Refurbished 15 Sep 98

Estimated Uncertainty:

Vwind	Cras Uncer	Total Uncert:
4 - 5 m/s	0.083	0.096
5 - 10 m/s	0.067	0.083
10 - 15 m/s	0.078	0.092

Customer:
National Wind Technology Center - Certification Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Dates of Calibration:
Test Start: 1-Oct-98
Test End: 28-Oct-98
Report: 6-Nov-98

Procedure:
NWTC-CT: GI21-98237, Field Calibrate Anemometers

Deviations from procedure:
None

Results:

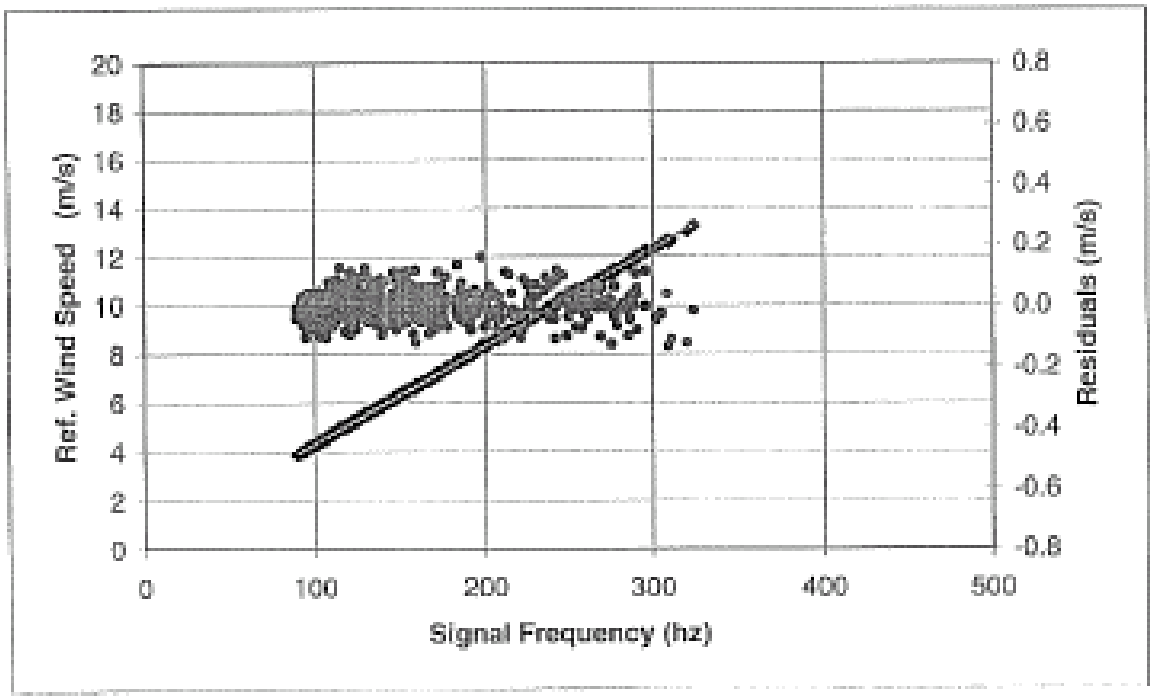
Slope:	0.0399	m/s/hertz
Offset:	0.3247	m/s

