U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: DEEP BOREHOLE TESTING FOR FLOW PROCESSES

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OVERVIEW OF PRESENTATION TO NWTRB DECEMBER 11-12, 1989

- PURPOSE/SCOPE/MEASUREMENTS - AN OVERVIEW
- UZ-1 EXPERIENCE - OBSERVATIONS
- G-TUNNEL EXPERIENCE - AN ANALOG SITE
- BENEFITS OF IN SITU MONITORING

PURPOSE

- DEFINE THE FLUID FLOW POTENTIAL FIELD WITHIN THE UNSATURATED ZONE
- DETERMINE THE IN-SITU BULK-PERMEABILITY AND BULK HYDRAULIC PROPERTIES OF THE UNSATURATED MEDIA

RELATED INTERFACES

- SYSTEMATIC DRILLING PROGRAM
- SATURATED-ZONE HYDROLOGIC INVESTIGATIONS
- MATRIX AND PHYSICAL ROCK PROPERTIES TESTING PROGRAMS
- HYDROCHEMISTRY STUDIES
- EXPLORATORY STUDIES FACILITY INVESTIGATIONS
- SITE INTEGRATION MODELING PROGRAMS
- PERFORMANCE ASSESSMENT AND ENGINEERING DESIGN PROGRAMS

FEATURES BASED DRILLING PROGRAM

SCOPE

- **DRY DRILLING AND CONTINUOUS CORING**
  - 19 VERTICAL BOREHOLES - 32,000 FEET
  - 1 (+) HORIZONTAL BOREHOLE - 1,000 FEET
- **HYDRO INSTRUMENTATION OF 17 VERTICAL AND 1 (+) HORIZONTAL BOREHOLE**
  - PASSIVE IN-SITU MONITORING - 3 TO 5 YEARS
  - ACTIVE IN-SITU TESTING - INTERMITTENT
- **GEOPHONE INSTRUMENTATION OF 2 VERTICAL BOREHOLES**
  - CROSS HOLE TOMOGRAPHY
  - VERTICAL SEISMIC PROFILING (VSP)

FEATURES BASED DRILLING PROGRAM

SCOPE
(CONTINUED)

- GEOPHYSICAL LOGGING - 15 TO 17 LOGS/BOREHOLE
- GEOLOGIC AND LITHOLOGIC LOGGING
- MATRIX AND PHYSICAL ROCK PROPERTIES TESTING
- AIR PERMEABILITY TESTING
- GAS TRACER DIFFUSION TESTING
- WATER INJECTION TESTING

N. B. VERTICAL BOREHOLES PENETRATE CALICO HILLS - TERMINATE AT WATER TABLE

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FEATURES BASED DRILLING PROGRAM

