WBS 1.2.6.9.4.2

USGS THERMOCOUPLE PSYCHROMETER EXPERIENCE

RESULTS OF LABORATORY CALIBRATION and GTUF FIELD APPLICATIONS

11 April 1989

by:

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THERMOCOUPLE PSYCHROMETER
General Facts And Figures

- Used to measure water potential ψ (bars)
- Calibrated using monovalent salt solutions (NaCl, KCl) at different temperatures to create artificial humidity environments
- Operational range is 0 to -80 bars or 93 to 100% RH
- Functions in a manner similar to a dry bulb/wet bulb hygrometer
- Cooling capacity is 0.6^{o}C dew-point depression equivalent

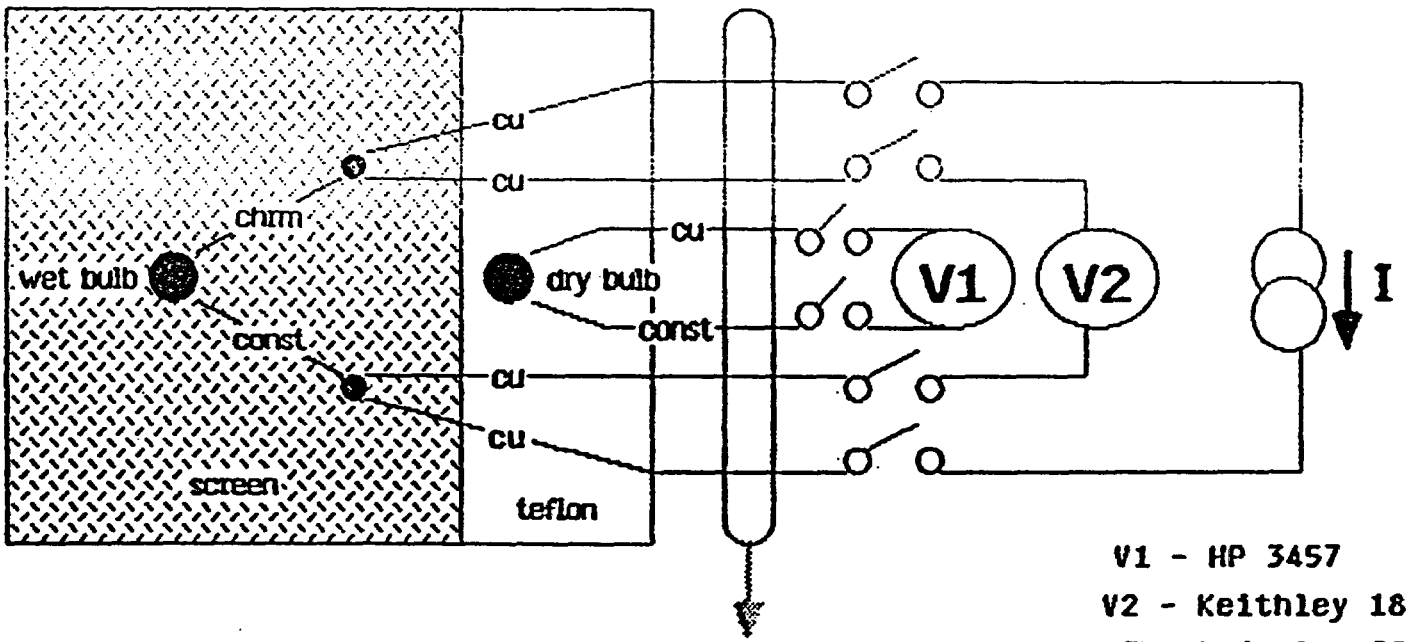
PROBLEM AREAS

- Thermal gradients
- Many variables to contend with
  - cooling time
  - cooling current
  - equilibration time
- Calibration requires
  - good technique
  - controlled environment
  - time
  - patience
  - stable and accurate support instrumentation

WBS 1.2.6.9.4.2

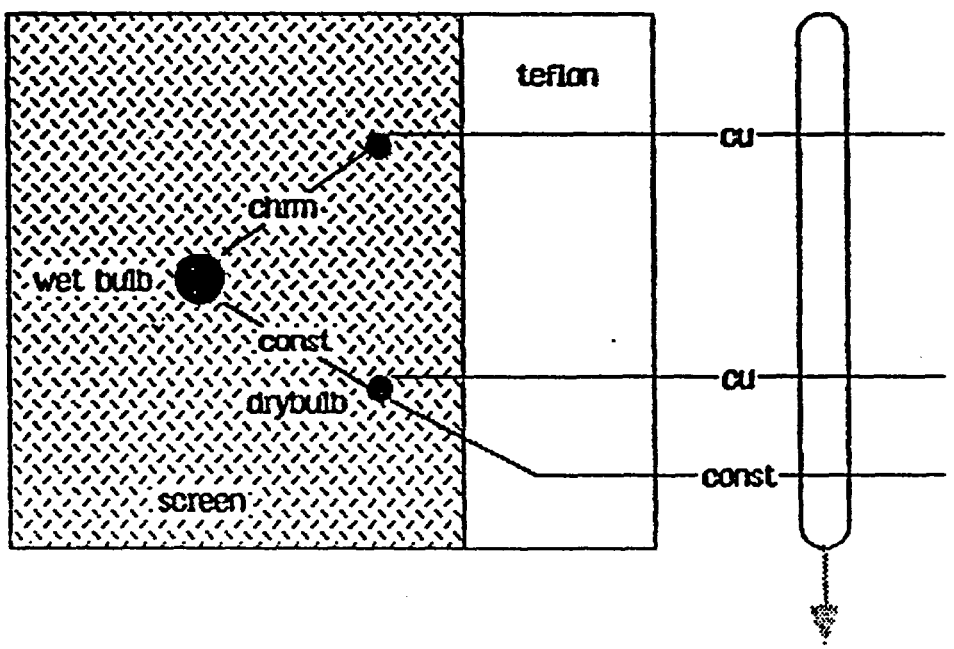
THERMOCOUPLE PSYCHROMETER
CALIBRATION AND MEASUREMENT EQUIPMENT

Unit	Function	Pertinent Manufacturer's Specs
Keithley 220 Current Source	wet bulb excitation (5.0mA)	5μA step size in 10mA range accuracy: .10% rdg. +10μA (1 year)
Keithley 181 Nanovoltmeter	zero voltage, wet bulb voltage (2mV range)	10nV resolution accuracy: 0.015% rdg. +5 counts (1 year)
Keithley 7168 Nanovoltmeter Scanner Card	relay switching for zero voltage/wet bulb voltage	less than 20nV thermal offset
Keithley 705/ 706 Scanner	system control	
HP 3457A Multimeter	dry bulb voltage	accuracy: .004% rdg. +365 counts (90 days) in 30mV range
HP 3497 Scanner	system control	
HP 44421A 20-channel relay multiplexer	relay switching for: dry bulb voltage current excitation	thermal offset not provided, estimate 1μV
HP 44422A relay multi-plexer with thermocouple compensation	dry bulb voltage	thermal offset not provided, estimate 1μV
Fluke 8520A Multimeter/ PRT Precision Temperature System	water bath reference temp.	accuracy: .015°C (1 year) .001°C resolution
Hart Scientific Water Bath	controlled thermal environment	temperature resetability: .005°C temperature stability: .0005°C



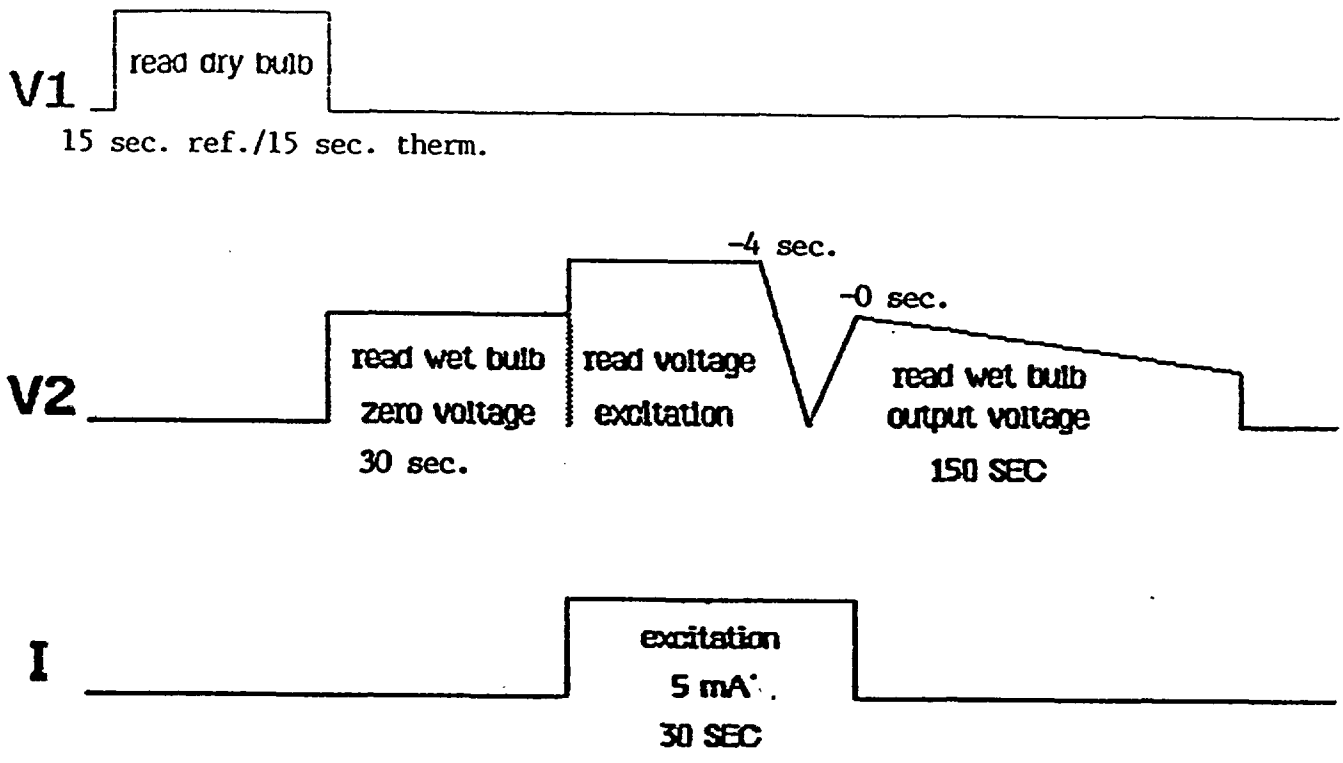
V1 - HP 3457
V2 - Keithley 181
I - Keithley 220

"NEW" TCP CONFIGURATION



"OLD" TCP CONFIGURATION

PSYCHROMETER DESIGN

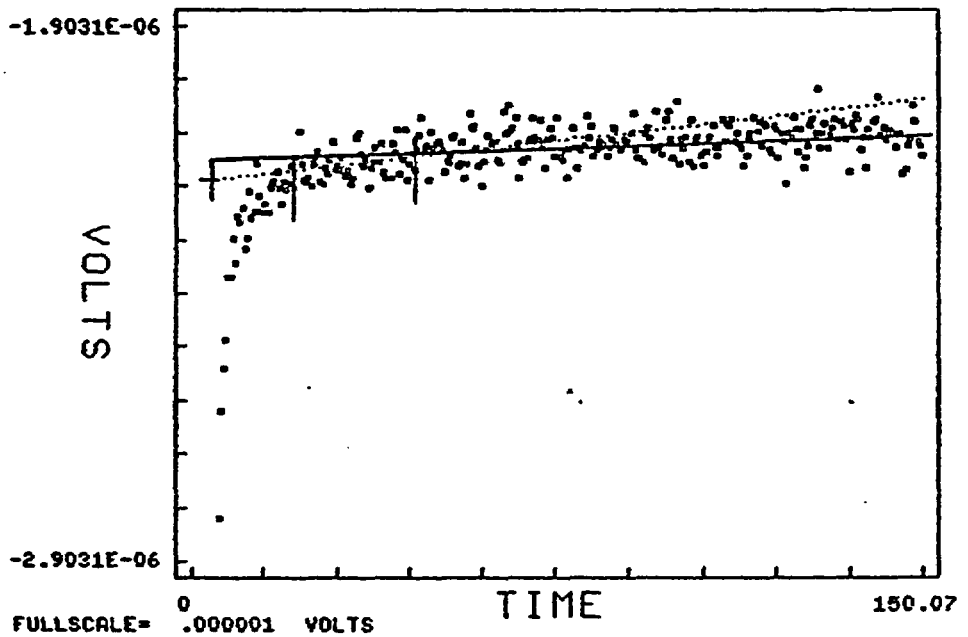


Psychrometer Scanning Sequence

0.05m ⑦
25°C
Rip #2

Voltmeter Zero Determination
Number of measurements is 30
Mean output voltage is -1.0579E-06
Standard deviation of the output voltage is 2.441502E-08
Intercept is -1.062275E-06 Sigma is 9.257174E-09
Slope is 2.622716E-10 Sigma is 5.214448E-10
Correlation coefficient (r^2): 0.010

Voltage output during current generation
Number of measurements is 27
Mean output voltage is -3.508922E-02
Standard deviation of the output voltage is 5.64508E-07
Intercept is -3.508958E-02 Sigma is 4.348349E-06
Slope is 2.695066E-08 Sigma is 2.853076E-07
Correlation coefficient (r^2): 1.058E-04



Datafile name: B:\TCPDAT\TCP26.DAT DISK NUMBER: 156
MEAN ZERO TIME VOLTAGE: -1.0579E-06 VOLTS
COOLING TIME: 30 Sec COOLING CURRENT: 5 mA
SOLUTION BATCH NUMBER: A.2-0.05m MOLALITY: .05 M
TCP SERIAL NUMBER: A8-0050 OPERATOR: LOSKOT
NOMINAL TEMPERATURE: 25 C DRYBULB TEMPERATURE: 25.01 C
Drybulb Reference: 0.3306E+01 +/- 0.78E-04 V
Drybulb Voltage: -.3304E-03 +/- 0.31E-06 V
Actual temperature from SPRT: 24.985 C
Sample size: 51 Delta Intercept: -1.131 microvolts

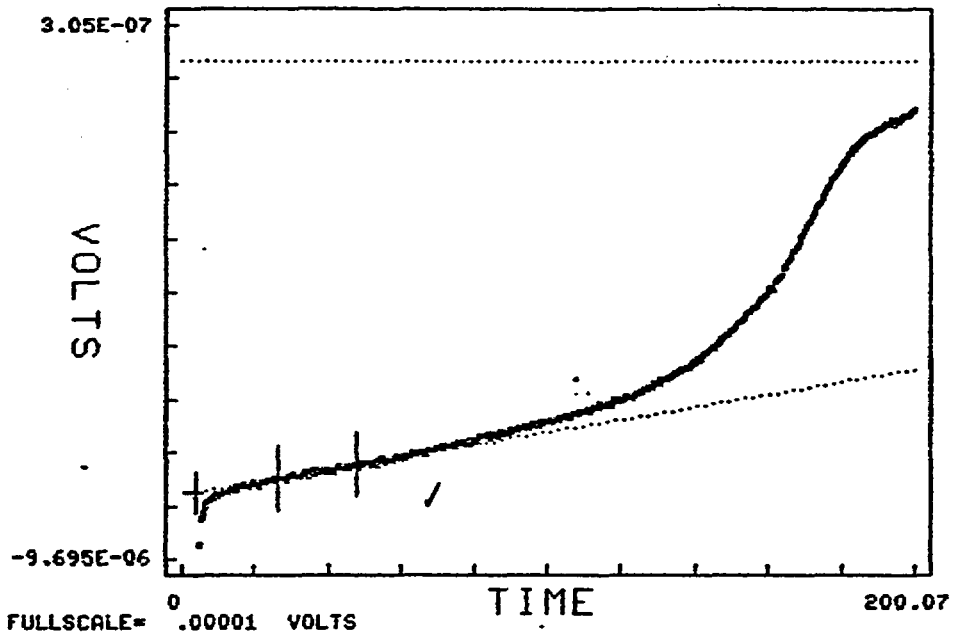
10-10-1988 03:24:16
USGS Computer Program TCPCAL.BAS; Version 1.010 for QA Level III only
Technical Contact: Mark Kurzmack

0.4m ⑧

23°C

Voltmeter Zero Determination
Number of measurements is 30
Mean output voltage is -3.691E-07
Standard deviation of the output voltage is 1.764076E-08
Intercept is -3.673446E-07 Sigma is 6.712828E-09
Slope is -1.132427E-10 Sigma is 3.78125E-10
Correlation coefficient (r^2): 0.003

Voltage output during current generation
Number of measurements is 37
Mean output voltage is -.034551
Standard deviation of the output voltage is 1.192895E-06
Intercept is -3.455271E-02 Sigma is 5.8006E-09
Slope is 9.412483E-08 Sigma is 2.761154E-10
Correlation coefficient (r^2): -0.005



Datafile name: B:\TCPDAT\TCP33.DAT DISK NUMBER: 143
MEAN ZERO TIME VOLTAGE: -3.691E-07 VOLTS
COOLING TIME: 40 Sec COOLING CURRENT: 5 mA
SOLUTION BATCH NUMBER: A-0.4m MOLALITY: .4 M
TCP SERIAL NUMBER: A8-0050 OPERATOR: Loskot
NOMINAL TEMPERATURE: 23 C DRYBULB TEMPERATURE: 23.07 C
Actual temperature from SPRT: 23.005 C
Sample size: 44 Delta Intercept: -8.077 microvolts

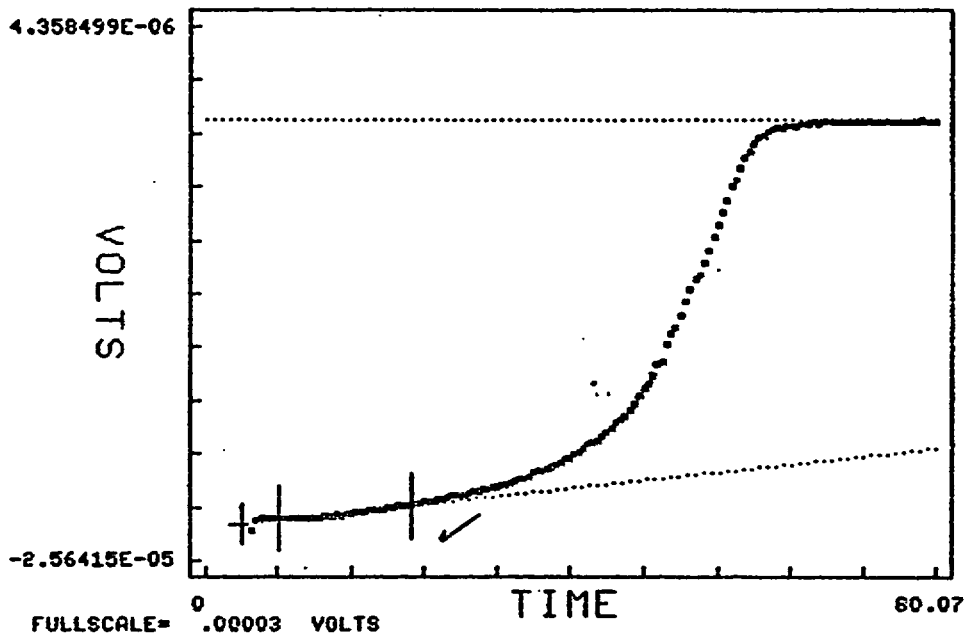
09-08-1988 08:42:53
USGS Computer Program TCPCAL.BAS; Version 1.009 for QA Level III only
Technical Contact: Mark Kurzmack

1.1m
25°C

(9)