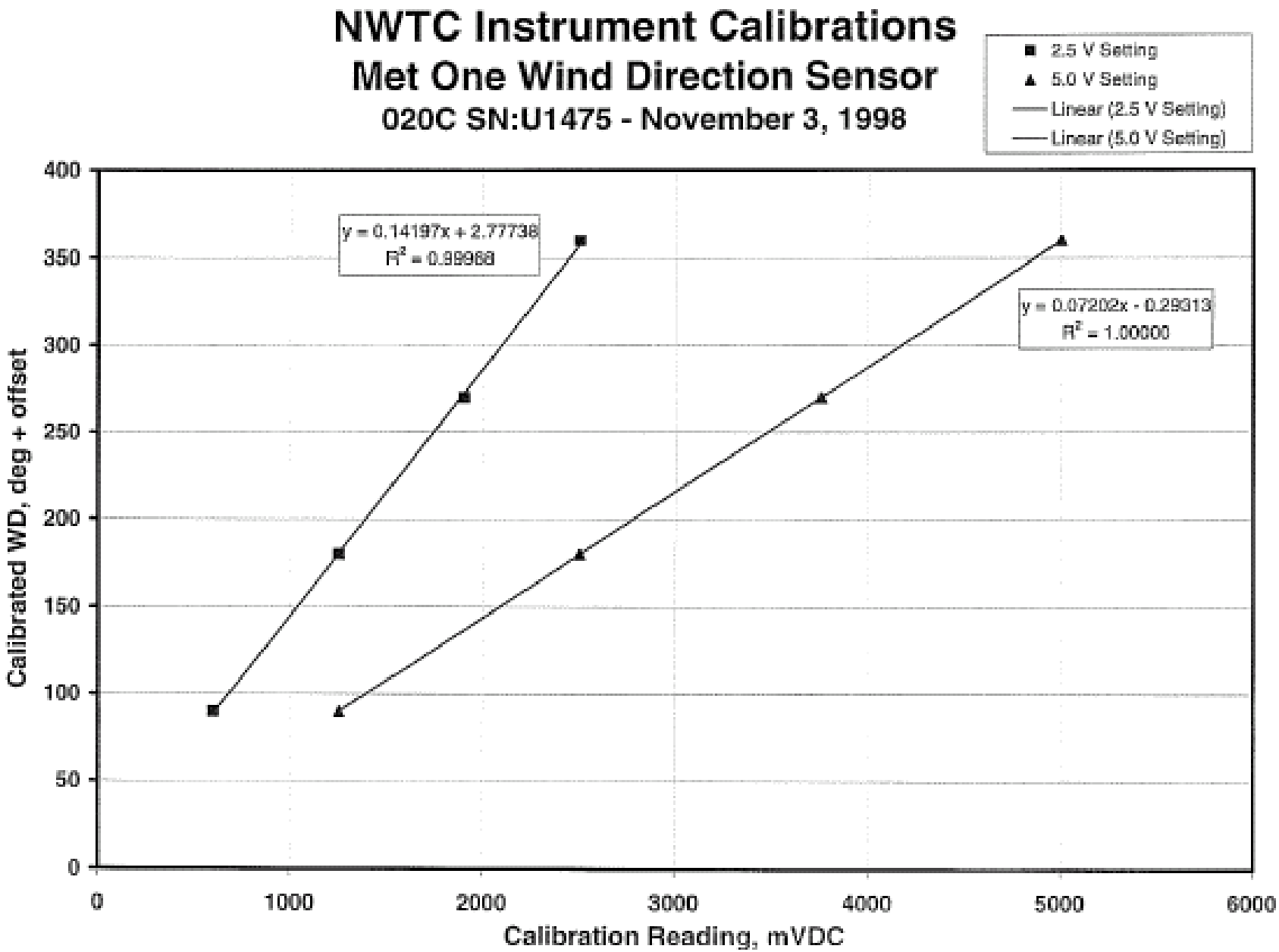
Traceability:

Reference Cup:	Met One, 010C, s/n: U2645
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	11-Mar-98

Approved: Hal Link

6 Nov 98
Date




NWTC Instrument Calibrations
Met One Wind Direction Sensor
020C SN:U1475 - November 3, 1998
2.5 V Setting
5.0 V Setting
Linear (2.5 V Setting)
Linear (5.0 V Setting)
y = 0.14197x + 2.77738
R² = 0.99968
y = 0.07202x - 0.29313
R² = 1.00000
Calibrated WD, deg + offset
Calibration Reading, mVDC
0
50
100
150
200
250
300
350
400
0
1000
2000
3000
4000
5000
6000