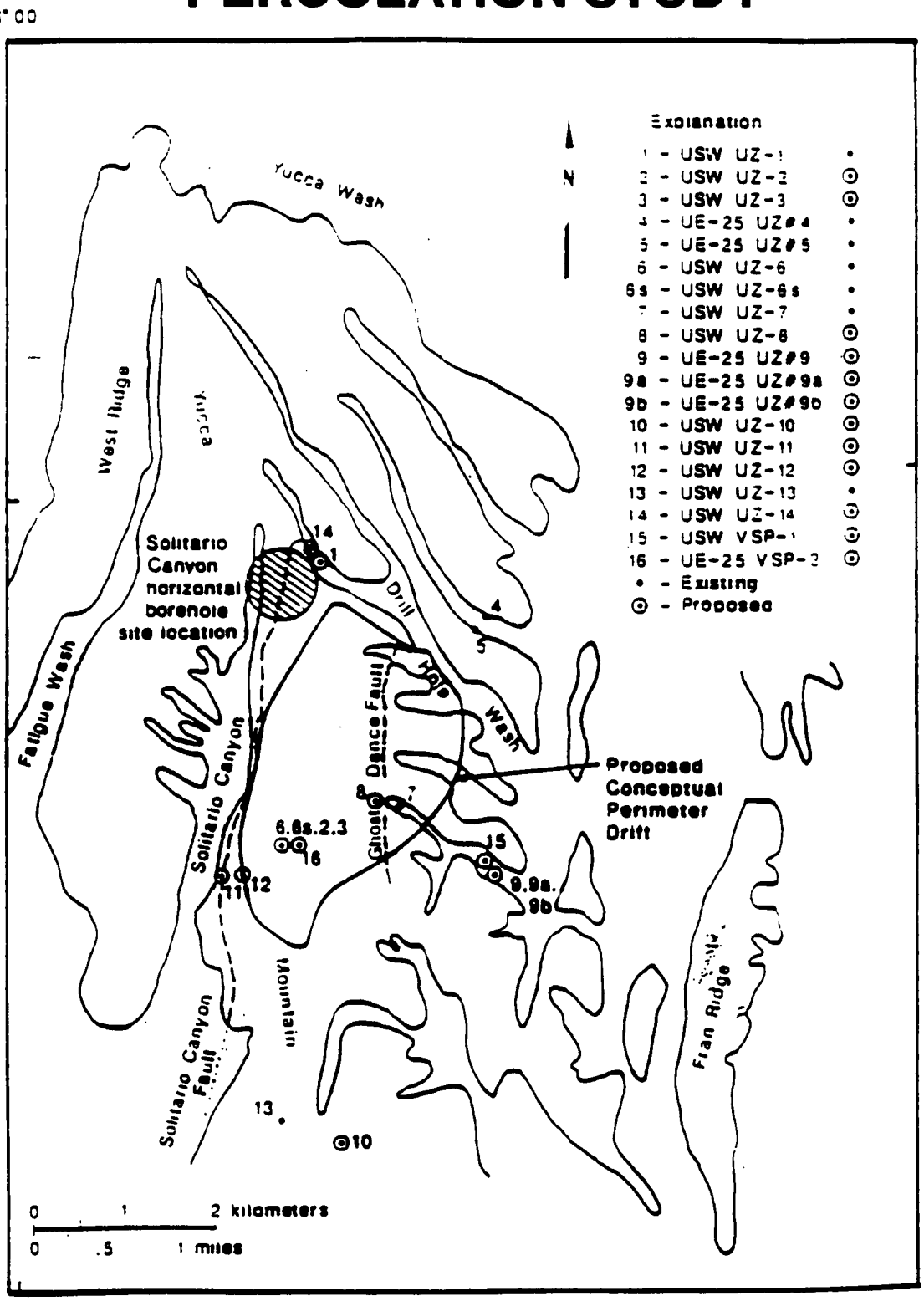
SITING STRATEGY

- "...TARGET THOSE AREAS OF INTEREST WITH THE GREATEST POTENTIAL TO PROVIDE THE EVIDENCE NEEDED TO ASSESS THE SUITABILITY OF YUCCA MOUNTAIN AS A REPOSITORY FOR HIGH-LEVEL RADIOACTIVE WASTE" (YMP-USGS-SP 8.3.1.2.2.3)

- CONSIDERATIONS

  - SURFACE DRAINAGE FEATURES
  - LARGE SCALE STRUCTURAL FEATURES
  - TOPOGRAPHIC FEATURES
  - AREAL COVERAGE
    * FRACTURE SYSTEM CONTINUITY
    * BROAD DEFINITION OF THE POTENTIAL FIELD
    * LITHOLOGIC VARIATIONS
    * PERMEABILITY CHARACTERISTICS
  - TESTING REQUIREMENTS
  - DISTURBANCE TO THE INTEGRITY OF THE REPOSITORY
  - ADVERSE INFLUENCES OF PRIOR ACTIVITIES

MAP SHOWING EXISTING AND PROPOSED BOREHOLE LOCATION FOR THE SURFACE-BASED UNSATURATED-ZONE PERCOLATION STUDY



SITING STRATEGY FOR
UZ BOREHOLES

UZ 9, 9a, 9b, VSP #1	IMBRICATE FAULT ZONE
UZ 6, 6s, 2, 3 VSP #2	YUCCA MOUNTAIN RIDGE
UZ 7, 8	GHOST DANCE FAULT
UZ 11,12	SOLITARIO CANYON FAULT
UZ 4, 5	PAGANY WASH
UZ 1, 14	DRILLHOLE WASH, STEEP GRADIENT FEATURES
UZ 10, 13	YUCCA MOUNTAIN RIDGE AND TIVA CANYON
SOLITARIO CANYON HORIZONTAL BOREHOLE	SOLITARIO CANYON, TOPOPAH SPRING

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DRILL HOLE INSTRUMENTATION AND MONITORING

SIMPLIFYING ASSUMPTIONS

IDEAL ASSUMPTIONS ARE THOSE THAT MINIMIZE COMPLEXITY

- **REQUIRE FEWER MEASUREMENTS WITH LESS ANALYSIS**

- **ARE APPROPRIATE AND REALISTIC ENOUGH TO REPRESENT THE CRITICAL ELEMENTS OF THE SYSTEM**

(MODIFIED FROM PRT REVIEW - SEPTEMBER, 1990)