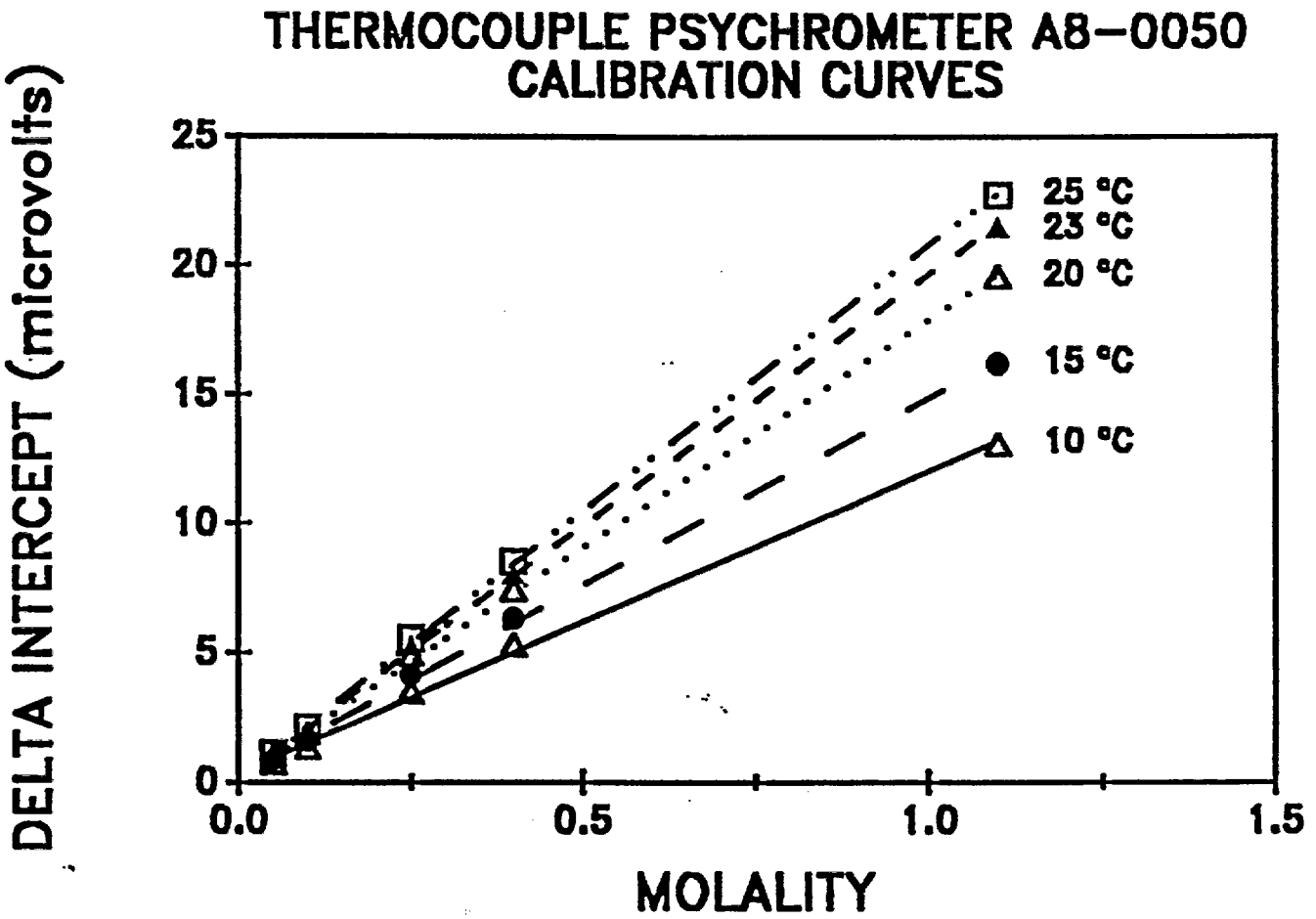
Voltmeter Zero Determination
Number of measurements is 30
Mean output voltage is -9.201667E-07
Standard deviation of the output voltage is 2.12734E-08
Intercept is -9.240672E-07 Sigma is 8.061043E-09
Slope is 2.516332E-10 Sigma is 4.540582E-10
Correlation coefficient (r^2): 0.011

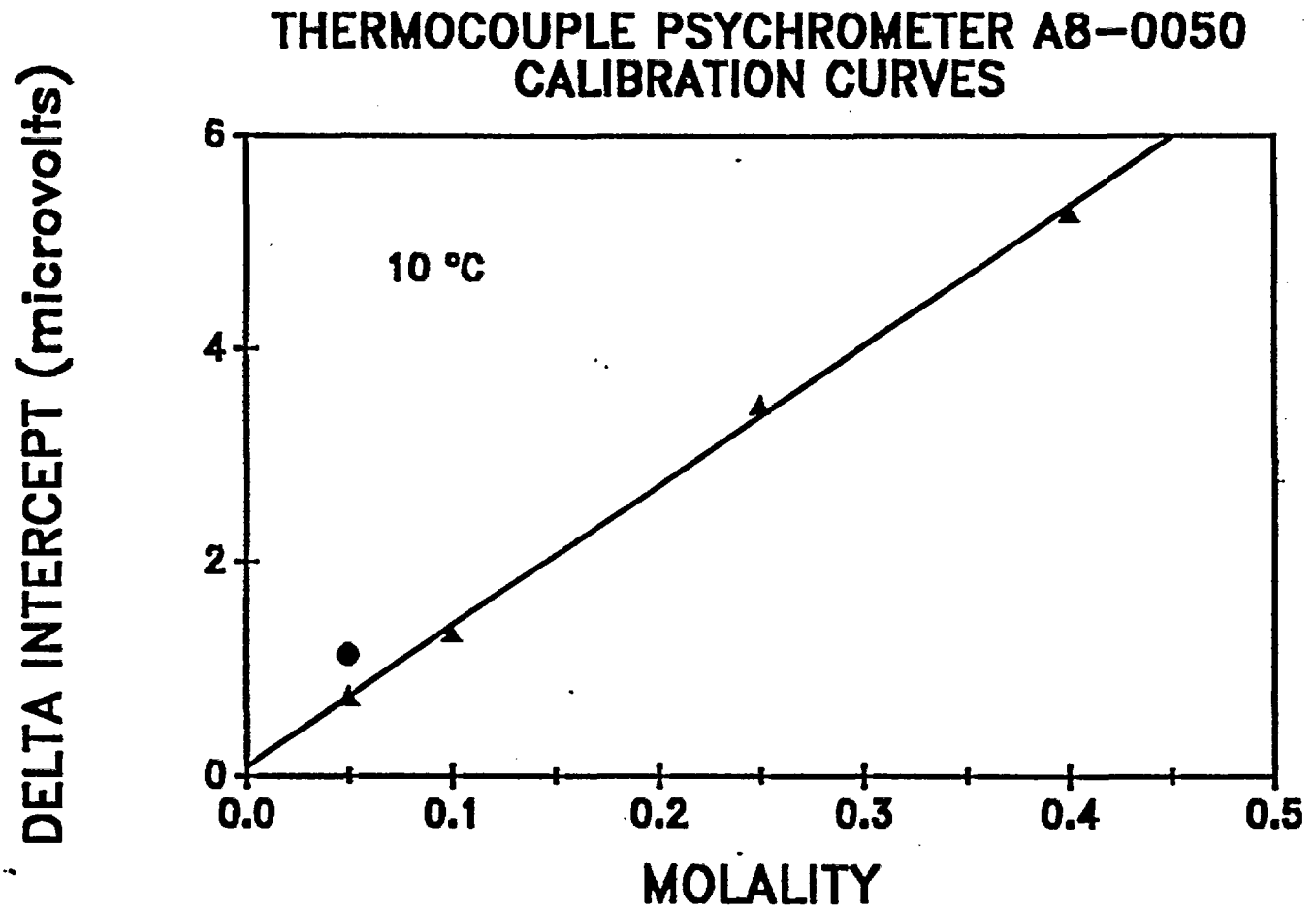
Voltage output during current generation
Number of measurements is 57
Mean output voltage is -3.517218E-02
Standard deviation of the output voltage is 5.206195E-07
Intercept is -3.517242E-02 Sigma is 5.431664E-06
Slope is 8.626824E-09 Sigma is 1.668364E-07
Correlation coefficient (r^2): 3.865E-05

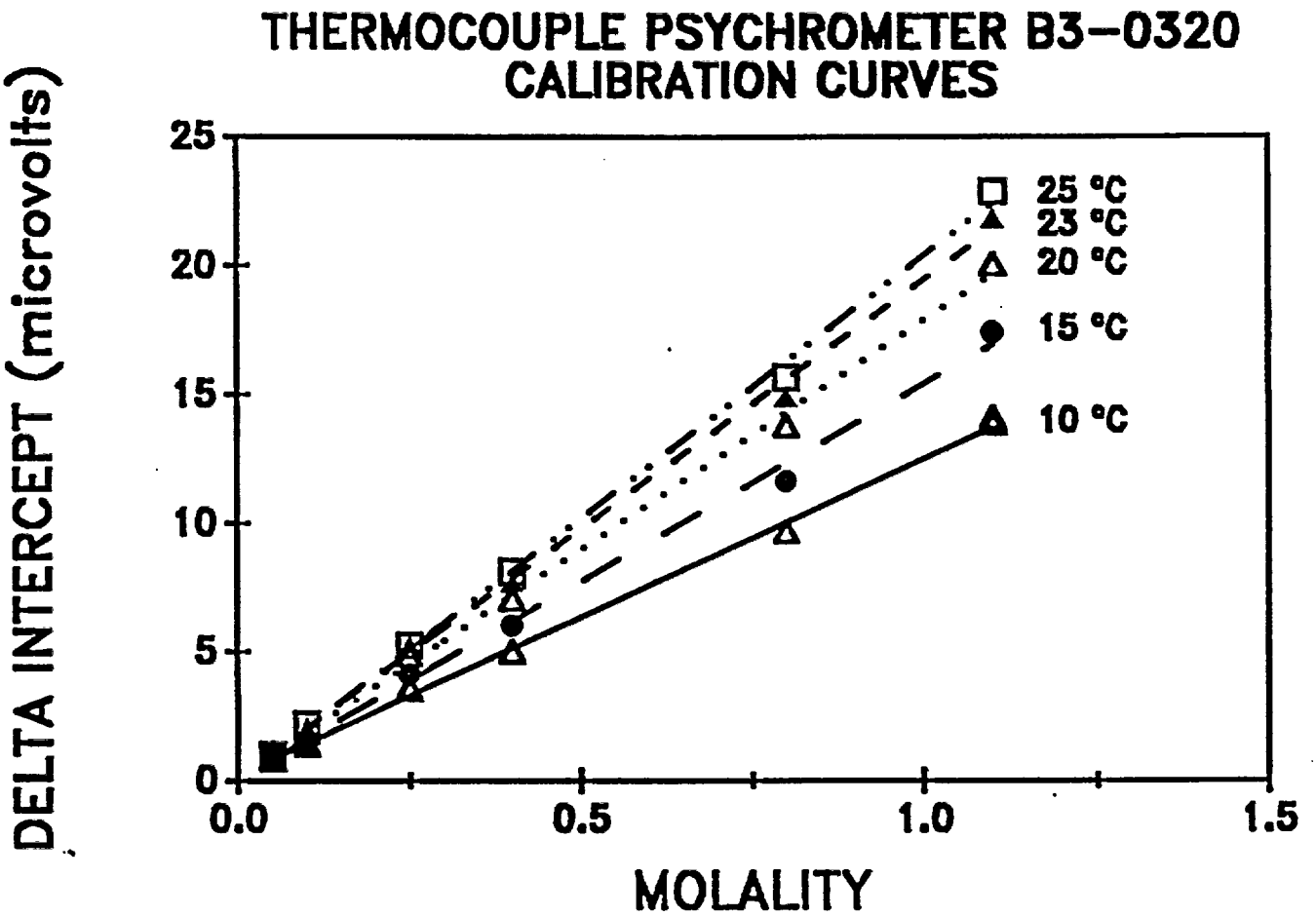


Datafile name: B:\TCPDAT\TCP138.DAT DISK NUMBER: 156
MEAN ZERO TIME VOLTAGE: -9.201667E-07 VOLTS
COOLING TIME: 60 Sec COOLING CURRENT: 5 mA
SOLUTION BATCH NUMBER: A-1.1m MOLALITY: 1.1 M
TCP SERIAL NUMBER: A8-0050 OPERATOR: LOSKOT
NOMINAL TEMPERATURE: 25 C DRYBULB TEMPERATURE: 25.07 C
Drybulb Reference: 0.3270E+01 +/- 0.15E-03 V
Drybulb Voltage: -.3130E-03 +/- 0.71E-06 V
Actual temperature from SPRT: 24.992 C
Sample size: 30 Delta Intercept: -22.699 microvolts

10-13-1988 00:38:04
USGS Computer Program TCPCAL.BAS; Version 1.010 for QA Level III only
Technical Contact: Mark Kurzmack


THERMOCOUPLE PSYCHROMETER A8–0050
CALIBRATION CURVES
DELTA INTERCEPT (microvolts)
25
20
15
10
5
0
0.0
0.5
1.0
1.5
MOLALITY
25 °C
23 °C
20 °C
15 °C
10 °C


THERMOCOUPLE PSYCHROMETER A8–0050
CALIBRATION CURVES
DELTA INTERCEPT (microvolts)
10 °C
6
4
2
0
0.0
0.1
0.2
0.3
0.4
0.5
MOLALITY


THERMOCOUPLE PSYCHROMETER B3–0320
CALIBRATION CURVES
DELTA INTERCEPT (microvolts)
25
20
15
10
5
0
0.0
0.5
1.0
1.5
MOLALITY
25 °C
23 °C
20 °C
15 °C
10 °C

PSYCHROMETER B3-0320

Curve	Treat-ment	Zero voltage (uv)	Delta intercept (uv)	Mean delta intercept (uv)	SPRT temp (deg C)	Dry bulb temp (deg C)	Molality	Bar equiv-alents*
	1	-1.5388	-0.8162		10.003	10.17	0.05	-2.22
A	1	-1.5473	-0.8922	-0.8484	10.004	10.22	0.05	-2.22
	1	-1.6296	-0.8368		10.004	10.12	0.05	-2.22
	2	-0.4662	-1.4363		9.999	10.11	0.1	-4.39
A	2	-0.3823	-1.3823	-1.4003	9.999	10.16	0.1	-4.39
	2	-0.4356	-1.3845		9.999	10.20	0.1	-4.39
	3	-2.2377	-3.5275		10.001	10.20	0.25	-10.90
A	3	-2.5933	-3.5589	-3.5348	10.002	10.21	0.25	-10.90
	3	-2.8062	-3.5180		10.003	10.21	0.25	-10.90
	4	-0.3445	-4.9714		10.002	10.18	0.4	-17.27
A	4	-0.3676	-4.9929	-4.9908	10.002	10.20	0.4	-17.27
	4	-0.3488	-5.0081		10.002	10.13	0.4	-17.27
	5	-2.5145	-9.6470		10.001	10.24	0.8	-34.72
A	5	-2.5217	-9.6783	-9.6577	10.000	10.20	0.8	-34.72
	5	-2.5445	-9.6479		10.001	10.17	0.8	-34.72
	6	-1.2012	-13.8459		10.002	10.26	1.1	-48.20
A	6	-1.1845	-14.0631	-13.9963	10.002	10.26	1.1	-48.20
	6	-1.1793	-14.0800		10.002	10.14	1.1	-48.20
		[SPRT temperature average = 10.0016 deg C, +/-0.0026]						
	1	-1.7354	-1.0483		15.001	15.16	0.05	-2.26
B	1	-1.4655	-0.9477	-0.9904	15.001	15.16	0.05	-2.26
	1	-1.4385	-0.9751		15.001	15.17	0.05	-2.26
	2	0.0317	-1.5702		15.001	15.23	0.1	-4.47
B	2	-0.1914	-1.4805	-1.5316	15.001	15.10	0.1	-4.47
	2	-0.0786	-1.5441		15.000	15.07	0.1	-4.47
	3	-2.1022	-4.1218		15.000	15.17	0.25	-11.10
B	3	-1.9517	-4.1756	-4.1571	14.999	15.12	0.25	-11.10
	3	-1.9294	-4.1739		14.998	15.11	0.25	-11.10
	4	-0.0722	-6.0142		15.000	15.17	0.4	-17.59
B	4	-0.0300	-6.0432	-6.0373	15.001	15.16	0.4	-17.59
	4	-0.0461	-6.0544		15.000	15.14	0.4	-17.59
	5	-0.6876	-11.6225		15.000	15.26	0.8	-35.43
B	5	-0.7291	-11.6820	-11.6465	15.000	15.24	0.8	-35.43
	5	-0.7135	-11.6349		15.001	15.21	0.8	-35.43
	6	0.3525	-17.3264		15.001	15.23	1.1	-49.24
B	6	0.3946	-17.4581	-17.4103	15.000	15.20	1.1	-49.24
	6	0.3803	-17.4464		15.001	15.14	1.1	-49.24
		[SPRT temperature average = 15.0003 deg C, +/-0.0023]						

PSYCHROMETER B3-0320

Curve	Treatment	Zero voltage (uv)	Delta intercept (uv)	Mean delta intercept (uv)	SPRT temp (deg C)	Dry bulb temp (deg C)	Molality	Bar equivalents*
	1	-1.0548	-1.0691		19.999	20.07	0.05	-2.30
C	1	-1.0251	-1.1242	-1.0698	20.000	20.15	0.05	-2.30
	1	-1.0158	-1.0135		20.000	20.14	0.05	-2.30
	2	-0.9420	-1.8379		20.000	20.22	0.1	-4.54
C	2	-0.7012	-1.8518	-1.8294	20.001	20.10	0.1	-4.54
	2	-0.6889	-1.7984		20.002	20.05	0.1	-4.54
	3	-1.3761	-4.8730		20.001	20.19	0.25	-11.29
C	3	-1.3338	-4.8514	-4.8521	20.001	20.22	0.25	-11.29
	3	-1.3626	-4.8318		20.000	20.22	0.25	-11.29
	4	-0.7659	-7.0511		20.002	20.15	0.4	-17.91
C	4	-0.7419	-7.0312	-7.0348	20.001	20.15	0.4	-17.91
	4	-0.7791	-7.0221		20.001	20.13	0.4	-17.91
	5	-0.6176	-13.7890		20.002	20.15	0.8	-36.12
C	5	-0.6256	-13.7439	-13.7784	20.002	20.20	0.8	-36.12
	5	-0.7486	-13.8022		20.001	20.12	0.8	-36.12
	6	0.7570	-19.8479		20.002	20.16	1.1	-50.26
C	6	0.7175	-20.1090	-20.0394	20.002	20.12	1.1	-50.26
	6	0.6944	-20.1614		20.002	20.20	1.1	-50.26
		[SPRT temperature average = 20.0010 deg C, +/-0.0020]						
	1	-0.7976	-1.1567		23.000	23.09	0.05	-2.32
D	1	-1.0368	-1.1133	-1.1409	23.000	23.13	0.05	-2.32
	1	-1.1004	-1.1527		23.000	23.09	0.05	-2.32
	2	0.7054	-2.0383		23.002	23.13	0.1	-4.59
D	2	0.6628	-2.0316	-2.0295	23.001	23.11	0.1	-4.59
	2	0.5983	-2.0186		23.001	23.08	0.1	-4.59
	3	-1.1430	-5.2807		23.000	23.10	0.25	-11.40
D	3	-1.4441	-5.2750	-5.2950	23.000	23.16	0.25	-11.40
	3	-1.5083	-5.3292		23.000	23.11	0.25	-11.40
	4	-0.3413	-7.6895		23.000	23.09	0.4	-18.10
D	4	-0.6052	-7.7186	-7.7035	23.000	23.14	0.4	-18.10
	4	-0.6564	-7.7024		23.000	23.21	0.4	-18.10
	5	-0.9032	-14.9594		23.001	23.16	0.8	-36.54
D	5	-0.8603	-14.9142	-14.9187	23.001	23.16	0.8	-36.54
	5	-0.8483	-14.8824		23.001	23.16	0.8	-36.54
	6	-1.5643	-21.6327		23.001	23.15	1.1	-50.87
D	6	-1.7562	-21.9597	-21.8272	23.001	23.15	1.1	-50.87
	6	-1.8696	-21.8891		23.002	23.14	1.1	-50.47
		[SPRT temperature average = 23.0006 deg C, +/-0.0014]						

- PSYCHROMETER B3-0320

Curve	Treat-ment	Zero voltage (uv)	Delta intercept (uv)	Mean delta intercept (uv)	SPRT temp (deg C)	Dry bulb temp (deg C)	Molality	Bar equiv-alents*
	1	-0.6564	-1.1908		24.999	25.14	0.05	-2.34
E	1	-0.5576	-0.8120	-0.9764	25.000	25.11	0.05	-2.34
	1	-0.9472	-1.0204		24.999	25.17	0.05	-2.34
	2	0.7923	-2.1862		25.001	25.15	0.1	-4.62
E	2	0.7693	-2.1930	-2.1832	25.002	25.22	0.1	-4.62
	2	0.7368	-2.1704		25.002	25.13	0.1	-4.62
	3	-0.8364	-5.6315		25.002	25.15	0.25	-11.48
E	3	-0.7944	-5.5020	-5.220	25.002	25.19	0.25	-11.48
	3	-0.7619	-5.4324		25.003	25.11	0.25	-11.48
	4	-0.3665	-8.1476		25.001	25.21	0.4	-18.23
E	4	-0.5280	-8.1073	-8.1220	25.001	25.13	0.4	-18.23
	4	-0.5728	-8.1112		25.001	25.07	0.4	-18.23
	5	-0.3780	-15.6549		25.001	25.17	0.8	-36.82
E	5	-0.4559	-15.6616	-15.6532	25.002	25.19	0.8	-36.82
	5	-0.5139	-15.6432		25.002	25.22	0.8	-36.82
	6	-0.9624	-22.6980		25.002	25.22	1.1	-51.27
E	6	-1.0247	-22.8939	-22.8548	25.001	25.15	1.1	-51.27
	6	-1.0635	-22.9725		25.001	25.13	1.1	-51.27

[SPRT temperature average = 25.0012 deg C, +/-0.0022]

[* Based on SPRT temperatures]