INSTRUMENT REPAIR LABS INC

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 981023192
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Met One	020C	
SERIAL NUMBER	CALIBRATION ID #	CUSTOMER ID #
U1475	17815	

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 11/03/99	
STANDARD(S)	Used MD1 FL8	
CALIBRATION PROCEDURE USED	MPGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Mark Shann
DATE CALIBRATED: 11/03/98
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS CERT NO. 12 100 1851

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

page 1 of 2

Form 07, Rev. 03, 3-26-98

INSTRUMENT REPAIR LABS

Report of Calibration

Customer NREL Manufacturer MET ONE Calibration # 9802802

Model # 020C Serial # 41475 / 12515 Tech 18

Date 11-3-98 Due 11-3-99 Ambient ____ °F ____ % RH

☒ As Received ☒ As Returned

READINGS

5VDC OUTPUT	READING	2.5VDC OUTPUT	READING
MARK ALIGNED	2.5069	1.2542	
CW 90°	3.7527	1.9012	
CW 180°	4.9995	2.5026	
CW 270°	1.2539	.6025	
CW 360°	2.5023	1.2515	
MARK ALIGNED	2.5005	1.2495	
CCW 270°	1.2540	.6072	
CCW 180°	5.0039	2.5010	
CCW 90°	3.7573	1.8999	
CCW 0°	2.5009	1.2495	

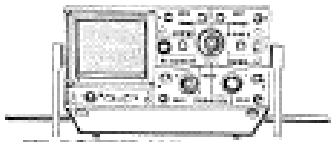
TOLERANCE = +/- 3°

5V OUTPUT = +/- .042V

2.5V OUTPUT = +/- .021V

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

Page 2 of 2



INSTRUMENT
REPAIR LABS
INC

Certificate of Calibration

COMPANY NAME: National Renewable Energy Laborator
CERTIFICATION #: 980925781
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Vaisala	PTB101B	
SERIAL NUMBER	CALIBRATION ID #	CUSTOMER ID #
R4230002	17392	02520C

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 09/28/99	
STANDARD(S)	Used FL14, FL21, FL6, DR1	
CALIBRATION PROCEDURE USED	MPGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Ronald Horton
DATE CALIBRATED: 09/28/98
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS CERT NO. 17 680 9021