ASPECTS OF MULTIPHASE FLUID FLOW PROCESSES YUCCA MOUNTAIN, NEVADA

DEGREE OF SIMPLIFICATION	SYSTEM DESCRIPTION	DOMINANT FLOW PROCESSES & GEOMETRIES	CANDIDATE HYDROGEOLOGIC UNITS
high (least complex)	Isothermal Flow, Homogenous Porous Media	Single phase, liquid flow simple boundaries	Paintbrush, nonwelded *vitric tuff* Calico Hills, nonwelded zeolitized tuff
	Isothermal Flow, Heterogeneous Porous Media	Single phase, liquid flow REVs with simple boundaries	
		Liquid and gas flow, REV's with simple to complex boundaries	Calico Hills, *nonwelded* vitric tuff Topopah Spring densely welded tuff Tiva Canyon densely welded tuff
	Non-Isothermal Flow, Heterogeneous Porous Media	Liquid and gas flow, continum approach with simple to complex boundaries	
		Liquid and gas flow, discrete fracture systems, complex boundaries, transients	
	Non-Isothermal Flow, Heterogeneous Fractured, Porous Media		Faults, topographic features and surface drainages
low (most complex)		Liquid and gas flow, discrete fractures with internal and external boundaries, complex circulation systems, perched water, transients	

TRANSITIONAL

GRADATIONAL

DRILLHOLE INSTRUMENTATION AND MONITORING
FAST FACTS

- 12.25 INCH DIAMETER BOREHOLES
- MAXIMUM DEPTH - 2500+ FEET
- 16 INSTRUMENT STATIONS PER BOREHOLE
- APPROXIMATELY 300 INSTRUMENT STATIONS TOTAL
- SOLID STEMMING DESIGN
  - GROUT ISOLATION & STRUCTURAL SUPPORT PLUGS
  - POLYETHYLENE BEADS
  - INERT FILTER BETWEEN INSTRUMENT STATIONS
  - HOLLOW STEMMING TUBE

DRILLHOLE INSTRUMENTATION AND MONITORING
FAST FACTS
(CONTINUED)

- SENSORS NOT RECOVERABLE IN USEABLE FORM
- 3 TO 5+ YEARS OF MONITORING
- SAMPLING FREQUENCY
  - 1 READING EVERY 5 HOURS, EACH PRIMARY SENSOR
  - HIGH FREQUENCY MEASUREMENTS
    * IN-SITU RECALIBRATION
    * INTERACTIVE TESTING

DRILLHOLE INSTRUMENTATION AND MONITORING
FAST FACTS
(CONTINUED)

- **MEASUREMENTS**
  - PNEUMATIC PRESSURE : > $\pm$ 0.005 PSIA - 2 + σ (SEMICONDUCTOR STRAING GAUGE)
  - TEMPERATURE: > $\pm$0.005°C - 2+σ (THERMISTOR)
  - WATER PONTENTIAL (VAPOR PHASE): > -1 BAR TO <-75 BAR (THERMOCOUPLE PSYCHROMETER) RELATIVE ERROR 1% TO 10%

- **GAS SAMPLING - DRY CARRIER GAS**
  - VERIFICATION OF THERMOCOUPLE PSYCHROMETER
  - PRESERVATION OF HEAVY GAS ISOTOPES
  - HYDRAULIC TESTING

DRILLHOLE INSTRUMENTATION AND MONITORING
FAST FACTS
(CONTINUED)

- SYSTEM RELIABILITY
  - IN-SITU RECAL OF PRESSURE TRANSDUCERS
  - DUPLICATE SENSORS AT EACH STATION
    * CONFIRMATION OF SENSOR ACCURACY
    * SENSOR BACKUP IN EVENT OF FAILURE
    * SENSOR DRIFT CHARACTERIZATION

  - ROLE OF CENTRAL STEMMING TUBE
    * WATER INJECTION TESTING
    * GAS TRACER DIFFUSION TESTING
    * BACK-UP TO GAS SAMPLING SYSTEM
    * BACK-UP TO THERMISTOR
    * NEUTRON MOISTURE METER LOGGING
    * ACCESS TO SATURATED ZONE - WATER LEVEL MEASUREMENT

CHARACTERISTICS OF IN-SITU MEASUREMENTS
PNEUMATIC PRESSURE

- HIGH FREQUENCY, RELATIVELY HIGH AMPLITUDE
- EQUILIBRATION - HOURS TO DAYS
- STRONG DIURNAL AND SEASONAL SIGNATURES
- STRONGLY INFLUENCED BY OPEN, INTERCONNECTED FRACTURES
- VERTICAL AND HORIZONTAL PRESSURE DISTRIBUTION DEFINES CONVECTIVE CIRCULATION SYSTEM
- PHASE LAGGING AND DAMPING EFFECTS USED TO COMPUTE
  - PERMEABILITY TO AIR
  - HYDRAULIC CONDUCTIVITY (KLINKENBERG EFFECT MINIMAL)

PRESSURE TRANSDUCER
SUMMARY FACT SHEET

- DRUCK PDCR 930, NON-THERMALLY COMPENSATED, 700 mBAR FULL RANGE

- ACCURACY
  - MANUFACTURER'S SPECIFICATION - 0.06% FULL SCALE
  - USGS - CALIBRATION - 0.03% FULL SCALE - 2+ σ

- RESOLUTION (SENSITIVITY) - APPROXIMATE > 0.001 PSIA

- STABILITY
  - SILICON DIAPHRAGM TRANSDUCER - INDUSTRY STANDARD FOR STABILITY
  - UNDER USGS EVALUATION
  - NO APPARENT PROBLEMS TO DATE
  - IN-SITU RECALIBRATION OPTION