PSYCHROMETER A8-0050

Curve	Treatment	Zero voltage (uv)	Delta intercept (uv)	Mean delta intercept (uv)	SPRT temp (deg C)	Dry bulb temp (deg C)	Molality	Bar equivalents
	1a	-8.2398	-1.1106		10.249	10.60	0.05	-2.22
A	1a	-8.0580	-1.0992	-1.1337	10.249	10.57	0.05	-2.22
	1a	-9.5497	-1.1913		10.248	10.56	0.05	-2.22
	1b	-1.8813	-0.7627		10.250	10.43	0.05	-2.22
A	1b	-2.1599	-0.7637	-0.7502	10.250	10.44	0.05	-2.22
	1b	-2.2151	-0.7243		10.250	10.45	0.05	-2.22
	2	-1.4682	-1.3478		10.251	10.38	0.1	-4.39
A	2	-1.6472	-1.3523	-1.3432	10.249	10.36	0.1	-4.39
	2	-1.6700	-1.3296		10.249	10.41	0.1	-4.39
	3	-1.8380	-3.4318		10.169	10.34	0.25	-10.91
A	3	-2.1342	-3.5054	-3.4717	10.169	10.29	0.25	-10.91
	3	-2.1816	-3.4779		10.169	10.30	0.25	-10.91
	4	-1.9125	-5.2912		10.253	10.39	0.4	-17.29
A	4	-2.0721	-5.2487	-5.2805	10.253	10.43	0.4	-17.29
	4	-2.1105	-5.3015		10.252	10.41	0.4	-17.29
	5	-1.3111	-12.9771		10.259	10.43	1.1	-48.25
A	5	-1.3241	-13.0675	-13.0286	10.258	10.38	1.1	-48.25
	5	-1.3338	-13.0413		10.259	10.41	1.1	-48.25
	[SPRT temperature average = 10.2331 deg C, +/-0.0691]							
	1a	-7.6697	-1.2631		15.202	15.46	0.05	-2.26
B	1a	-7.9220	-1.2802	-1.2749	15.202	15.49	0.05	-2.26
	1a	-7.9873	-1.3342		15.202	15.45	0.05	-2.26
	1a	-7.7930	-1.2219		15.202	15.50	0.05	-2.26
	1b	-1.6920	-0.8535		15.204	15.37	0.05	-2.26
B	1b	-1.7789	-0.8730	-0.8788	15.204	15.37	0.05	-2.26
	1b	-1.8377	-0.9100		15.204	15.28	0.05	-2.26
	2	-1.0967	-1.5622		15.204	15.31	0.1	-4.47
B	2	-1.0853	-1.6233	-1.5927	15.204	15.36	0.1	-4.47
	2	-0.9795	-1.5925		15.205	15.31	0.1	-4.47
	3	-1.2351	-4.2128		15.172	15.38	0.25	-11.11
B	3	-1.2236	-4.1722	-4.1680	15.172	15.28	0.25	-11.11
	3	-1.3053	-4.1190		15.173	15.29	0.25	-11.11
	4	-0.9882	-6.2936		15.209	15.35	0.4	-17.60
B	4	-0.9985	-6.3043	-6.3072	15.209	15.33	0.4	-17.60
	4	-1.0318	-6.3237		15.208	15.33	0.4	-17.60
	5	-1.3168	-16.1533		15.220	15.28	1.1	-48.25
B	5	-1.3857	-16.2163	-16.1856	15.220	15.35	1.1	-48.25
	5	-1.4157	-16,1872		15.220	15.28	1.1	-48.25
	[SPRT temperature average = 15.2019 deg C, +/-0.0299]							

PSYCHROMETER A8-0050

Curve	Treatment	Zero voltage (uv)	Delta intercept (uv)	Mean delta intercept (uv)	SPRT temp (deg C)	Dry bulb temp (deg C)	Molality	Bar equivalents*
	1a	-7.4244	-1.4231		20.078	20.32	0.05	-2.30
C	1a	-7.4257	-1.3970	-1.4152	20.078	20.30	0.05	-2.30
	1a	-7.2346	-1.4254		20.079	20.33	0.05	-2.30
	1b	-1.2049	-0.9439		20.081	20.22	0.05	-2.30
C	1b	-1.1870	-1.0140	-0.9969	20.081	20.21	0.05	-2.30
	1b	-1.1808	-1.0329		20.081	20.23	0.05	-2.30
	2	-0.5570	-1.8419		20.082	20.20	0.1	-4.54
C	2	-0.5558	-1.8764	-1.8698	20.083	20.12	0.1	-4.54
	2	-0.6800	-1.8911		20.083	20.16	0.1	-4.54
	3	-1.0955	-4.8358		20.085	20.21	0.25	-11.29
C	3	-1.2387	-4.9234	-4.8831	20.083	20.24	0.25	-11.29
	3	-1.3268	-4.8900		20.084	20.21	0.25	-11.29
	4	-1.0877	-7.4061		20.084	20.21	0.4	-17.92
C	4	-1.1821	-7.3803	-7.4073	20.084	20.18	0.4	-17.92
	4	-1.2192	-7.4356		20.083	20.19	0.4	-17.92
	5	-0.8613	-19.5125		20.089	20.21	1.1	-50.28
C	5	-0.8558	-19.4798	-19.5219	20.089	20.25	1.1	-50.28
	5	-0.8615	-19.5733		20.088	20.25	1.1	-50.28
	[SPRT temperature average = 20.0831 deg C, +/-0.0059]							
	1a	-5.5652	-1.3776		22.999	23.20	0.05	-2.32
D	1a	-5.7767	-1.3950	-1.4208	22.999	23.21	0.05	-2.32
	1a	-6.4251	-1.4899		22.999	23.19	0.05	-2.32
	1b	-1.1264	-1.0412		23.002	23.06	0.05	-2.32
D	1b	-1.2211	-0.9709	-1.0789	23.001	23.07	0.05	-2.32
	1b	-1.2141	-1.0902		23.001	23.11	0.05	-2.32
	1b	-1.2452	-1.2132		22.999	23.21	0.05	-2.32
	2	-0.5659	-1.9715		23.002	23.07	0.1	-4.59
D	2	-0.2685	-1.9509	-1.9612	23.003	23.13	0.1	-4.59
	3	-0.6664	-5.3290		23.003	23.08	0.25	-11.40
D	3	-0.6886	-5.1729	-5.2584	23.003	23.17	0.25	-11.40
	3	-0.6923	-5.2734		23.002	23.15	0.25	-11.40
	4	-0.3691	-8.0772		23.005	23.07	0.4	-18.10
D	4	-0.3156	-7.9947	-8.0379	23.005	23.06	0.4	-18.10
	4	-0.1776	-8.0418		23.005	23.07	0.4	-18.10
	5	-0.7050	-21.4765		23.019	23.10	1.1	-50.87
D	5	-0.7313	-21.4021	-21.4728	23.019	23.14	1.1	-50.87
	5	-0.8762	-21.5398		23.018	23.10	1.1	-50.87
	[SPRT temperature average = 23.0047 deg C, +/-0.0143]							

- PSYCHROMETER A8-0050

Curve	Treat-ment	Zero voltage (uv)	Delta intercept (uv)	Mean delta intercept (uv)	SPRT temp (deg C)	Dry bulb temp (deg C)	Molality	Bar equiv-alents*
	1a	-5.2052	-1.4963		24.980	25.20	0.05	-2.34
E	1a	-4.6157	-1.3631	-1.4021	24.978	25.13	0.05	-2.34
	1a	-4.1275	-1.3470		24.978	25.15	0.05	-2.34
	1b	-1.0564	-1.1005		24.986	25.15	0.05	-2.34
E	1b	-1.0740	-1.1028	-1.1115	24.986	25.18	0.05	-2.34
	1b	-1.0579	-1.1313		24.986	25.01	0.05	-2.34
	2	-0.0797	-2.0893		24.984	25.07	0.1	-4.62
E	2	0.0345	-2.1181	-2.1264	24.983	25.03	0.1	-4.62
	2	-0.1289	-2.1719		24.982	25.11	0.1	-4.62
	3	-0.7666	-5.5384		24.988	25.04	0.25	-11.48
E	3	-0.9067	-5.4898	-5.5249	24.988	25.15	0.25	-11.48
	3	-0.9297	-5.5466		24.988	25.13	0.25	-11.48
	4	-0.6859	-8.4530		24.985	25.10	0.4	-18.23
E	4	-0.7318	-8.5543	-8.4943	24.985	25.06	0.4	-18.23
	4	-0.1864	-8.4756		24.986	25.06	0.4	-18.23
	5	-0.8779	-22.7611		24.993	25.07	1.1	-51.27
E	5	-0.9202	-22.6989	-22.7322	24.992	25.07	1.1	-51.27
	5	-0.9305	-22.7611		24.993	25.05	1.1	-51.27

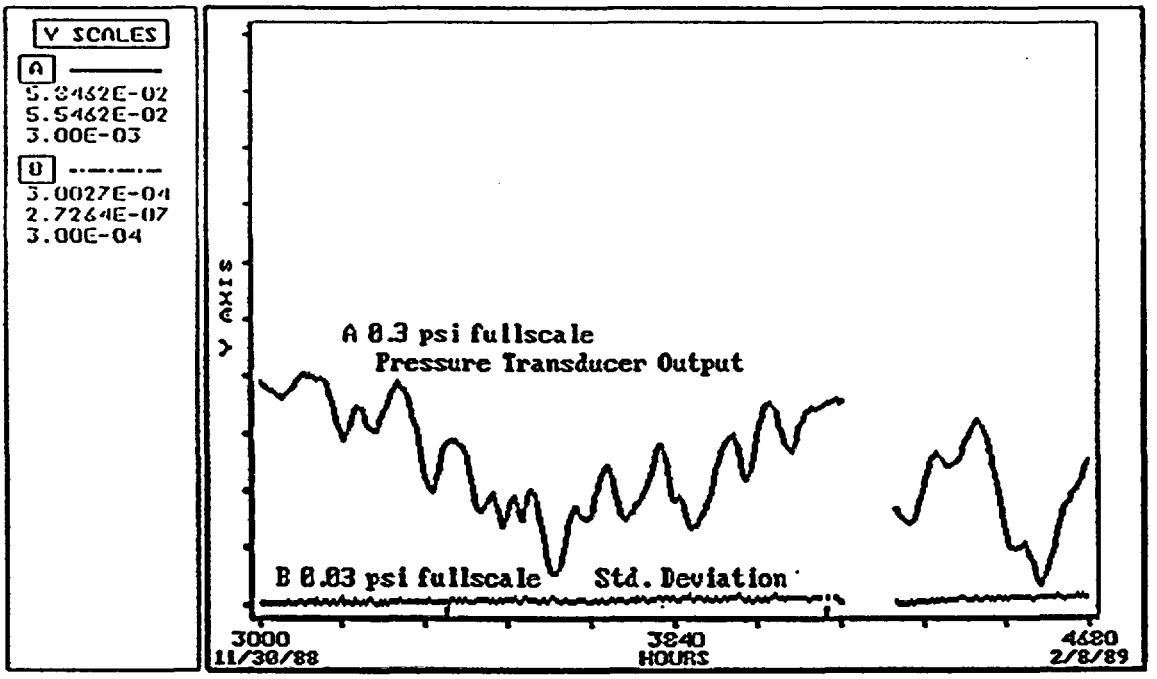
[SPRT temperature average = 24.9856 deg C, +/-0.0076]

[* Based on SPRT temperatures]

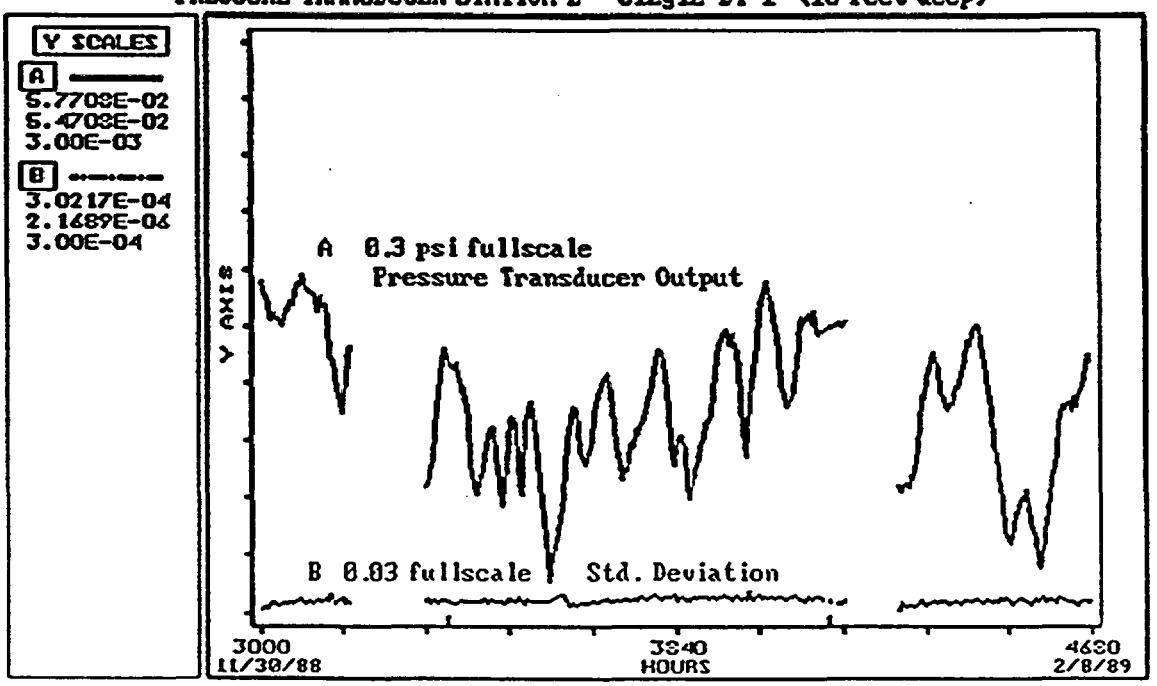
Estimated Time Schedule for Psychrometer Calibration

Molality	Temperature (deg C)	Equilibrium time (hrs)	Delay time between cycles (hrs)	Time per 3 cycles (hrs)	Total run time (hrs)	Total per time run (hrs)
0.02 m	10	12:00	2:30	5:00	10:00	22:00
	15	8:00	2:00	5:00	9:00	17:00
	20	4:00	1:40	5:00	8:00	12:00
	23	3:00	1:20	5:00	7:00	10:00
	25	2:00	1:00	5:00	6:30	8:30
	estimated time to clean and dry psychrometers for next run					4:00
					Total time	73:30
0.05 m	10	12:00	2:30	5:00	10:00	22:00
	15	8:00	2:00	5:00	9:00	17:00
	20	4:00	1:40	5:00	8:00	12:00
	23	3:00	1:20	5:00	7:00	10:00
	25	2:00	1:00	5:00	6:30	8:30
	estimated time to clean and dry psychrometers for next run					4:00
					Total time	73:30
0.1 m	10	12:00	2:30	5:00	10:00	22:00
	15	8:00	2:00	5:00	9:00	17:00
	20	4:00	1:40	5:00	8:00	12:00
	23	3:00	1:20	5:00	7:00	10:00
	25	2:00	1:00	5:00	6:30	8:30
	estimated time to clean and dry psychrometers for next run					4:00
					Total time	73:30
0.25 m	10	10:00	2:00	4:30	8:30	18:30
	15	6:00	1:45	4:30	8:00	14:00
	20	4:00	1:30	4:30	7:30	11:30
	23	3:00	1:15	4:30	7:00	10:00
	25	2:00	1:00	4:30	6:30	8:30
	estimated time to clean and dry psychrometers for next run					4:00
					Total time	66:30
0.4 m	10	10:00	1:30	4:30	7:30	17:30
	15	6:00	1:30	4:30	7:30	13:30
	20	3:00	1:15	4:30	7:00	10:00
	23	2:30	1:00	4:30	6:30	9:00
	25	2:00	1:00	4:30	6:30	8:30
	estimated time to clean and dry psychrometers for next run					4:00
					Total time	62:30
0.8 m	10	9:00	1:30	4:00	7:00	16:00
	15	5:00	1:15	4:00	6:30	11:30
	20	2:30	1:15	4:00	6:30	9:00
	23	2:00	1:00	4:00	6:00	8:00
	25	1:30	1:00	4:00	6:00	7:30
	estimated time to clean and dry psychrometers for next run					4:00
					Total time	56:00
1.1 m	10	9:00	1:30	3:30	6:30	15:30
	15	4:00	1:15	3:30	6:00	10:00
	20	2:00	1:15	3:30	6:00	8:00
	23	1:30	1:00	3:30	5:30	7:00
	25	1:30	1:00	3:30	5:30	7:00
	estimated time to clean and dry psychrometers for next run					4:00
					Total time	51:30

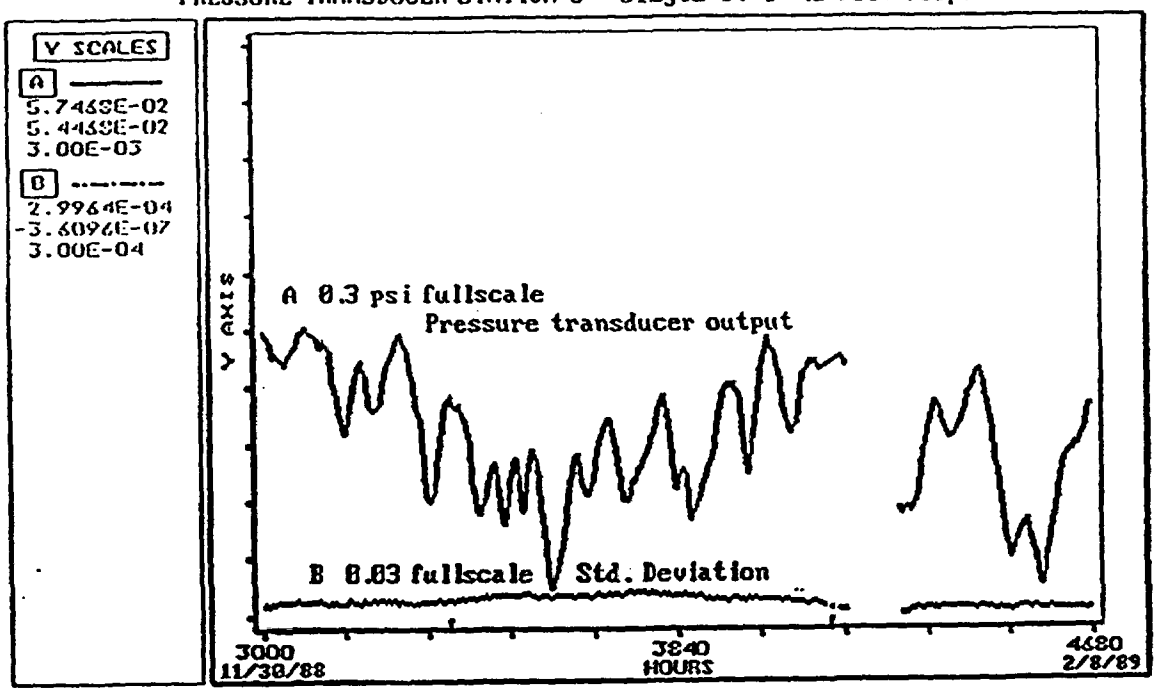
PRESSURE TRANSDUCER STATION A - U12g12-DI-1 (15 feet deep)



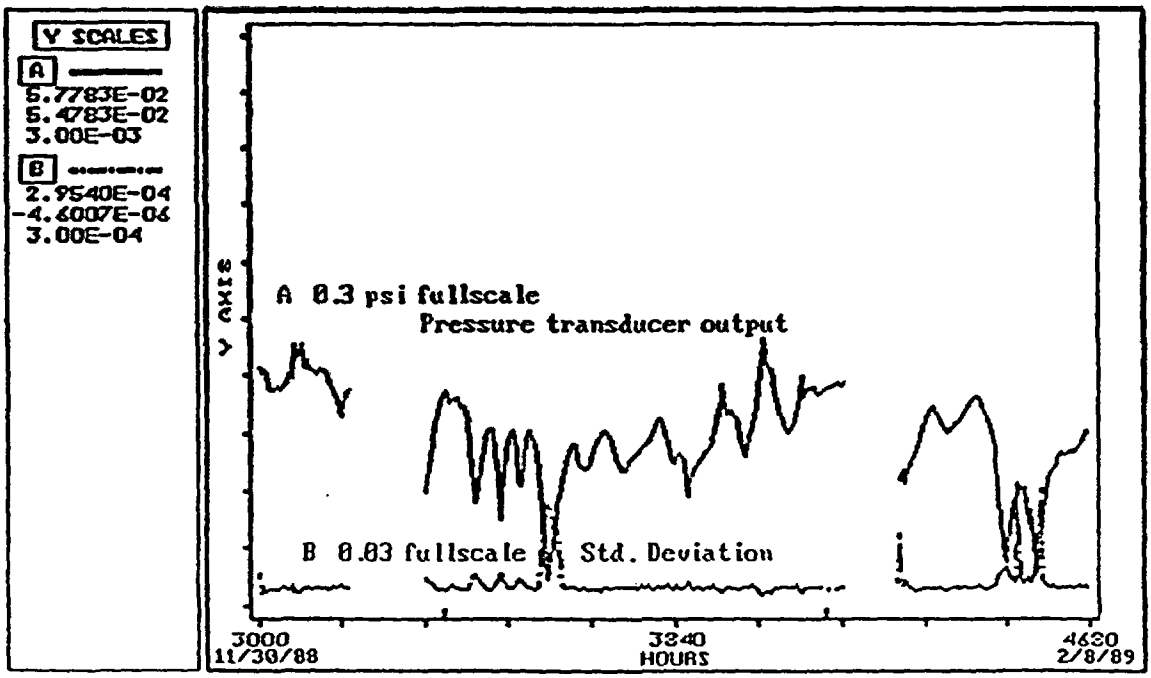
PRESSURE TRANSDUCER STATION B - U12g12-DI-1 (18 feet deep)