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

INSTRUMENT REPAIR LABS

Report of Calibration

Customer NREL Manufacturer VAISALA Calibration # _____

Model # PTB101B Serial # S/N R4230002 / 025206 / CAL 17392 Tech RWW-3

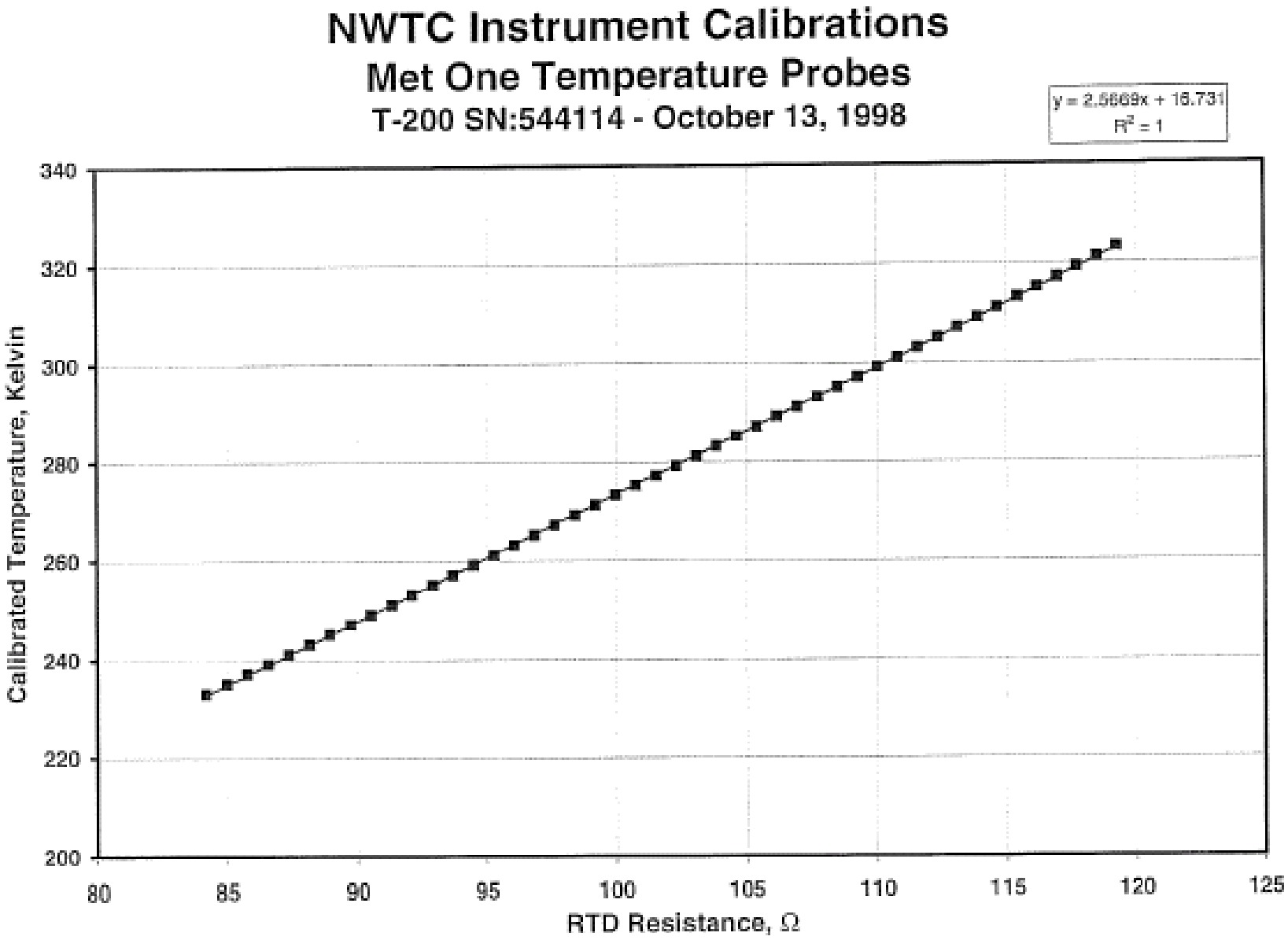
Date 9-28-98 Due 9-28-99 Ambient 68 °F 38 % RH

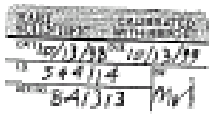
☑ As Received ☑ As Returned

READINGS

	Actual (STD)		Read (Out)
INPUT	617.60 mbar	OUTPUT	.18002 VDC
	691.16		5.0000 ~~5.0002~~
	789.13		0.9997
	875.42		1.4998
	968.41		2.0045
	1059.42		2.4985
	837.71 ATMOS.		1.2950

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378


NWTC Instrument Calibrations
Met One Temperature Probes
T-200 SN:544114 - October 13, 1998
y = 2.5669x + 16.731
R² = 1
Calibrated Temperature, Kelvin
340
320
300
280
260
240
220
200
80
85
90
95
100
105
110
115
120
125
RTD Resistance, Ω



INSTRUMENT
REPAIR LABS
INC

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 980918521
CALIBRATION LOCATION: Subcontractor

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Met One	T-200	
SERIAL NUMBER	CALIBRATION ID #	CUSTOMER ID #
S44114	17350	

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 10/13/99	
STANDARD(S)	Used SUBCONTRACT SEE - ATTACHED	
CALIBRATION PROCEDURE USED	MPGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Subcontractor
DATE CALIBRATED: 10/13/98
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS ISO 9002 • CERT NO. 12 100 2921

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

Form 87, Rev. 03, 3-26-98

CAMPBELL SCIENTIFIC, INC.
815 W. 1800 N. • Logan, Utah 84321-1784 • (801) 753-2342 • FAX (801) 752-3268