- EFFECTS OF LONG WIRES - INSIGNIFICANT

- OPERATED IN CURRENT MODE

PRESSURE TRANSDUCER
SUMMARY FACT SHEET
(CONTINUED)

- 50 VOLTAGE SAMPLES PER READING FOLLOWING 25 TO 40 SECOND DELAY TO ALLOW FOR DISSIPATION OF HEAT ON THE DIAPHRAGM

- CALIBRATION
  - PRESSURE - 8 CYCLES AT 85, 95, 100, 110, 90, 80 kPa
  - TEMPERATURE - 1 CYCLE PER 8 PRESSURE CYCLES - 10, 20, 30°C
  - TOTAL NUMBER OF SAMPLES PER CALIBRATION IS 144

- SUPPORT EQUIPMENT
  - KEITHLEY 220 CURRENT GENERATOR
  - HP-3457A MULTIMETER
  - HP-3497A SCANNER
  - HP-44421A 20 CHANNEL RELAY MULTIPLEXER ASSEMBLY
  - YSI-46033 THERMISTOR
  - FLUKE SPRTD
  - HART SCIENTIFIC PROGRAMMABLE WATER BATH
  - DRUCK DPI 140 PRESSURE GAGE
  - DRUCK DPI 500 PRESSURE CONTROLLER
  - RUSKA 2465 PRIMARY STANDARD DEADWEIGHT GAGE
  - MICROCOMPUTER

TEMPERATURE

- MODERATE TO LOW FREQUENCY, VARIABLE AMPLITUDE SIGNAL
- EQUILIBRATION - WEEKS TO MONTHS
- STRONG DIURNAL AND SEASONAL CHARACTERIZATION AT NEAR SURFACE
- DOMINATED BY GEOTHERMAL GRADIENT AT DEPTH
- THERMAL PROFILE INFLUENCED BY
  - THERMAL CONDUCTIVITY OF MEDIA
  - VOLUMETRIC HEAT CAPACITY OF MEDIA
  - LATENT HEAT OF VAPORIZATION PROCESSES

TEMPERATURE

(CONTINUED)

- LIQUID WATER (SATURATION) INFLUENCES THERMAL DIFFUSIVITY
- THERMAL PROFILE INDICATIVE OF LIQUID AND VAPOR FLUX PROCESSES
- HEAT FLOW USED TO
  - COMPUTE AMBIENT SATURATION
  - VAPOR FLUX - LIQUID FLUX
  - ESTABLISH VALIDITY OF WATER POTENTIAL MEASUREMENT

THERMISTOR
SUMMARY FACT SHEET

- YSI 46033 SUPER STABLE - GLASS ENCAPSULATED - BEAD THERMISTOR - 2252 OHM @ 25°C
- ACCURACY > +/-0.005°C AT 2σ SIGNIFICANCE
- RESOLUTION > +/-0.0005°C
- STABILITY/DRIFT < +/-0.010°C - 100 MONTHS @ 25°C
- EFFECTS OF LONG WIRE (2500+ ft) APPLICATIONS ARE INSIGNIFICANT

THERMISTOR
SUMMARY FACT SHEET
(CONTINUED)

- **CALIBRATION**
  - TEMPERATURE RANGE - 5 TO 40°C
  - SAMPLING INTERVAL - 5°C
  - 8 REPILCATES/TEMPERATURE

- **SUPPORT EQUIPMENT**
  - KEITHLEY 220 CURRENT GENERATOR
  - HP-3457 MULTIMETER
  - HP-3497 SCANNER
  - HP-44421A CHANNEL ACQUISITION CARD
  - FLUKE SPRTD
  - HART SCIENTIFIC PROGRAMMABLE WATER BATH
  - MICROCOMPUTER

WATER POTENTIAL
(VAPOR PHASE)

- LOW FREQUENCY, LOW AMPLITUDE SIGNAL
- EQUILIBRATION - MONTHS TO YEARS
- STRONGLY INFLUENCED BY DRILLING METHODOLOGY
- MAY EXHIBIT SEASONAL CHARACTERISTICS
- TRUE MEASUREMENT REQUIRES ISOTHERMAL CONDITIONS
- REFERENCED TO MEASUREMENTS OF MATRIX HYDROLOGIC PROPERTIES
- USED TO COMPUTE LIQUID FLUX
- PRESENCE OF OPEN, INTERCONNECTED FRACTURES MAY PRODUCE HIGH FREQUENCY, HIGH AMPLITUDE SIGNALS

THERMOCOUPLE PSYCHROMETER
SUMMARY FACT SHEET

- MODIFIED DESIGN OF PELTIER PSYCHROMETER (USGS)
  - SIX WIRES
  - DRY BULB/WET BULB DECOUPLED
  - MANUFACTURED BY JRD MERRILL SPECIALTY EQUIPMENT CO.