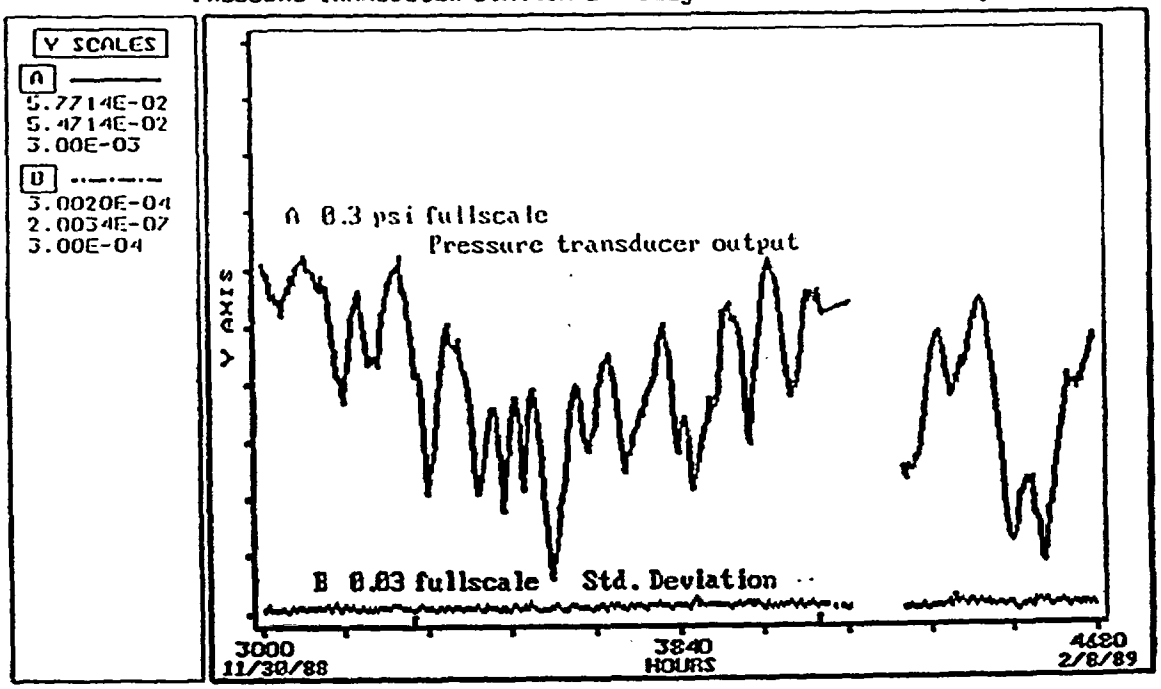
PRESSURE TRANSDUCER STATION C - U12g12-DI-1 (5 feet deep)



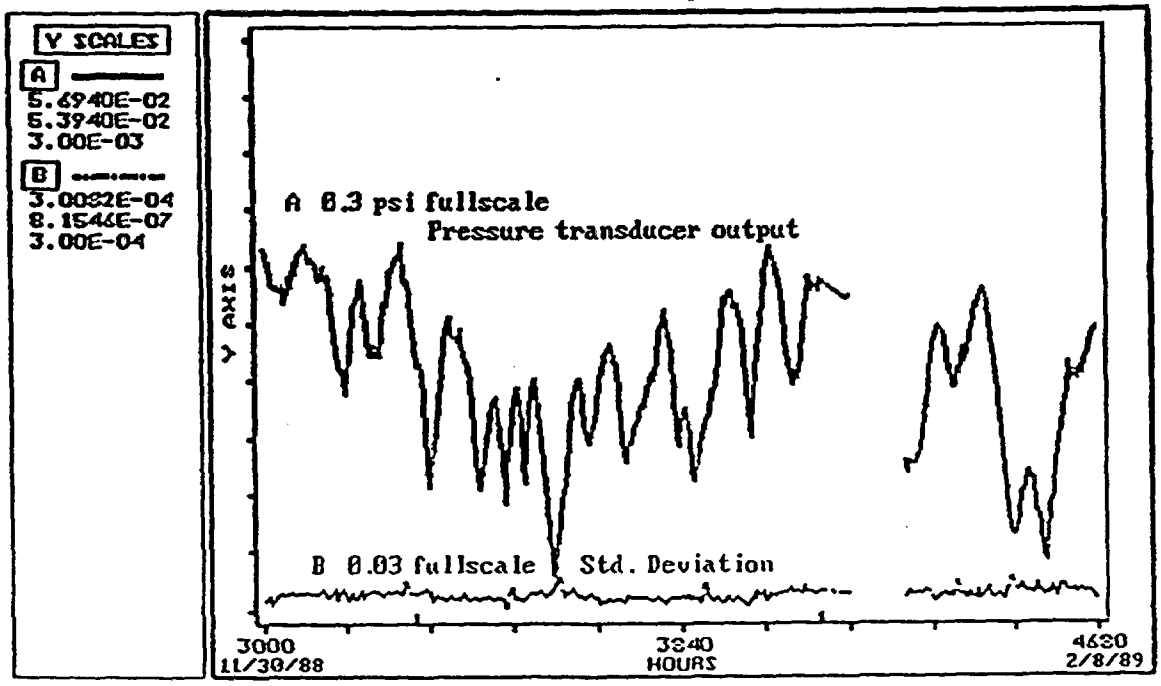
PRESSURE TRANSDUCER STATION D - U12g12-DI-2 (120 feet deep)



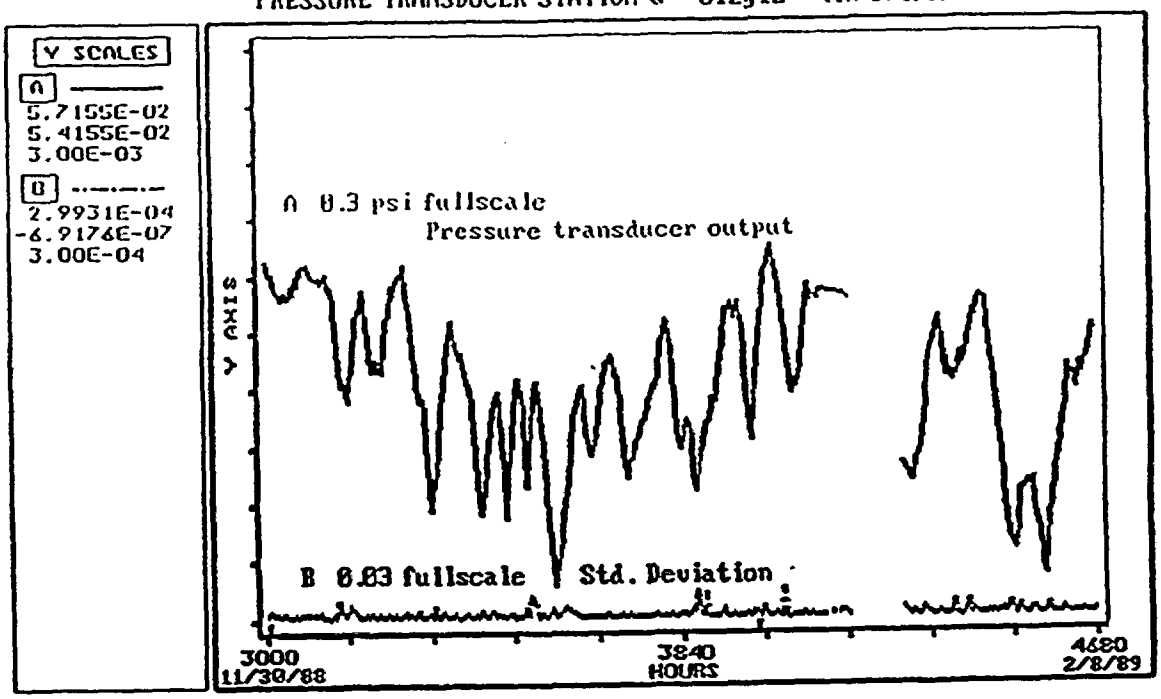
PRESSURE TRANSDUCER STATION E - U12g12-DI-2 (90 feet deep)



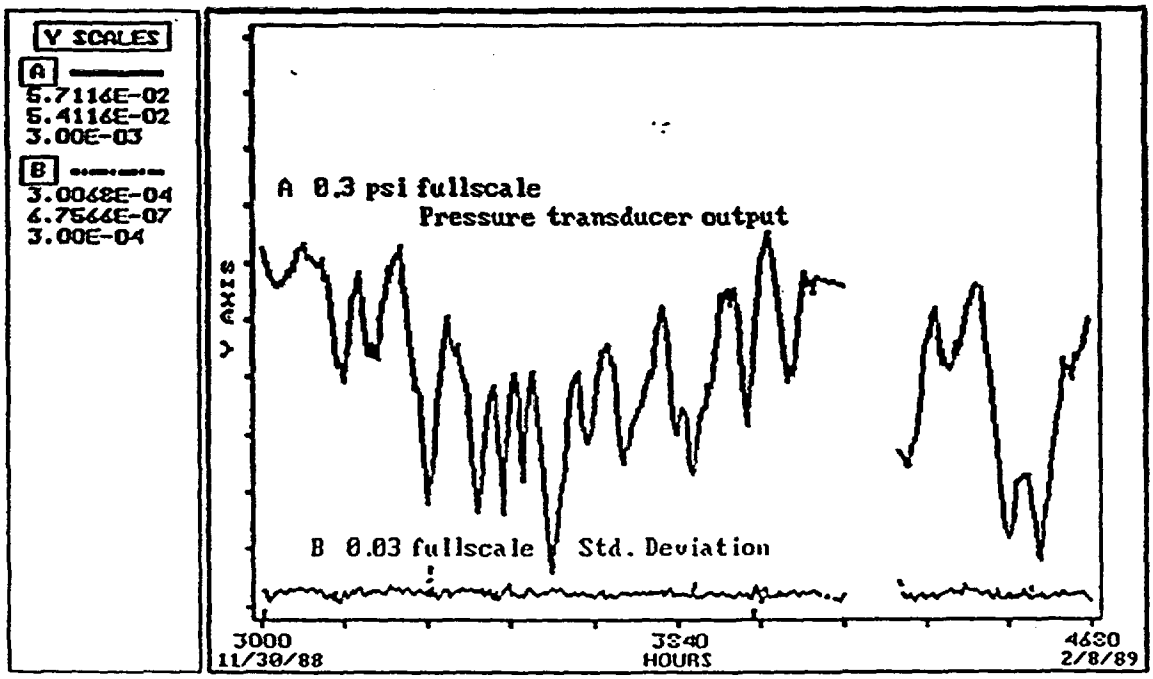
PRESSURE TRANSDUCER STATION F - U12g12-DI-2 (12 feet deep)



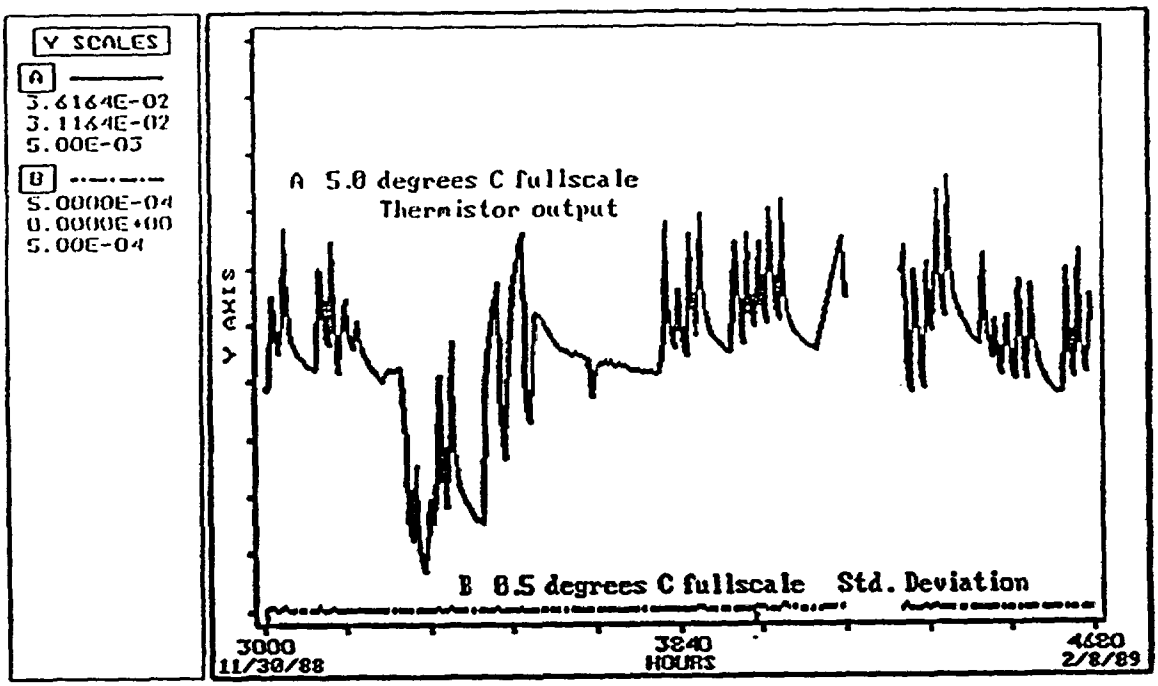
PRESSURE TRANSDUCER STATION G - U12g12 (In Drift)



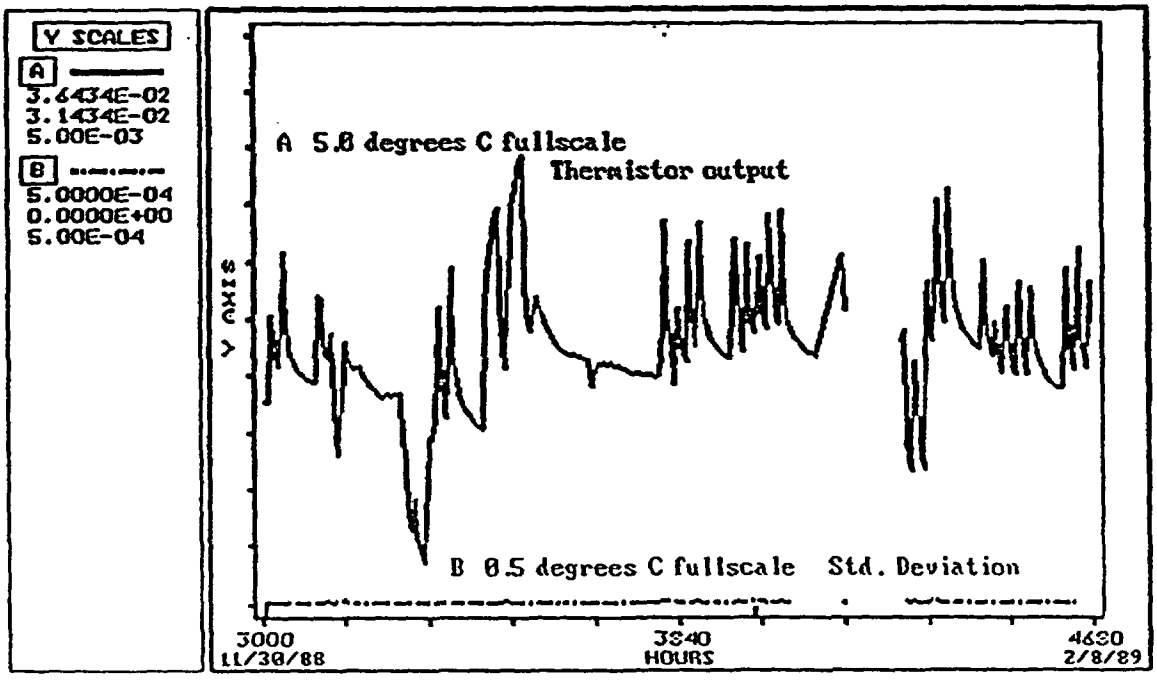
PRESSURE TRANSDUCER STATION H - U12g12 (In Drift)



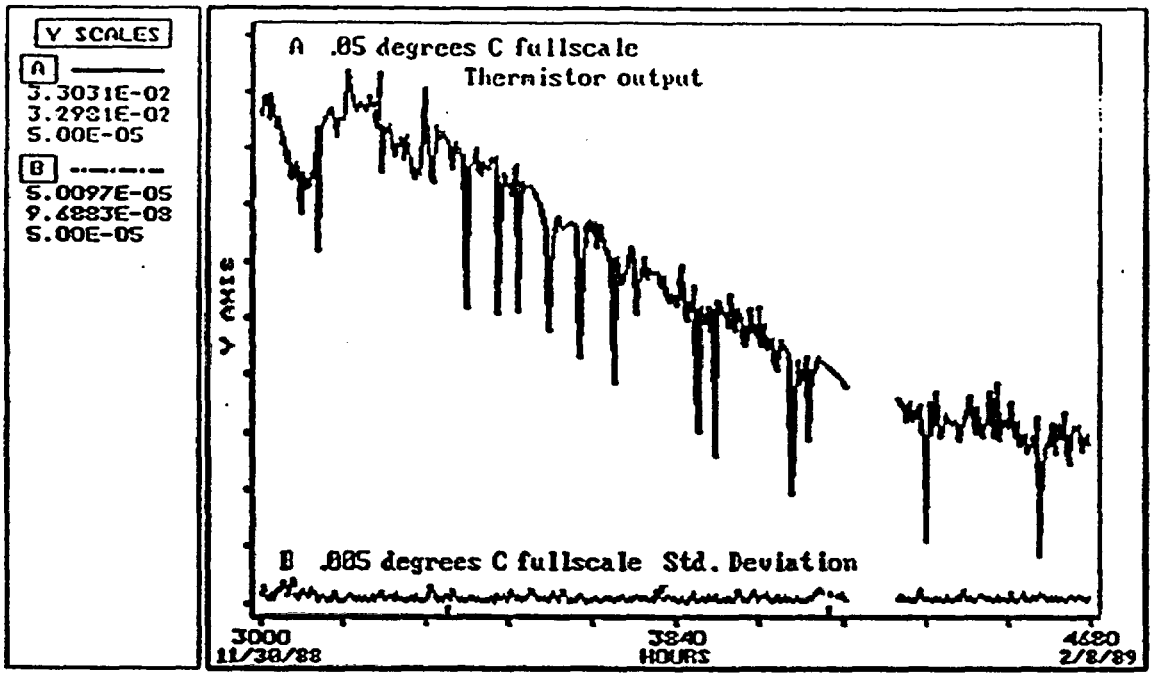
THERMISTOR STATION G - U12g12 (In Drift)



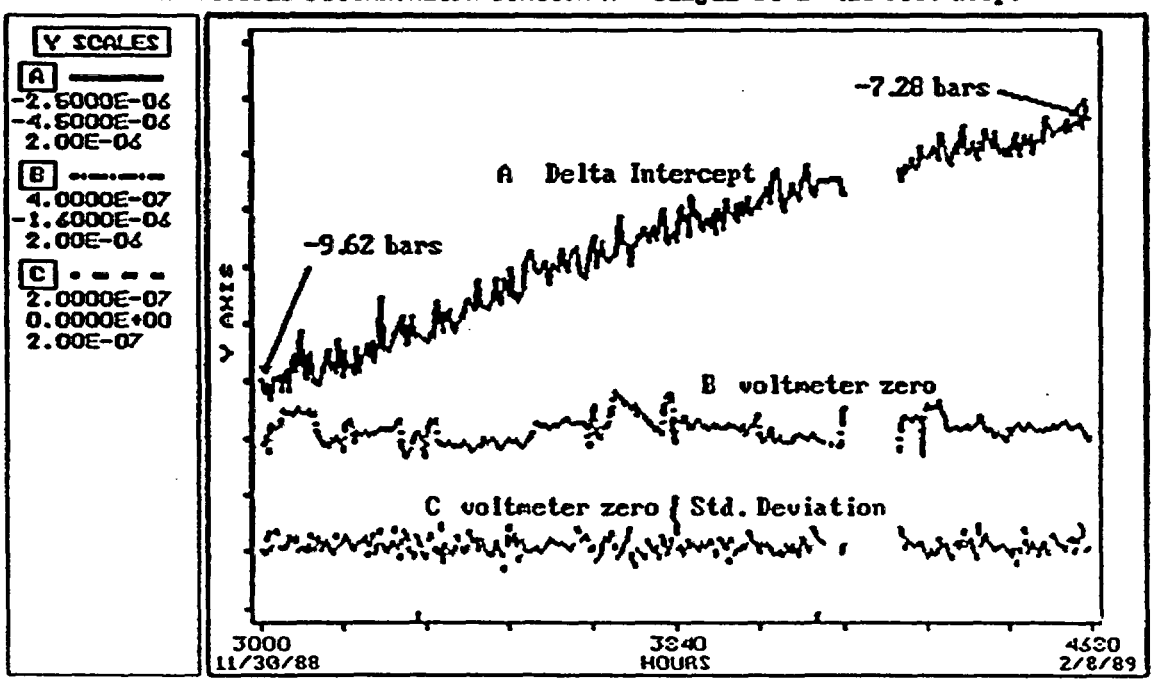
THERMISTOR STATION H - U12g12 (In Drift)