23X Calibration Report

Datalogger Type 23X **Serial Number:** 1214 **RMA#** 22883 **Contract #:**

When Received, this instrument was found as follows:

In Tolerance: X
Out of tolerance
Operational failure (No incoming tolerance declared)

		Single Ended measurements		Differential measurements	
Range	Input	Before	After	Before	After
5	-5000mv	-4999.1	-5000.7	-4999.9	-5000.6
5	5000mv	5000.8	5000.7	4999.8	5000.3
4	1000mv	1000.25	1000.37	999.96	1000.10
3	200mv	200.043	200.043	199.988	200.007
2	50mv	49.997	49.991	49.998	50.003
1	10mv	10.0014	10.0004	9.9994	10.0012
1	-10mV	-9.9992	10.0036	-9.9996	10.0013

Note: X = Out of tolerance

Time Clock Deviation (PPM)	Before	After
	3	0

Test Details..

Test Doc/Rev.: PRC23A Rev/21 Temperature: 23.8 C RH: 14.8
Calibrated By: _____
Name: S. Palmer Title: Customer Service Technician

Calibration equipment used: (NIST traceable through certified documents on fil

	Make/ Model#	S/N	NIST#
Voltage Source:	DATA PRECISION 8200	A031746	0269A17
Frequency source	OSCILATEK TXCO/112	8786	01411WWVB
RTD Ref.:	ROSEMONT-ADSR544		1265

CSI certifies the above instrument meets or exceeds published specifications and has been calibrate using standards and instruments whose accuracies are traceable to the National Institute of Standards and Technology, an accepted value of a natural physical constant or a ratio calibration technique. The measurement uncertainty of the calibration process exceeds a 4:1 accuracy ratio. The policies and procedures at this calibration facility comply with ISO-9001.

Calibration date: Thursday, December 02, 1999
Calibration due: Saturday, December 02, 2000

CSI DATALOGGER
MODEL: CR23X 4M Item #10917
FINAL DATALOGGER TEST REPORT AND CALIBRATION CERTIFICATION

Serial # 1214
Test Panel Position 2

TEST #	ANALOG INPUTS	PASS/FAIL	INPUT V.	MEASURED mV.	% ERROR	TEST TEMP.
1	Diff.Range 5 (+-0.05% FSR*)	P	5	4997.2	.03	-25 C
2				5000.0	0.00	+50 C
3	Channel Multiplexing	P				
4	Panel Temperature	P				
5	Battery Voltage	P				
	ANALOG OUTPUTS					
6	Switched (+-0.05% FSR*)	P		5000.4	.00	-25 C
7				4996.4	.04	+50 C
8	Continuous (+-0.05% FSR*)	P		4999.5	.01	-25 C
9				4995.7	.04	+50 C
10	Excit. Multiplexing	P				
11	CAO Channels	P				
*FSR = +-5V range						
12	PULSE COUNTERS	P				
13	DIGITAL CONTROL OUT	P				
	CPU AND INTERFACE					
14	Memory	P				
15	Serial I/O	P				
16	Clock	P				
	SYSTEM POWER			MEASURED CURRENT		
17	Quiescent (2.2mA typ.)	P		1.880 mA		
18	Measurement (loaded)	P		152.0 mA		
	(70 mA typ., 150 mA loaded typ.)					

	TEMPERATURE RANGE	INPUT V.	MEASURED V.	% ERROR	TEST TEMP.
19	Diff Range 5 Cold (Derated)	5	4996.5	0.035	-40 C
20	Diff Range 5 Hot (Derated)	5	5002.2	0.022	+50 C

NOTE: The collective measurement uncertainty of the calibration process exceeds a 4:1 accuracy ratio.

TEST STANDARDS USED:
Test Procedure TST10517C Rev.13
Environmental Chamber:
DC Calibrator S/N A005541 (Traceable to NIST 2396111)
Oscillatek S/N 41957 TCXO (Traceable to NIST 0141/WWVB)

Final Report Validation By

S. Palmer 12/02/99