- RANGE > -1 BAR TO < -75

- ACCURACY
  - > ± 0.8 BARS [USING CUBIC MODEL] - FULL SCALE
  - RELATIVE: 7% AT -1 BAR TO 1% AT -75 BARS — AVERAGE
  - 11% AT -1 BAR TO 2% AT -75 BARS — WORST CASE

- RESOLUTION (SENSITIVITY) - APPROXIMATE
  30°C - 2.2 BARS /μ VOLT
  25°C - 2.4 BARS/μ VOLT
  20°C - 2.8 BARS/μ VOLT
  15°C - 3.3 BARS/μ VOLT

THEORETICAL LIMIT ≈0.1 TO 0.2 BARS

THERMOCOUPLE PSYCHROMETER

SUMMARY FACT SHEET

(CONTINUED)

- STABILITY (DRIFT) - UNKNOWN - OBSERVED CHANGES IN OUTPUT VOLTAGE (1 YEAR OPERATION/2000 CYCLES) DURING CURRENT EXCITATION MAY PROVIDE MECHANISM TO TRACK LONG-TERM DRIFT (QUALITATIVE?/ QUANTITATIVE?)

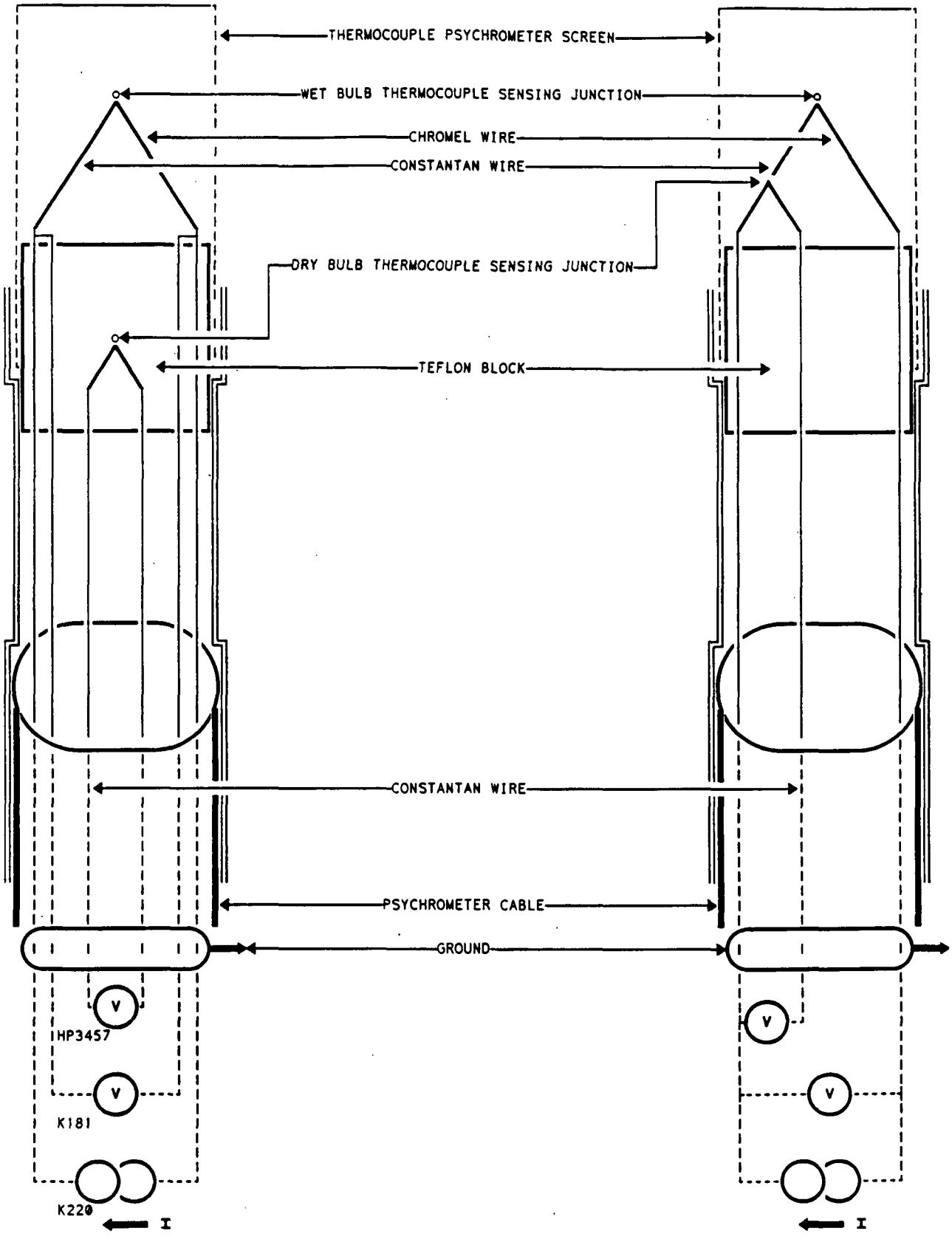
- EFFECTS OF LONG WIRE (2500 ft +) APPLICATIONS APPEAR TO BE INSIGNIFICANT

THERMOCOUPLE PSYCHROMETER
SUMMARY FACT SHEET
(CONTINUED)