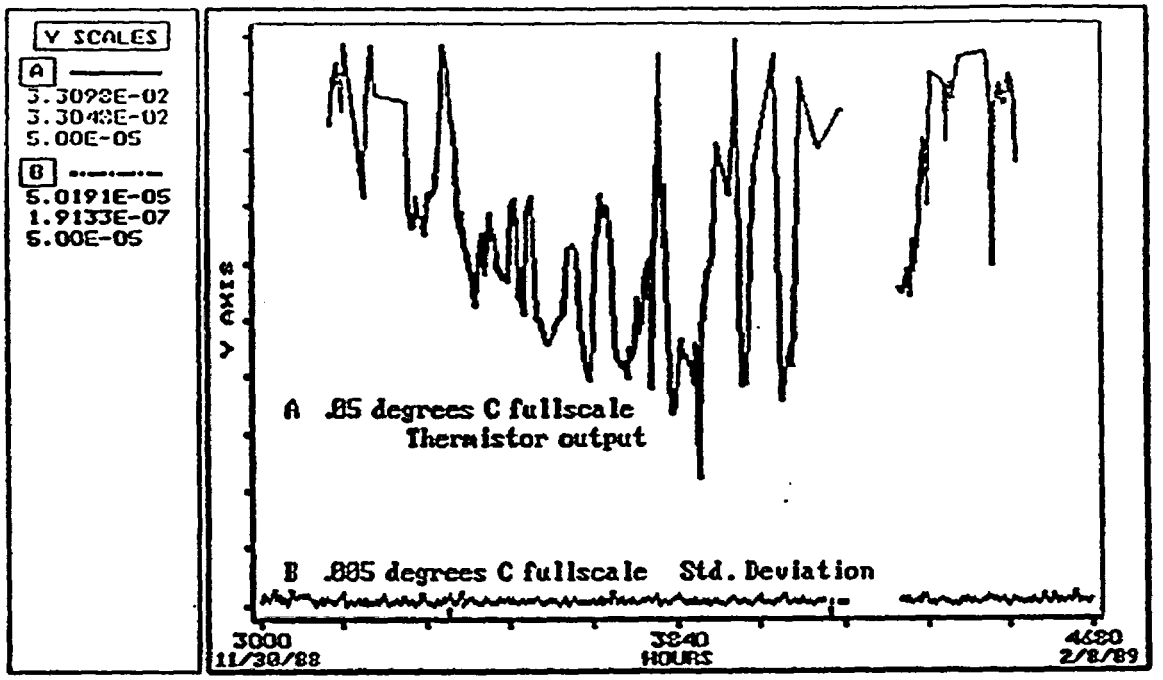
THERMISTOR STATION A - U12g12-DI-1 (15 feet deep)



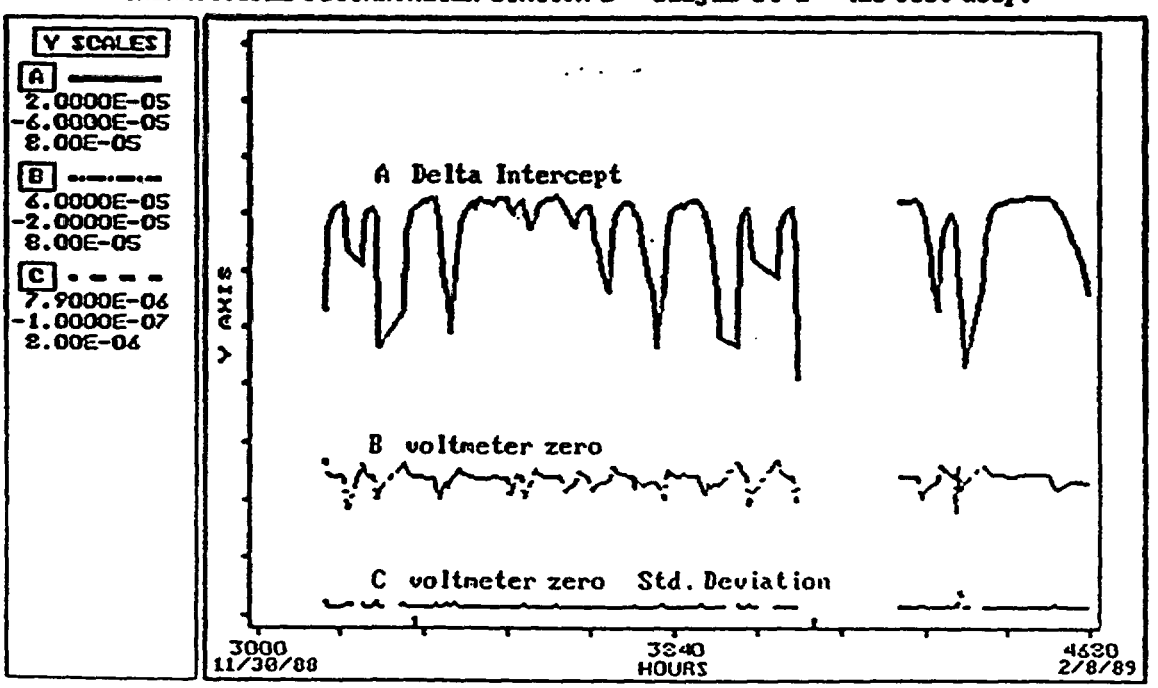
THERMOCOUPLE PSYCHROMETER STATION A - U12g12-DI-1 (15 feet deep)



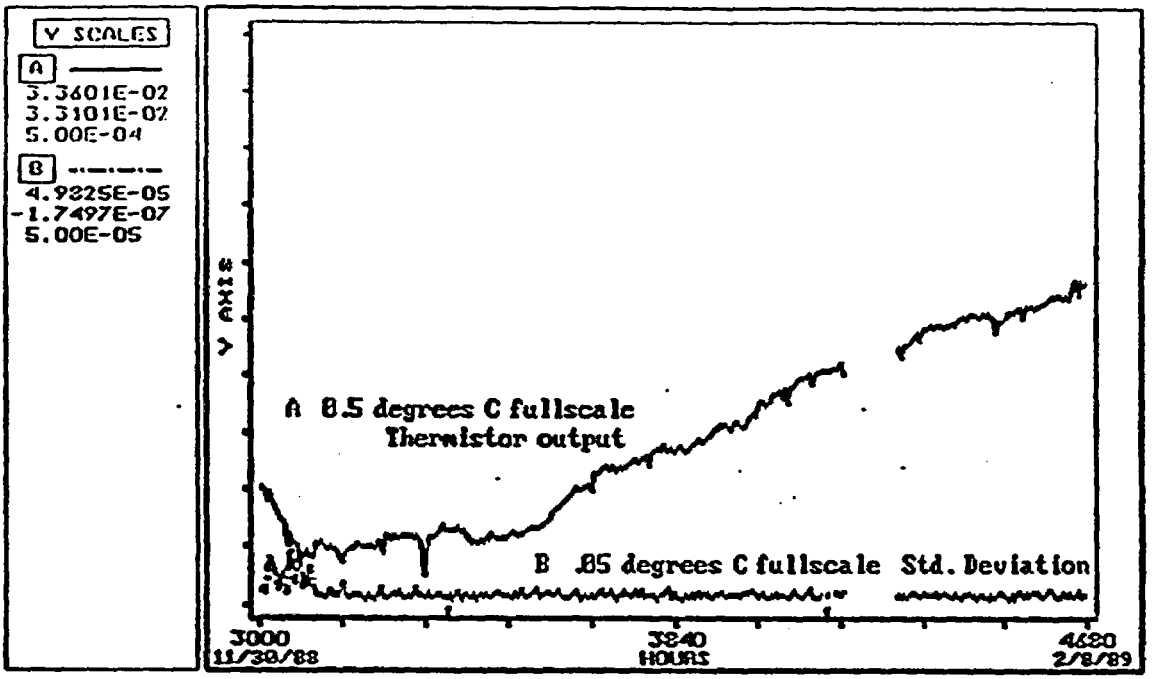
THERMISTOR STATION B - U12g12-DI-1 (18 feet deep)



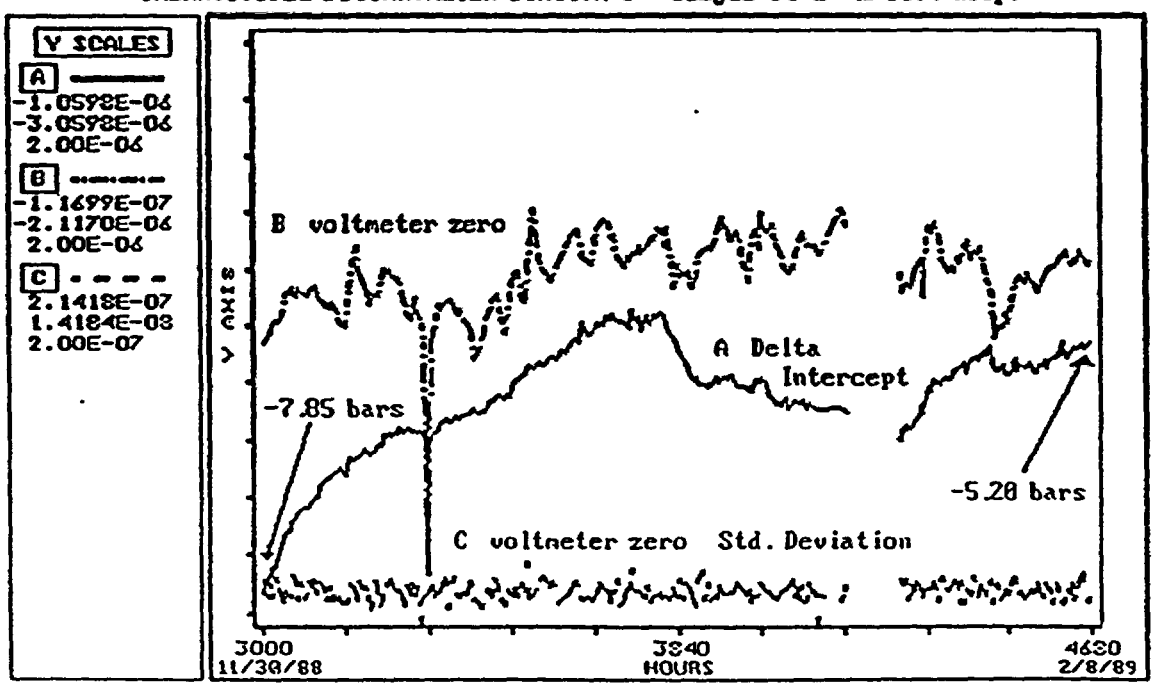
THERMOCOUPLE PSYCHROMETER STATION B - U12g12-DI-1 (18 feet deep)



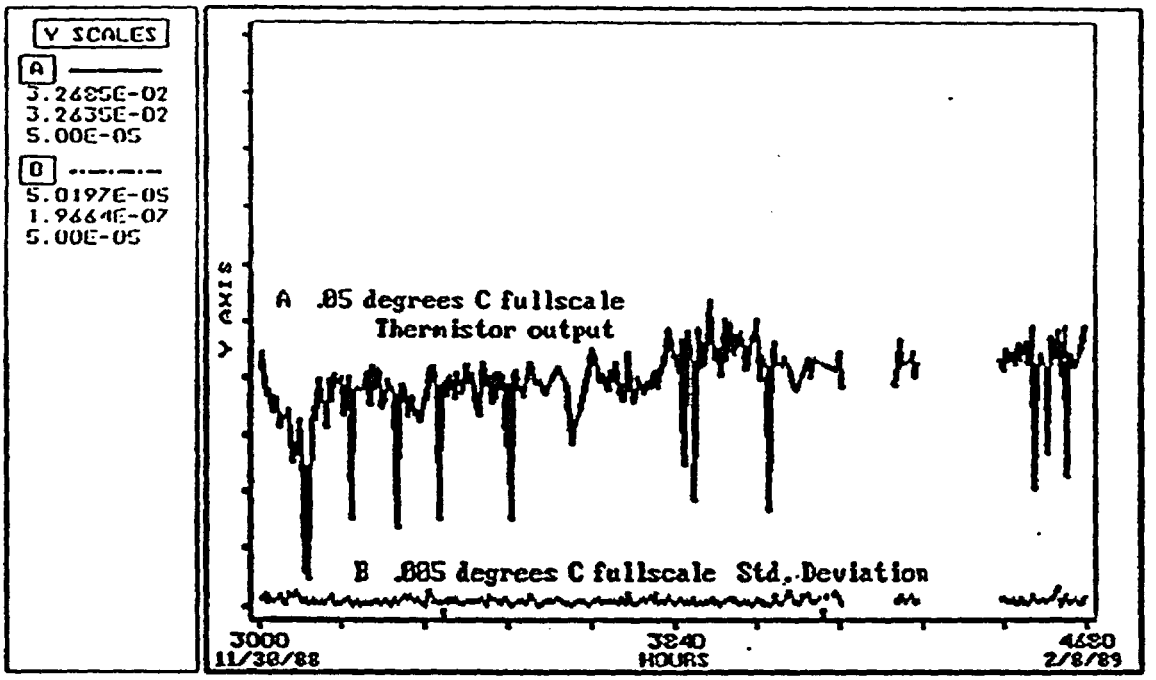
THERMISTOR STATION C - U12g12-DI-1 (5 feet deep)



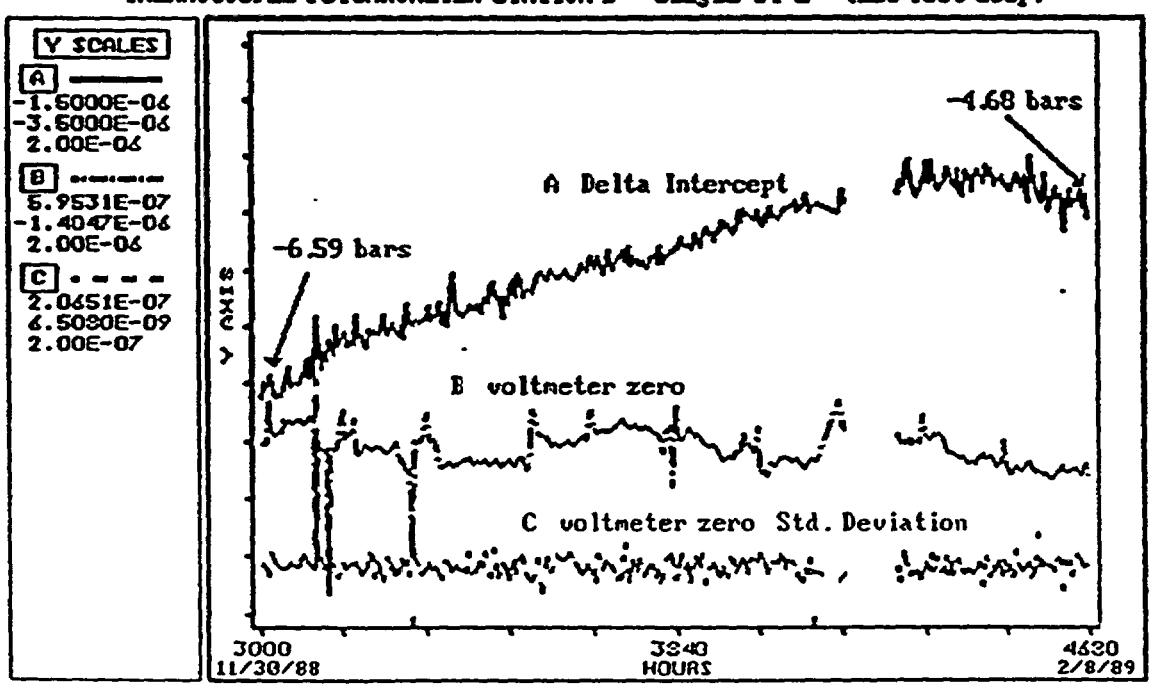
THERMOCOUPLE PSYCHROMETER STATION C - U12g12-DI-1 (5 feet deep)



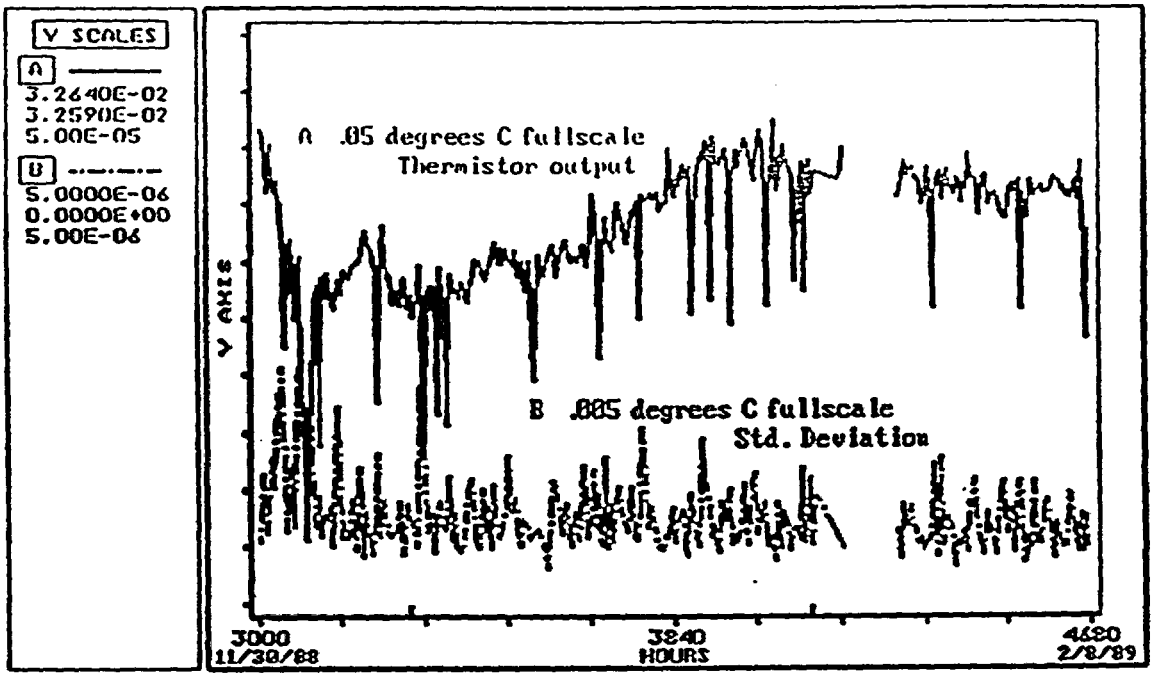
THERMISTOR STATION D - U12g12-D1-2 (128 feet deep)



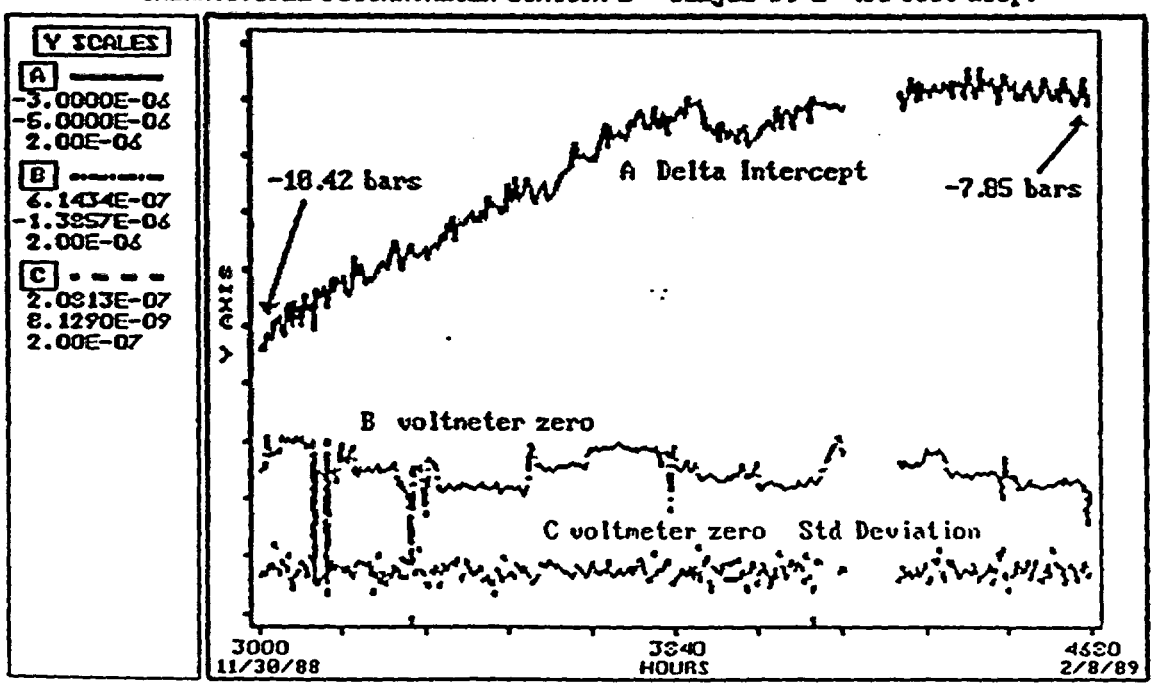
THERMOCOUPLE PSYCHROMETER STATION D - U12g12-D1-2 (128 feet deep)