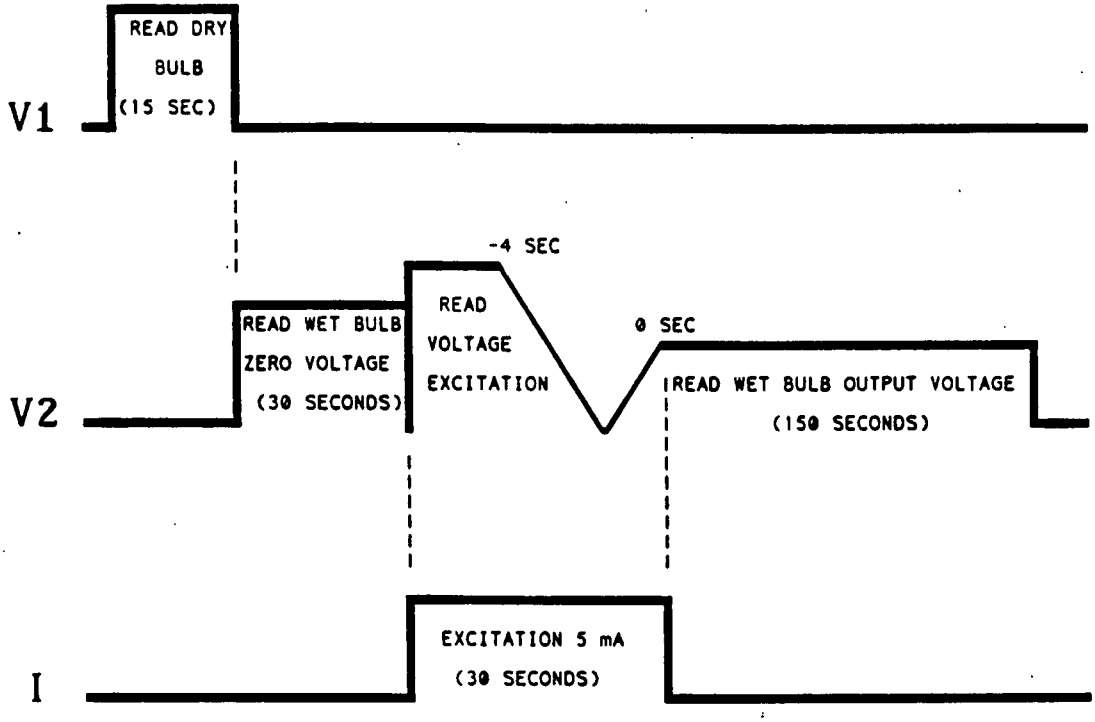
- **CALIBRATION**
  - SATURATED FILTER PAPER IN A CLOSED CHAMBER SUBMERGED IN A WATER BATH
  - 5 MILLIAMP CURRENT - 30 SEC. COOLING TIME
  - MOLALITIES: 0.02, 0.10, 0.40, 0.80, 1.5, 1.75
  - TEMPERATURES: 10, 15, 20, 25, 30
  - REPLICATES: 3 TO 5 PER TEMP PER MOLALITY
  - 75 TO 150 VOLTAGE READINGS PER SAMPLE
  - REGRESSION THROUGH PLATEAU USED TO DETERMINE PSYCHROMETER OUTPUT

THERMOCOUPLE PSYCHROMETER
SUMMARY FACT SHEET
(CONTINUED)