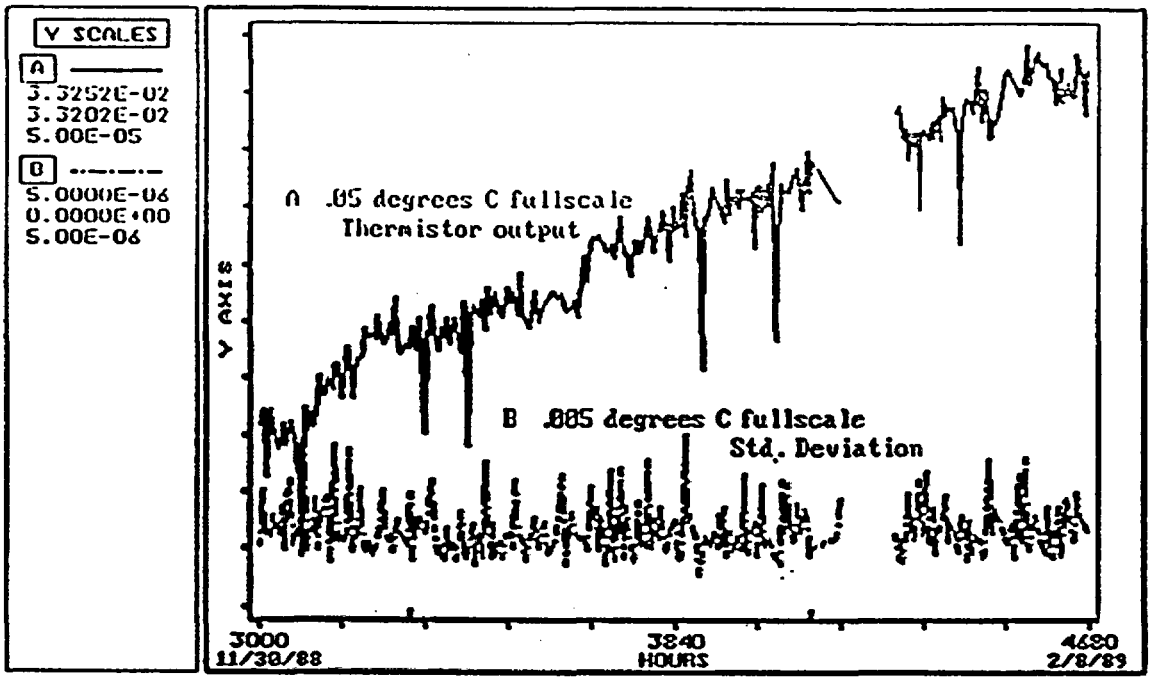
THERMISTOR STATION E - U12g12 (98 feet deep)



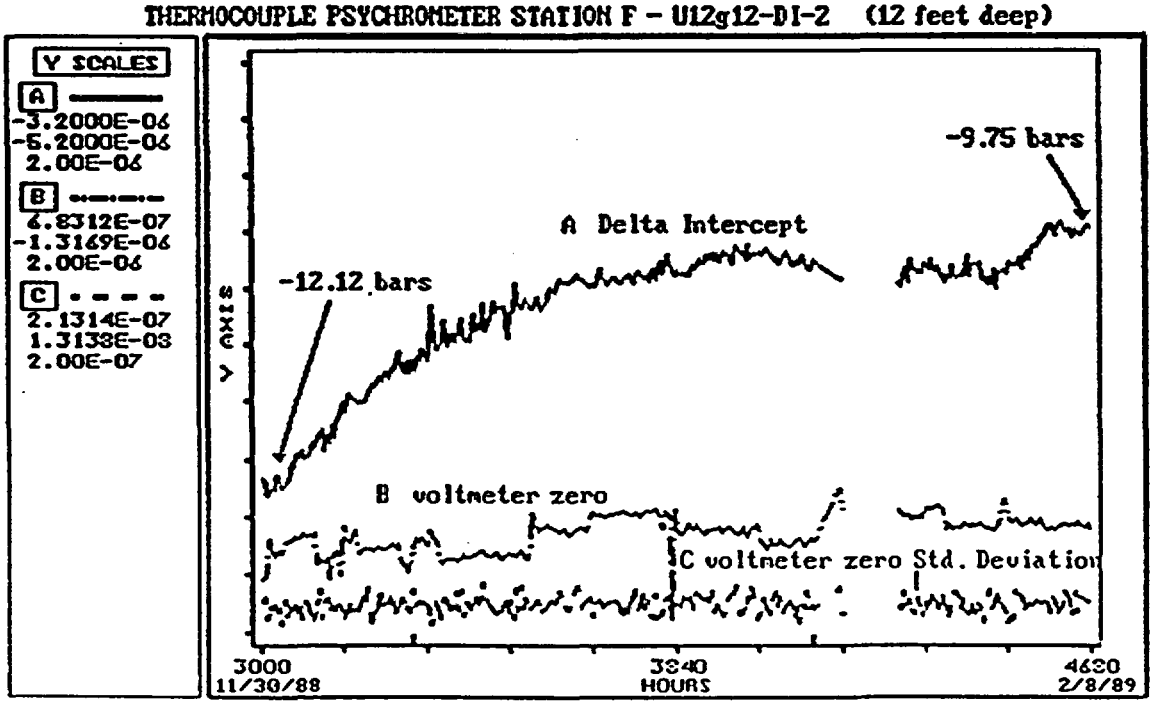
THERMOCOUPLE PSYCHROMETER STATION E - U12g12-D1-2 (98 feet deep)



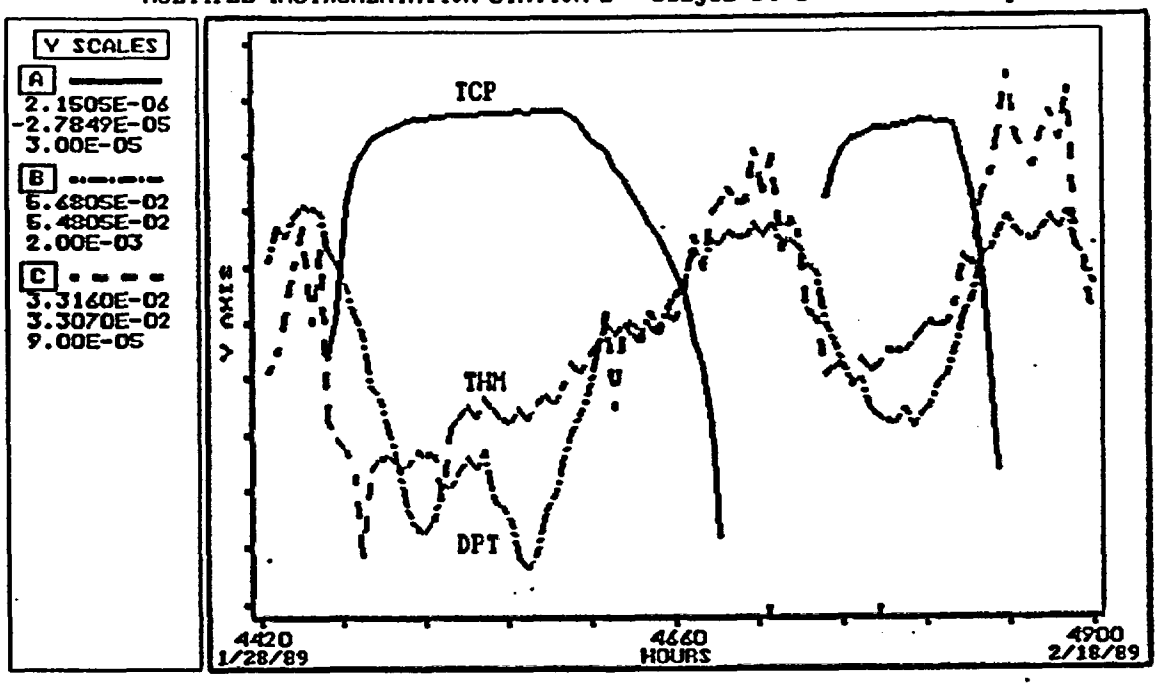
THERMISTOR STATION F - U12g12-DI-2 (12 feet deep)



THERMOCOUPLE PSYCHROMETER STATION F - U12g12-DI-2 (12 feet deep)

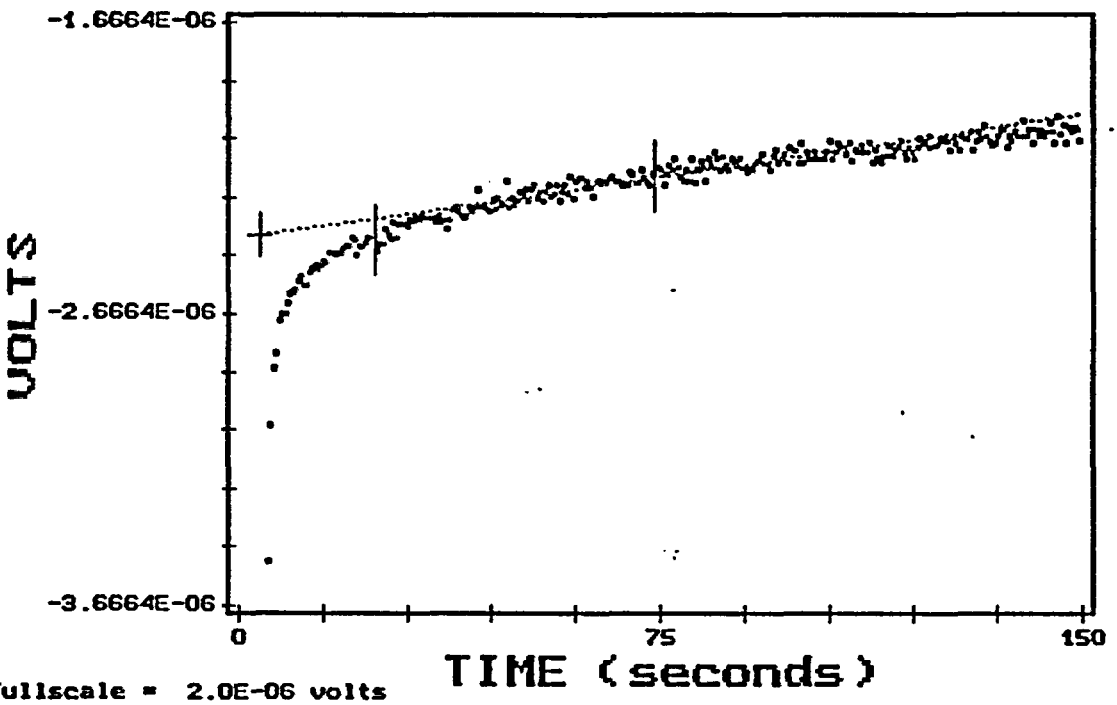


MULTIPLE INSTRUMENTATION STATION B - U12g12-DI-1 (10 feet deep)



Voltmeter Zero Determination
Number of measurements is 30
Voltmeter zero voltage is -4.662E-07 V Sigma is 2.432E-08
Intercept is -4.788E-07 V Sigma is 8.857E-09
Slope is 8.154E-10 Sigma is 4.989E-10
Correlation coefficient (r^2): 0.087

Voltage output during current generation
Number of measurements is 27
Mean output voltage is -3.694E-02 V Sigma is 6.164E-07
Intercept is -3.694E-02 V Sigma is 4.854E-06
Slope is 5.214E-08 Sigma is 3.185E-07
Correlation coefficient (r^2): 4.0E-04



Fullscale = 2.0E-06 volts

Mean Zero Time Voltage: -4.66167E-07 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.44 degrees C
Drybulb Reference: 3.000E+00 +/- 6.179E-05 V
Drybulb voltage: -5.496E-04 +/- 3.778E-07 V

DELTA INTERCEPT: -1.919 microvolts

Data collected: 02-13-1989 21:22:06 HOURS: 4801

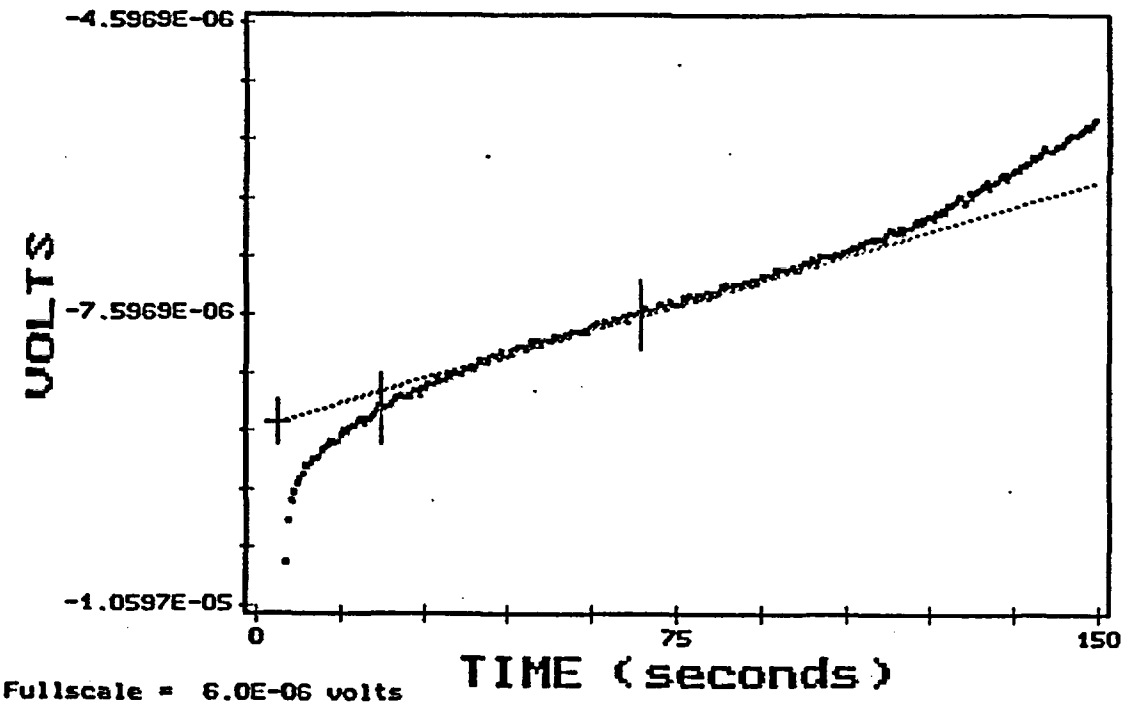
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB408.DAT

Voltmeter Zero Determination
Number of measurements is 31
Voltmeter zero voltage is -2.897E-06 V Sigma is 2.061E-08
Intercept is -2.889E-06 V Sigma is 7.118E-09
Slope is -5.597E-10 Sigma is 4.076E-10
Correlation coefficient (r^2): 0.061

Voltage output during current generation
Number of measurements is 27
Mean output voltage is -3.702E-02 V Sigma is 4.918E-07
Intercept is -3.702E-02 V Sigma is 6.362E-06
Slope is 4.242E-08 Sigma is 4.177E-07
Correlation coefficient (r^2): 7.9E-04



Fullscale = 6.0E-06 volts

Mean Zero Time Voltage: -2.89726E-06 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.38 degrees C
Drybulb Reference: 3.013E+00 +/- 8.013E-05 V
Drybulb voltage: -5.576E-04 +/- 4.249E-07 V

DELTA INTERCEPT: -5.789 microvolts

Data collected: 02-15-1989 03:22:01 HOURS: 4831

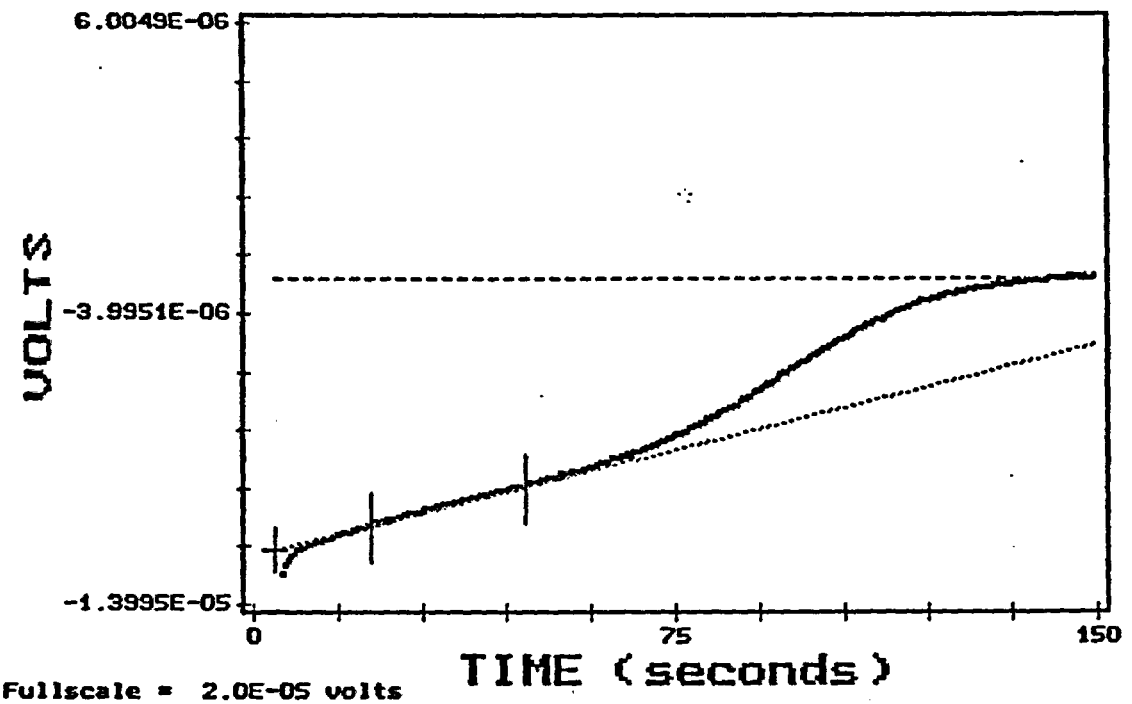
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB414.DAT

Voltmeter Zero Determination
Number of measurements is 30
Voltmeter zero voltage is -2.767E-06 V Sigma is 2.325E-08
Intercept is -2.759E-06 V Sigma is 8.699E-09
Slope is -5.023E-10 Sigma is 4.900E-10
Correlation coefficient (r^2): 0.036

Voltage output during current generation
Number of measurements is 27
Mean output voltage is -3.703E-02 V Sigma is 4.714E-07
Intercept is -3.703E-02 V Sigma is 8.782E-09
Slope is 2.347E-09 Sigma is 5.762E-10
Correlation coefficient (r^2): -2.4E-06



Fullscale = 2.0E-05 volts

Mean Zero Time Voltage: -2.76707E-06 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.40 degrees C
Drybulb Reference: 3.003E+00 +/- 4.521E-05 V
Drybulb voltage: -5.526E-04 +/- 4.652E-07 V

DELTA INTERCEPT: -9.271 microvolts

Data collected: 02-15-1989 08:21:23 HOURS: 4836

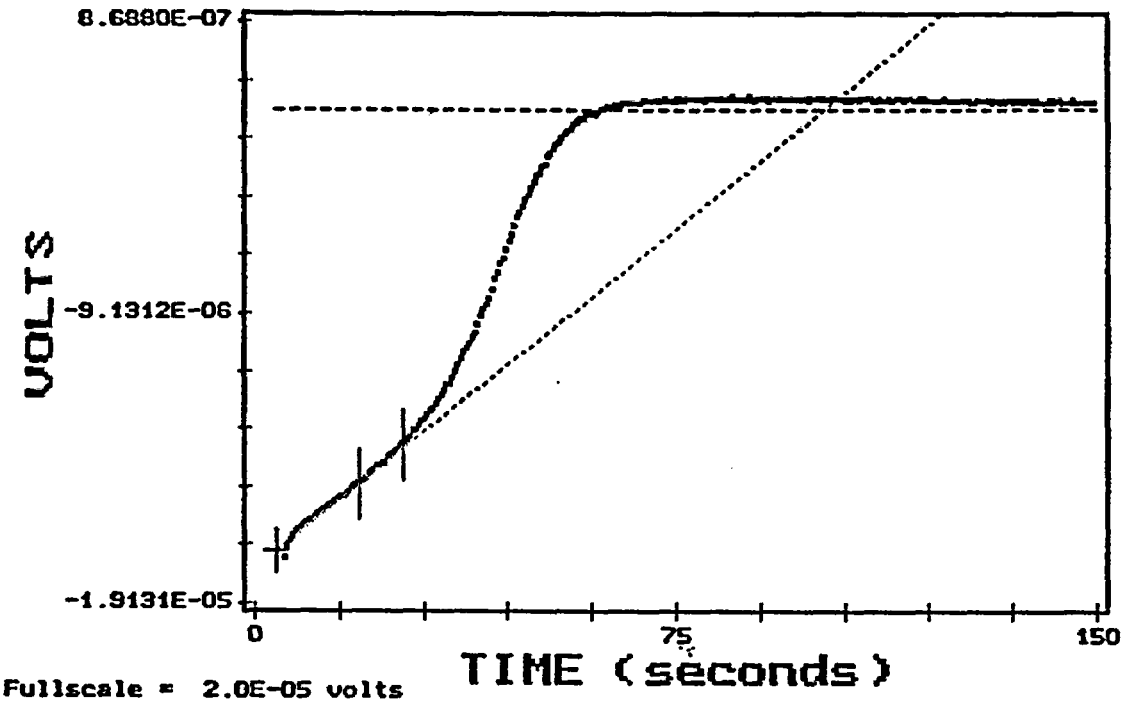
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB415.DAT

Voltmeter Zero Determination
Number of measurements is 31
Voltmeter zero voltage is -2.108E-06 V Sigma is 1.943E-08
Intercept is -2.109E-06 V Sigma is 6.925E-09
Slope is 7.736E-11 Sigma is 3.965E-10
Correlation coefficient (r^2): 0.001

Voltage output during current generation
Number of measurements is 27
Mean output voltage is -3.704E-02 V Sigma is 8.137E-07
Intercept is -3.704E-02 V Sigma is 7.466E-09
Slope is -4.929E-08 Sigma is 4.898E-10
Correlation coefficient (r^2): 0.001



Fullscale = 2.0E-05 volts

Mean Zero Time Voltage: -2.10793E-06 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.35 degrees C
Drybulb Reference: 2.940E+00 +/- 5.150E-05 V
Drybulb voltage: -5.285E-04 +/- 5.379E-07 V

DELTA INTERCEPT: -15.136 microvolts

Data collected: 02-15-1989 13:21:52 HOURS: 4841

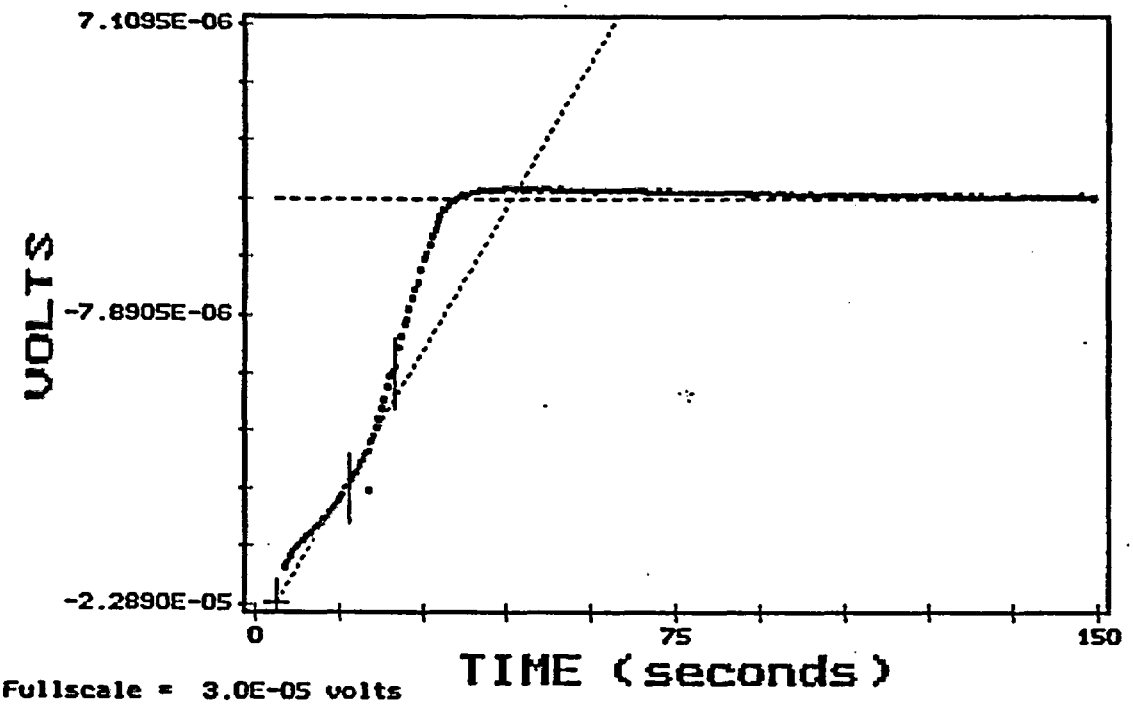
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB416.DAT

Voltmeter Zero Determination
Number of measurements is 30
Voltmeter zero voltage is -1.902E-06 V Sigma is 2.193E-08
Intercept is -1.900E-06 V Sigma is 8.353E-09
Slope is -1.383E-10 Sigma is 4.705E-10
Correlation coefficient (r^2): 0.003

Voltage output during current generation
Number of measurements is 28
Mean output voltage is -3.573E-02 V Sigma is 7.001E-03
Intercept is -3.205E-02 V Sigma is 2.514E-03
Slope is -2.706E-04 Sigma is 1.592E-04
Correlation coefficient (r^2): 0.100



Fullscale = 3.0E-05 volts

Mean Zero Time Voltage: -1.90227E-06 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.38 degrees C
Drybulb Reference: 2.961E+00 +/- 5.843E-05 V
Drybulb voltage: -5.357E-04 +/- 3.426E-07 V

DELTA INTERCEPT: -20.762 microvolts

Data collected: 02-15-1989 18:22:38 HOURS: 4846

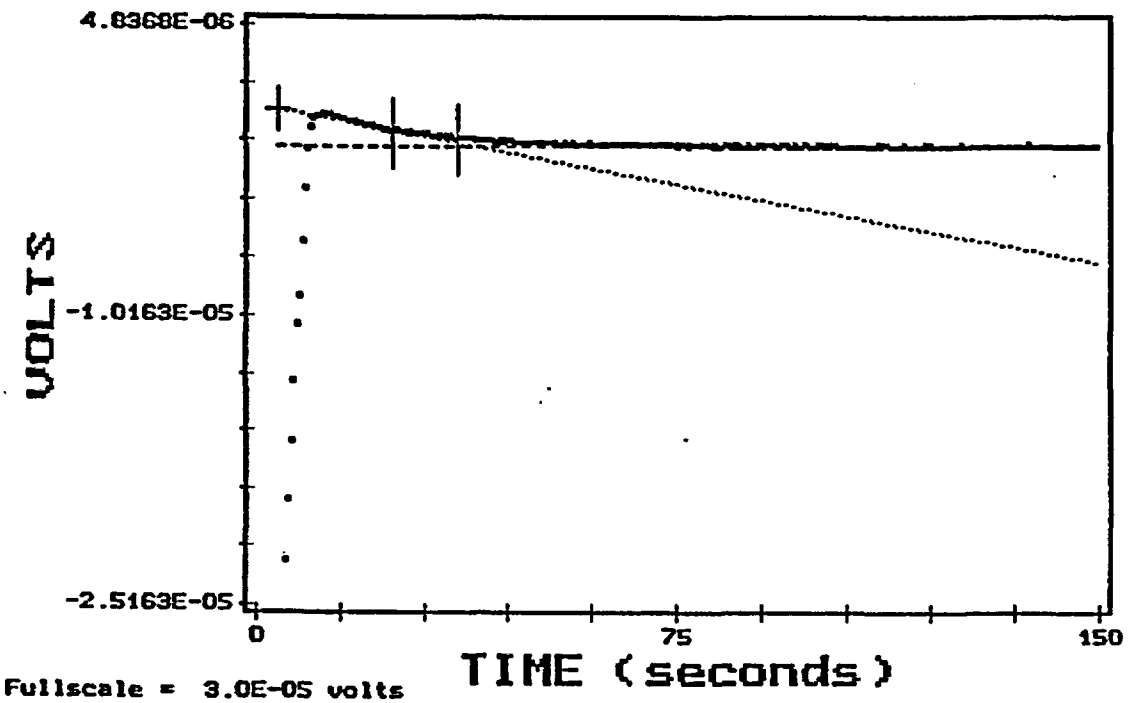
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB417.DAT

Voltmeter Zero Determination
Number of measurements is 31
Voltmeter zero voltage is -1.476E-06 V Sigma is 2.258E-08
Intercept is -1.474E-06 V Sigma is 8.049E-09
Slope is -1.327E-10 Sigma is 4.609E-10
Correlation coefficient (r^2): 0.003

Voltage output during current generation
Number of measurements is 28
Mean output voltage is -3.707E-02 V Sigma is 9.525E-07
Intercept is -3.707E-02 V Sigma is 1.225E-05
Slope is -8.564E-08 Sigma is 7.756E-07
Correlation coefficient (r^2): 0.001



Fullscale = 3.0E-05 volts

Mean Zero Time Voltage: -1.47552E-06 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.38 degrees C
Drybulb Reference: 3.003E+00 +/- 6.058E-05 V
Drybulb voltage: -5.535E-04 +/- 5.490E-07 V

DELTA INTERCEPT: 2.078 microvolts

Data collected: 02-16-1989 18:30:18 HOURS: 4870

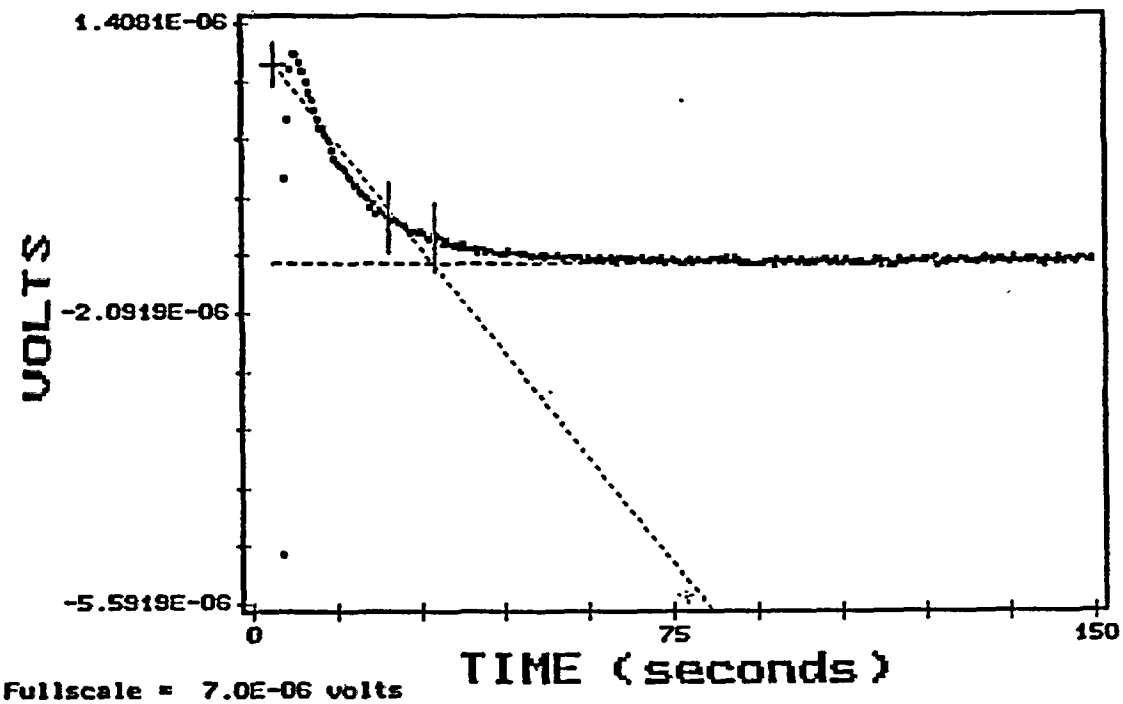
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB421.DAT

Voltmeter Zero Determination
Number of measurements is 30
Voltmeter zero voltage is -1.484E-06 V Sigma is 2.891E-08
Intercept is -1.470E-06 V Sigma is 1.062E-08
Slope is -8.721E-10 Sigma is 5.980E-10
Correlation coefficient (r^2): 0.071

Voltage output during current generation
Number of measurements is 27
Mean output voltage is -3.707E-02 V Sigma is 5.534E-07
Intercept is -3.707E-02 V Sigma is 1.072E-08
Slope is -2.347E-09 Sigma is 7.032E-10
Correlation coefficient (r^2): -8.0E-07



Fullscale = 7.0E-06 volts

Mean Zero Time Voltage: -1.48367E-06 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.36 degrees C
Drybulb Reference: 2.986E+00 +/- 3.124E-05 V
Drybulb voltage: -5.468E-04 +/- 3.541E-07 V

DELTA INTERCEPT: 2.410 microvolts

Data collected: 02-17-1989 09:29:40 HOURS: 4885

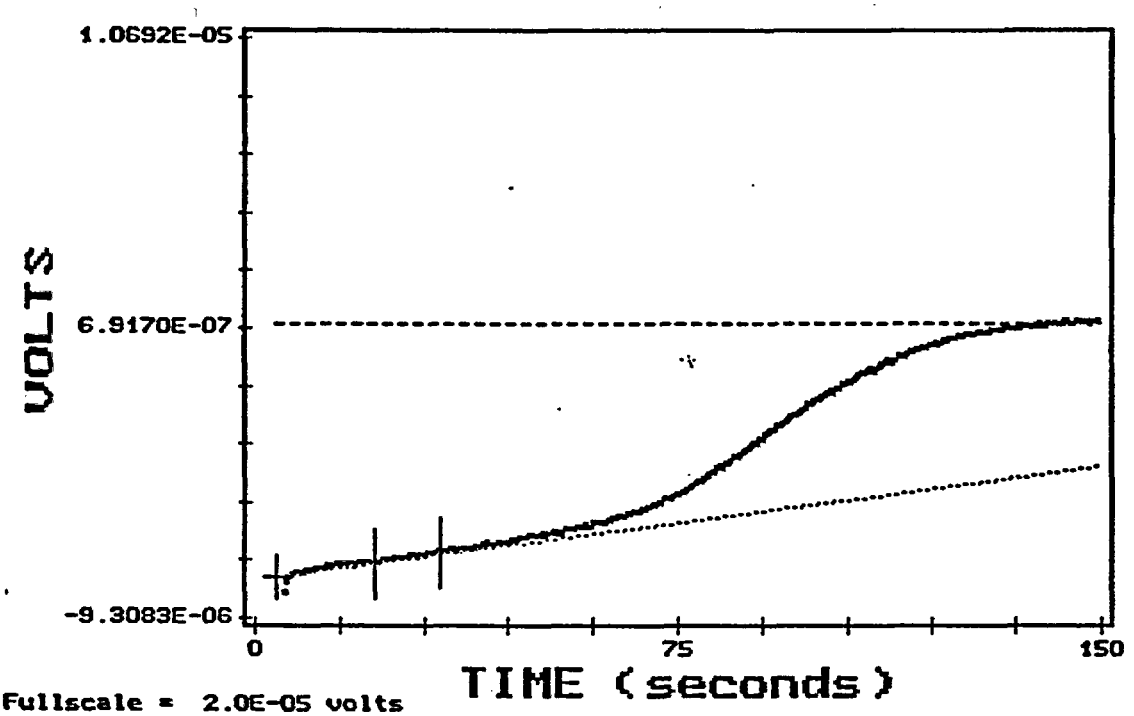
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB424.DAT

Voltmeter Zero Determination
Number of measurements is 30
Voltmeter zero voltage is 8.425E-07 V Sigma is 1.746E-08
Intercept is 8.412E-07 V Sigma is 6.647E-09
Slope is 8.522E-11 Sigma is 3.744E-10
Correlation coefficient (r^2): 0.002

Voltage output during current generation
Number of measurements is 28
Mean output voltage is -3.705E-02 V Sigma is 5.935E-07
Intercept is -3.705E-02 V Sigma is 7.026E-06
Slope is 5.135E-08 Sigma is 4.450E-07
Correlation coefficient (r^2): 6.4E-04



Fullscale = 2.0E-05 volts

Mean Zero Time Voltage: 8.42500E-07 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.50 degrees C
Drybulb Reference: 3.007E+00 +/- 5.922E-05 V
Drybulb voltage: -5.501E-04 +/- 2.978E-07 V

DELTA INTERCEPT: -8.626 microvolts

Data collected: 02-18-1989 00:29:54 HOURS: 4900

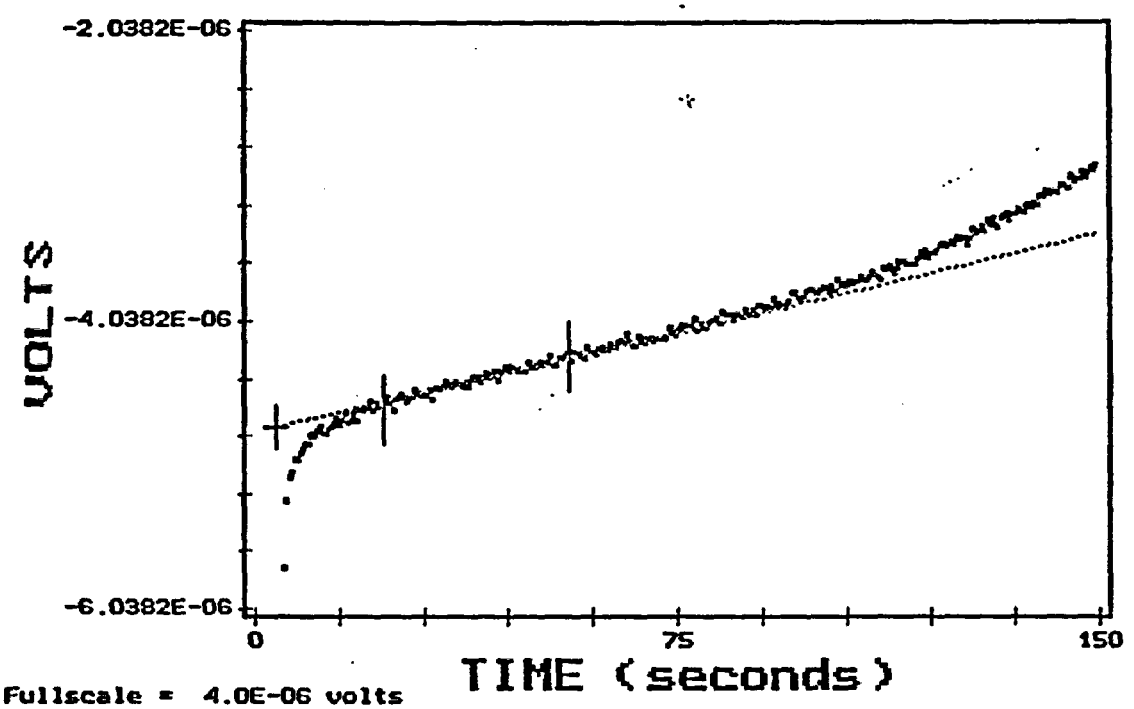
USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB427.DAT

Voltmeter Zero Determination
Number of measurements is 30
Voltmeter zero voltage is 1.207E-07 V Sigma is 2.449E-08
Intercept is 1.319E-07 V Sigma is 9.013E-09
Slope is -7.244E-10 Sigma is 5.077E-10
Correlation coefficient (r^2): 0.068

Voltage output during current generation
Number of measurements is 27
Mean output voltage is -3.705E-02 V Sigma is 8.250E-07
Intercept is -3.706E-02 V Sigma is 9.105E-09
Slope is 9.159E-08 Sigma is 5.991E-10
Correlation coefficient (r^2): -0.004



Fullscale = 4.0E-06 volts

Mean Zero Time Voltage: 1.20667E-07 volts
Cooling time: 30.00 sec Cooling Current: 5.00 mA
TCP Serial Number: A80050

Drybulb Temperature: 16.46 degrees C
Drybulb Reference: 3.029E+00 +/- 6.167E-05 V
Drybulb voltage: -5.607E-04 +/- 7.585E-07 V

DELTA INTERCEPT: -4.882 microvolts

Data collected: 02-18-1989 05:30:46 HOURS: 4905

USGS Computer Program TUNNEL.BAS;Version 1.001 for QA Level III only
Technical Contact: Mark Kurzmack

Printed by Tunnel File Graphing Program Version 1.001 04-10-1989

Datafile name: A:\TCPDAT\TCPB428.DAT

WBS 1.2.6.9.4.2

SUMMARY DATA

GTUF U12g.12

PROTOTYPE DRILLHOLE INSTRUMENTATION

WEEK OF 03/30/89 - 04/05/89 (5871 - 6007 HOURS)

THERMOCOUPLE PSYCHROMETER DATA

Station	Dry Bulb (°C)		Zero Voltage		Intercept			Sensitivity	Relative Error (1 σ Significance)
DI-1 (Vertical)	$\bar{X}$ Temp	$\bar{S}$ Temp	$\bar{X}(10^{-4}V)$	$\bar{S}(10^{-4}V)$	$\bar{X}(10^{-4}V)$	ψ(Bars)	$\bar{S}(10^{-4}V)$	Bars/$10^{-4}V$)	
A (15 feet)	16.531	0.022	0.977	0.015	2.575	-6.60	0.054	2.56	2.1%
B (10 feet)	16.445	0.031	----------Excluded From Analysis Due to Thermal Instability----------						
C (5 feet)	16.427	0.022	1.087	0.056	1.893	-4.85	0.028	2.56	1.5%
DI-2 (Horizontal)									
D (120 feet	16.753	0.021	0.921	0.087	1.947	-5.05	0.028	2.59	1.4%
E (90 feet)	16.763	0.026	0.931	0.041	3.065	-7.64	0.033	2.49	1.1%
F (12 feet)	16.475	0.026	0.967	0.014	3.544	-9.12	0.023	2.57	0.6%

* Above analysis assumes Stations A, C, D, E, F are in thermo/hydrodynamic equilibrium.

** N = 28 samples per treatment.

THERMISTOR DATA

Station	Temp Stability Analysis			Electronic Stability Analysis	
DI-1 (Vertical)	$\bar{X}(10^{-3}V)$	$\bar{S}(10^{-3}V)$	$\bar{S}(°C)$	$\bar{X}_{\bar{S}}(10^{-4}V)$	$\bar{S}_{\bar{X}_{\bar{S}}}(10^{-4}V)$
Station A (15 feet)	32.999	<0.002 (1 outlier)	<0.002	0.739	0.225
Station B (10 feet)	33.100	0.015 (non stationary process that is cyclic)	≈.015°C	0.631	0.236
Station C (5 feet)	33.146	0.006 (non stationary process that is monotonic)	≈.006°C	0.860	0.188
DI-2 (Horizontal)					
Station D (170 feet)	32.652	0.002	≈.002°C	0.693	0.189
Station E (80 feet)	32.627	0.002 (1 outlier)	≈.002°C	0.761	0.262
Station F (12 feet)	33.265	<0.001	<0.001	0.826	0.293

NOTE:

1) Temp stability - represents a between sample analysis for M = 28 samples for each station.

2) Electronic stability - represents a within sample analysis for each M sample (M = 28).

3) Above analysis assumes process is stationary for Stations A, D, E, F.

WBS 1.2.6.9.4.2

PROPOSED KURZMACK ALGORITHM FOR DETERMINING THE DELTA INTERCEPT OF A THERMOCOUPLE PSYCHROMETER CURVE

Version 1.000
Revised 4/7/89

Introduction: A representative thermocouple psychrometer (TCP) voltage output curve is shown in figure 1. The normal output consists of a rise phase, a plateau, and an addition rise back to the voltmeter zero level. The algorithm attempts to locate the plateau portion of the curve and extrapolate the plateau back to the initial start of relaxation.

The overall procedure for obtaining a TCP reading consists of three parts:

1) Determination of a voltmeter zero value

2) Excitation of the psychrometer with a cooling current causing condensation of the water vapor surrounding the thermocouple bead

3) Relaxation of the psychrometer from the excited state back to the voltmeter zero level as the bead warms up again and the condensed water evaporates.

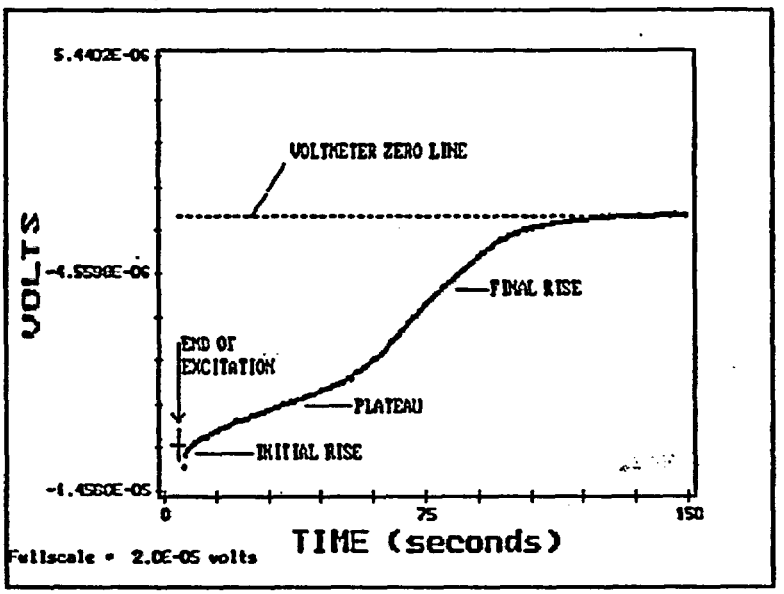


Figure 1 - Parts of a thermocouple psychrometer relaxation curve

When the TCP is in thermal equilibrium with it's environment, no net voltage is measured across the thermocouple except for any zero offset in the nanovoltmeter or measuring electronics. This small amount of voltage is refered to as the "voltmeter zero".

After the voltmeter zero is determined, a current is applied to the TCP to cool the thermocouple and displace it from thermal equilibrium. When the current is removed, (at 4 seconds in figure 1) the TCP decays back towards thermal equilibrium. The rate of the decay is modified by the evaporation of the water droplets on the thermocouple bead. This produces a slowing of the decay process (the plateau region) until all the water has evaporated. Extrapolating the plateau back to the start of the decay process gives a measure of the initial point of evaporation as a voltage offset from the voltmeter zero. This value will be called the delta intercept. Through calibration this can be related to

the vapor pressure or realtive humidity.

Algorithm Overview:
The problem in analyzing the TCP curve to determine the delta intercept arises in identifying the plateau region in a systematic and reproducible fashion. While it may appear trivial to pick out a plateau by eye, the problem becomes more complex when the entire curve is not available, and the portion of the curve that is available has a considerable amount of noise. This has necessitated a computerized determination of the delta intercept.

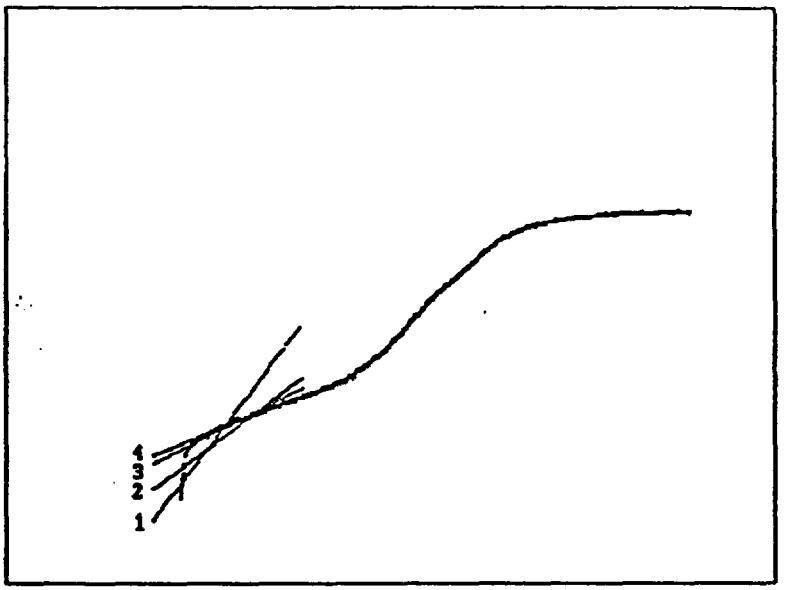


Figure 2 - Stepping the trial regression line along the TCP curve. The numbered lines represent sequential trial regressions along the curve. Line 4 best represents the plateau region.

The proposed algorithm steps along the curve from the begining and calculates linear regressions for sequential subsets of the TCP curve as shown in figure 2. Line 1 might represent the linear regression through the first 30 points of the curve. Due to the inclusion of the points in the initial rise, the line has a steep slope and the intercept is very negative. As the subset is moved along the curve, the first point is dropped off, and a point is added to the end to give line 2. Since less of the initial rise is included in the regression, the line is not as steep as line 1 and the intercept is not as negative. The intercept will continue moving upward until the regression has reached the plateau (i.e. line 4). At that point, the intercepts will oscillate around the true delta intercept due to the noise in the points in the plateau.

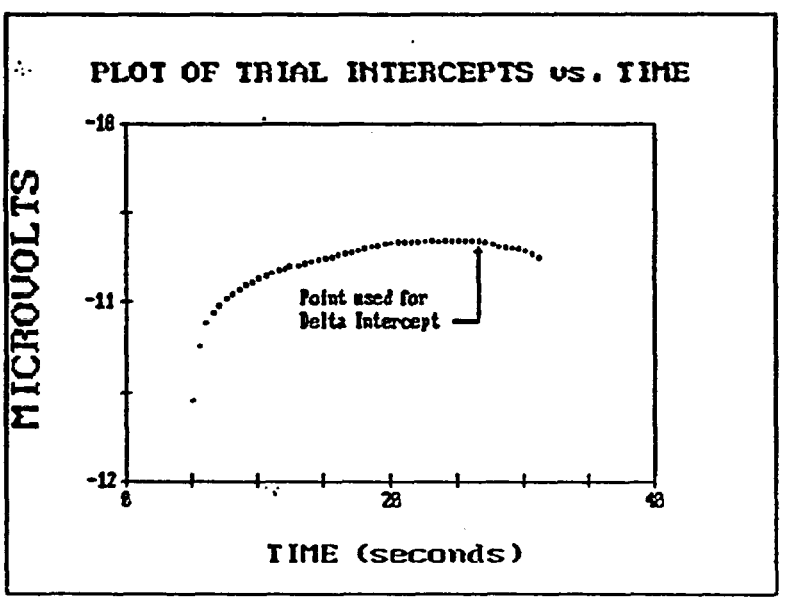


Figure 3 - Plot of trial intercepts vs. time

If we continued to step along the TCP curve in this fashion, the intercept would eventually become more negative again as points from the final rise begin to be included. Figure 3 shows a

plot of the trial intercepts vs. the starting time of the sequential subsets used for the linear regressions. There is a quick rise in the delta intercept and then a flattening out as the plateau is reached. The point that was used to calculate the actual delta intercept is indicated.

In order to determine the actual delta intercept, the algorithm looks for the highest (least negative) intercept. It continues to step along the curve until it finds several regressions with lower (more negative) intercepts than the trial delta intercept.

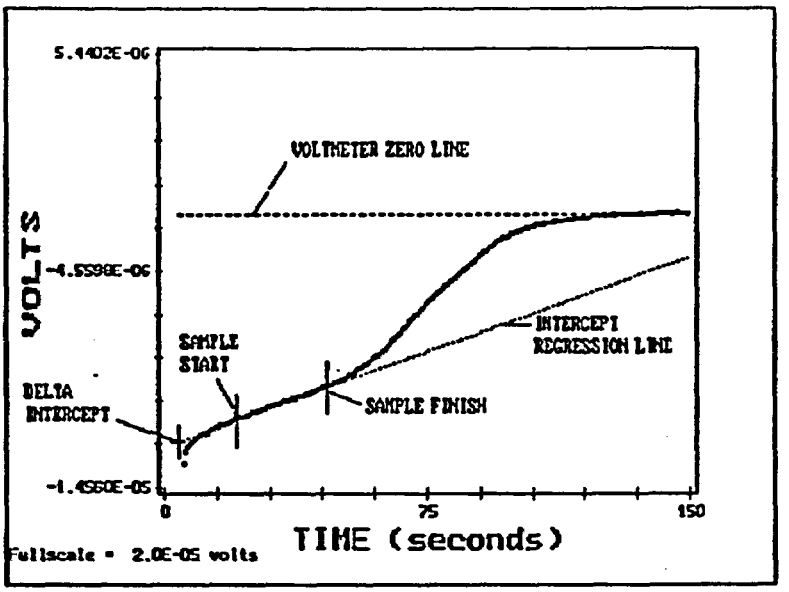


Figure 4 - Final calculation of the delta intercept

To compensate for noise in the curve and the fact that the plateau may not be perfectly flat, we first smooth the curve by replacing the measured values with median values. The number of points used in each regression is also adjusted to compensate for shorter plateaus with dry samples. In addition, 10 points with intercepts lower than the trial point are required to satisfy the stopping criteria. This insures that we have stepped up far enough on the curve to reach the plateau region (see figure 3).

In practice, the algorithm works best when there is a clearly defined plateau region. When the plateau is blurred, or shows curvature, the algorithm may be fooled by a local plateau-like region. It is also important to realize that the algorithm tries to find the *start* of the plateau. Plateaus may show considerable curvature which will result in different intercepts at different parts of the plateau. It was felt that the start of the plateau was closest to the initial conditions when excitation stopped and required the least extrapolation.

A more detailed description of the method is found in Appendix I.

Failure conditions and assumptions: The most basic assumption is that the TCP curve has a shape similar to that shown in Figure 1. If the curve has an overall negative slope (i.e. from a positive to a less positive voltage) or the curve has a continuous curvature so that the intercept keeps rising, the algorithm will fail. It is also possible for the algorithm to be fooled by local aberrations of the curve due to a noisy signal. It is also important to keep in mind that the accuracy of the final delta intercept is as dependent on the determination of the voltmeter zero as it is on the intercept of the regression line.

APPENDIX I
A PROCEDURE WRITTEN IN TURBO PASCAL TO CALCULATE THE DELTA INTERCEPT OF A THERMOCOUPLE PSYCHROMETER CURVE

Implementation: The source code for a procedure for calculating the delta intercept of a TCP curve follows this description. The procedure is written in Borland's Turbo Pascal 4.0 and uses some library routines from Turbo Power Software's Turbo Professional 5.0 package.

Global variables referenced in the procedure are:

numpts[3] - the number of points in the TCP relaxation curve
time3[i]- the time at which the ith voltage was measured
volts3[i] - the ith raw voltage in the relaxation curve
voltmeterzero - the value of the voltmeter zero voltage
sampsize - the number of points used in the linear regressions
delta_intercept - the calculated intercept of the line drawn through the plateau
delta_slope - the slope of the line drawn through the plateau

Local variables:

criterion - number of regression lines which must have intercepts below (more negative) the trial intercept in order to satisfy the stopping criterion
intercept_error_flag - normally false, but set to true if algorithm fails
maxnum - the maximum number of points in the curve; set to the smaller of the actual number of points or 250. If the stopping criterion has not been met by the time the regression subsample reaches maxnum, the algorithm has failed
v[i] - corrected voltages: the voltmeter zero is subtracted from the raw voltages
z[i] - smoothed TCP curve

Synopsis of Procedure:

1) Initialize variables
   criterion = 10
   intercept_error_flag = false
   maxnum = the smaller of 250 or the actual number of points in the curve
   corrected voltage v[i] = volts3[i]-voltmeterzero

2) Smooth using a running median of four followed by two. For more information, see Paul F. Velleman and David C. Hoaglin, Applications, Basics, and Computing of Exploratory Data Analysis, Duxbury Press, Boston, Massachusetts, pp 159-190. The smoothed curve is placed in z[i] where i ranges from 3 to maxnum - 2.

3) Select the sample size
This is done by averaging points 21 to 30, converting the average to microvolts, and subtracting the number of microvolts from 52. For instance, if the average was 25 microvolts, the sample size would be 27 points (52 - 25 = 27). The minimum number of points is 20. This compensates to some extent for the fact that very dry samples exhibit a much shorter plateau region than that shown by wet samples.

4) Now start stepping along the curve

We start at position=5 with the number of the first trial point (possmin) equal to 9. We take a linear regression of the points from position to (position + sampsize - 1) and calculate the intercept and slope of the regression line. If the position is less than 9, just increment the position and loop back to take another regression at the new point.

Once position has reached 9, the initial value of possmin, we increment position and loop until position reaches possmin + criterion (in this case 9 + 10 = 19). At that point we have calculated a long enough baseline to check our regression values against our stopping criteria.

The stopping criteria require that a number (criterion) of intercepts be less than (have a more negative voltage) the intercept calculated at the trial point (possmin). If the conditions are satisfied, possmin becomes the solution point. If the conditions are not satisfied, both position and possmin are incremented, and we continue to step along the curve and test for the stopping criteria.

If we step along the curve and are unable to satisfy the stopping criteria before the point at (maxnum-sampsize-criterion) is reached the algorithm has failed to determine the delta intercept normally. This may either be reported as a bad value, or the initial intercept calculated at possmin=9 may be used as an approximate value.

TURBO PASCAL SOURCE CODE FOR
Calculate_intercept PROCEDURE

```
PROCEDURE calculate_intercept;
VAR
  a, v, z                    : ARRAY[1..250] Of REAL;
  inter, sl                  : ARRAY[1..250] Of REAL;
  temp                       : REAL;
  s0, s3, s4, s7, s9         : REAL;
  i, j, k                    : INTEGER;
  maxnum, criterion          : INTEGER;
  position                   : INTEGER; {current position on curve}
  possmin                    : INTEGER; {# pt which is a potential minimum}
  done_flag                  : BOOLEAN;
```

```
BEGIN
  adv(0);
  WRITELN('Now determining intercept ...');
  criterion := 10;
  intercept_error_flag := FALSE;
  done_flag := FALSE;
  maxnum := minword(numpts[3], 250);
  FOR i := 1 To maxnum DO v[i] := volts3[i] - voltmeterzero;

  {smooth using a running median of 4 followed by 2}
  FOR j := 3 To maxnum - 2 DO
    BEGIN
      FOR i := j - 2 To j + 2 DO a[i] := v[i];
      FOR i := j - 1 To j + 1 DO
        IF a[i] < a[j - 2] THEN exchangestructs(a[i], a[j - 2], 6);
      IF a[j - 1] > a[j + 1] THEN exchangestructs(a[j - 1], a[j + 1], 6);
      IF a[j] < a[j + 1] THEN exchangestructs(a[j], a[j + 1], 6);
      z[j] := (a[j - 1] + a[j]) / 4.0; {average of first median}
      FOR i := j - 2 To j + 2 DO a[i] := v[i];
      FOR i := j To j + 2 DO
        IF a[i] < a[j - 1] THEN exchangestructs(a[i], a[j - 1], 6);
      IF a[j] > a[j + 2] THEN exchangestructs(a[j], a[j + 2], 6);
      IF a[j + 1] > a[j + 2] THEN exchangestructs(a[j + 1], a[j + 2], 6);
      z[j] := z[j] + (a[j] + a[j + 1]) / 4.0; {add average of second median}
    END;

  {select sample size}
  temp := 0;
  FOR i := 21 To 30 DO temp := temp + z[i];
  temp := ABS(temp * 100000.0); {convert to microvolts and average}
  sampsize := maxword(20, 52 - ROUND(temp));

  {now start stepping along curve}
  position := 5;     delta_intercept := 0;       delta_slope := 0;
  possmin := 9;   {check to see if the first trial point is best intercept}

  REPEAT
    IF position <= maxnum - sampsize - criterion THEN
      BEGIN
        s3 := 0; s4 := 0; s7 := 0; s9 := 0;
        FOR j := position To position + sampsize - 1 DO
          BEGIN
            {linear regression calculations}
            s3 := s3 + time3[j];  s4 := s4 + time3[j] * time3[j];
            s7 := s7 + z[j];      s9 := s9 + time3[j] * z[j];
          END;
        s0 := sampsize * s4 - s3 * s3;
        IF s0 <> 0 THEN
          BEGIN
            inter[position] := (s4 * s7 - s3 * s9) / s0;
            sl[position] := (sampsize * s9 - s3 * s7) / s0;
```

```
        END;
      IF position > 8 THEN
        BEGIN
          IF position < possmin + criterion THEN
            INC(position)
          ELSE
            BEGIN
              k := possmin + 1;
              WHILE (inter[k] <= inter[possmin]) AND (done_flag = FALSE) DO
                IF k < possmin + criterion
                   THEN INC(k) ELSE done_flag := True;
              IF (inter[k] > inter[possmin]) AND (done_flag = FALSE) THEN
                BEGIN
                  possmin := k;
                  INC(position);
                END;
            END;
        END
      ELSE INC(position);      {don't bother checking first three points}
    END
  ELSE
    BEGIN            {Algorithm failed - just use first possmin value}
      WRITELN('Unable to determine intercept normally');
      WRITELN('Continuous positive curvature assumed and intercept');
      WRITELN('calculated at maximum');
      possmin := 9;
      intercept_error_flag := True;
      done_flag := True;
    END;
UNTIL done_flag = True;
delta_intercept := inter[possmin];
delta_slope := sl[possmin];
WRITELN('Intercept: ', delta_intercept * 1e6:8:3, ' microvolts');
sampstart := possmin;
END;
```