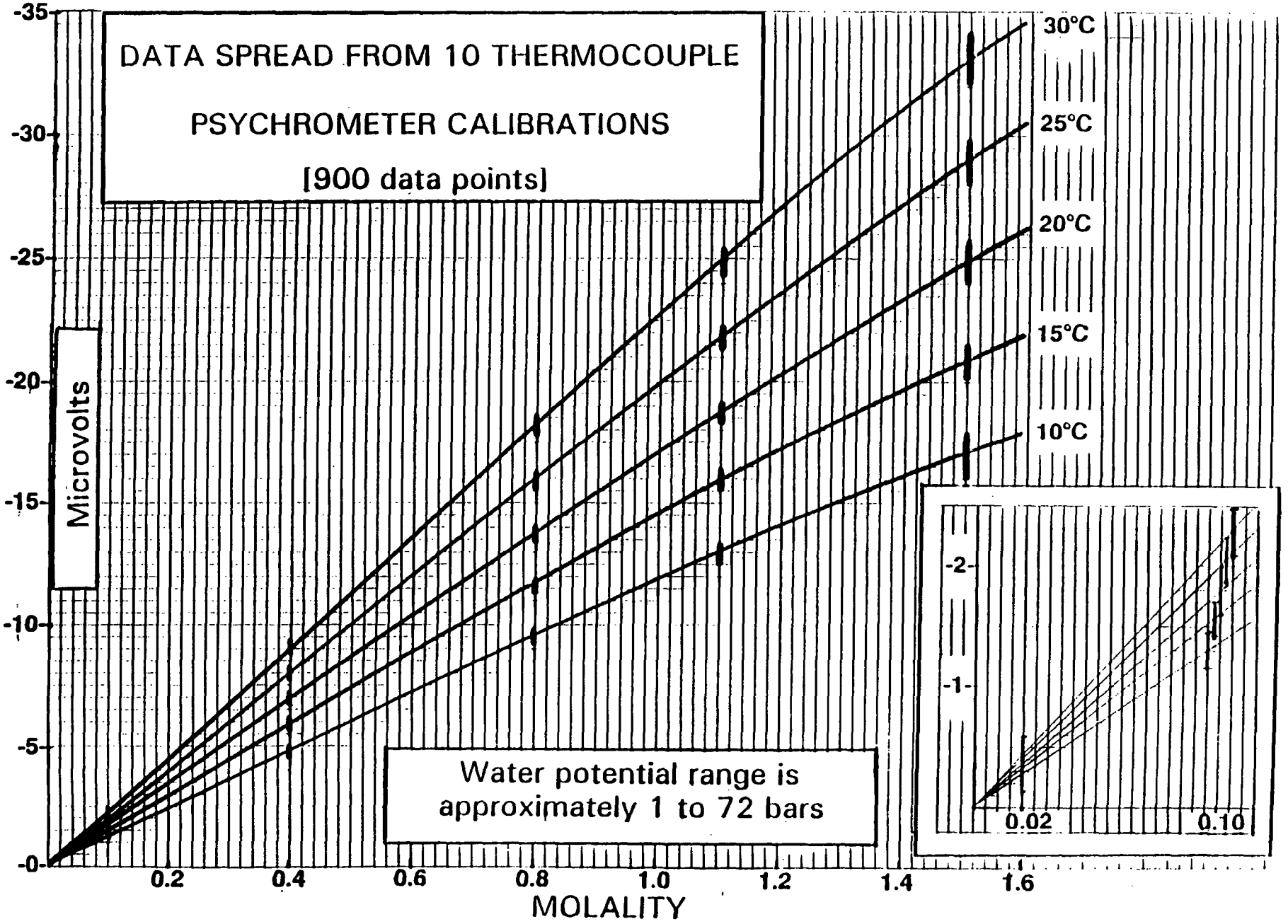
- SUPPORT EQUIPMENT
  - KEITHLEY 181 NANOVOLTMETER
  - KEITHLEY 220 CURRENT GENERATOR
  - KEITHLEY 705 SCANNER
  - KEITHLEY 7168 NANOVOLT CHANNEL ACQUISITION CARD
  - HP-3457 MULTIMETER
  - HP-3497 SCANNER
  - HP-44421A CHANNEL ACQUISITION CARD
  - HP-44422A THERMOCOUPLE COMPENSATED ACQUISITION CARD
  - FLUKE SPRTD
  - HARD SCIENTIFIC PROGRAMMABLE WATER BATH
  - MICROCOMPUTER



THERMOCOUPLE PSYCHROMETER DESIGN



PSYCHROMETER SCANNING SEQUENCE


DATA SPREAD FROM 10 THERMOCOUPLE
PSYCHROMETER CALIBRATIONS
[900 data points]
30°C
25°C
20°C
15°C
10°C
Microvolts
-35
-30
-25
-20
-15
-10
-5
-0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
MOLALITY
Water potential range is
approximately 1 to 72 bars
-2
-1
0.02
0.10

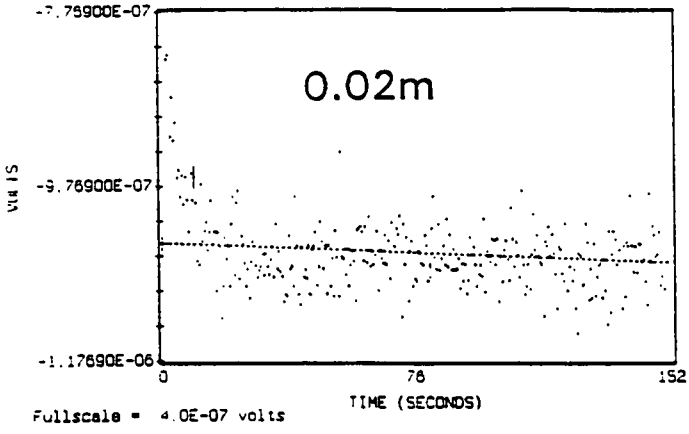
REGRESSION EQUATION FOR MODELING PSYCHROMETER OUTPUT

CUBIC FORM:

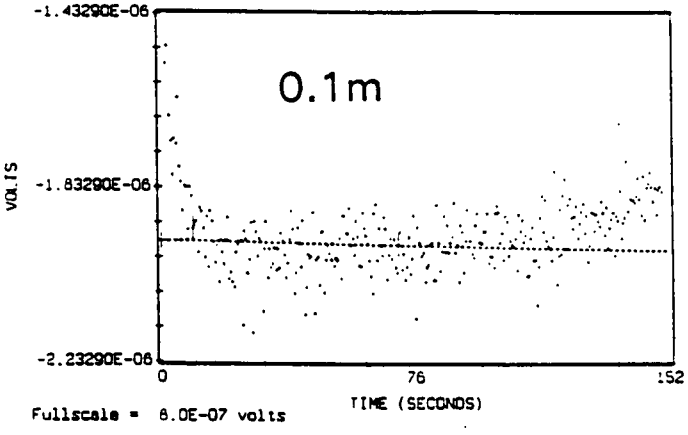
$$BARS = A + B(MICROVOLTS) + C(MICROVOLTS^2) + D(MICROVOLTS)(TEMP) + E(TEMP^2) + F(MICROVOLTS)(TEMP^2)$$

STANDARD ERROR = 0.815

E3-0110 CALIBRATIONS AT 20 DEG C



Fullscale = 4.0E-07 volts



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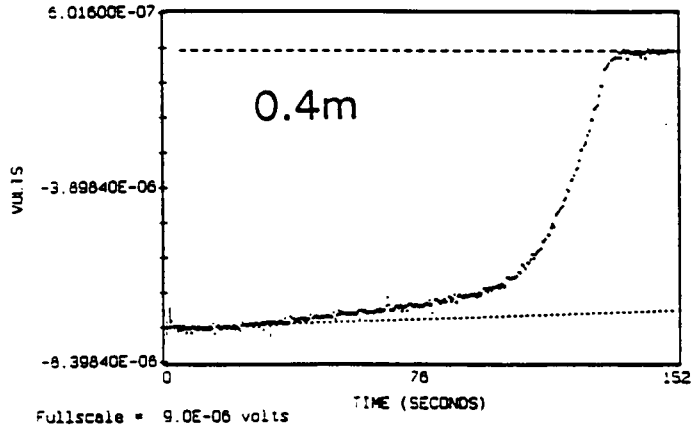
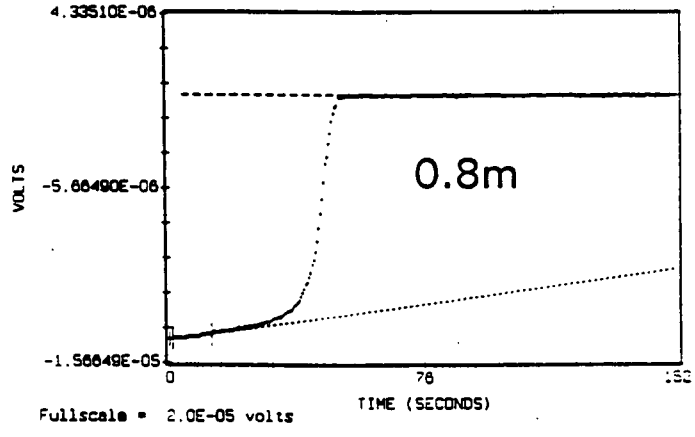
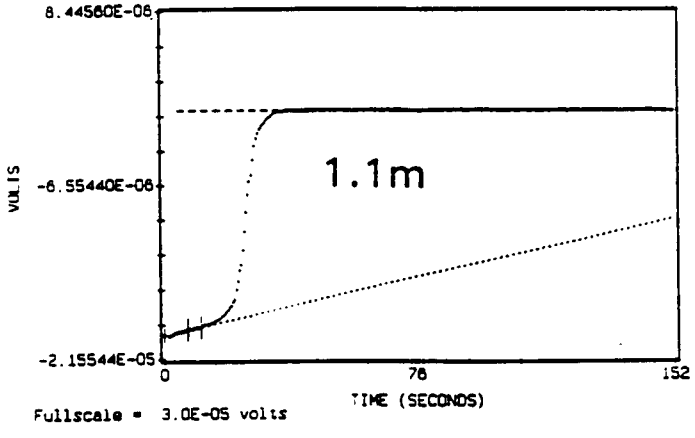


Fullscale = 9.0E-06 volts



Fullscale = 2.0E-05 volts



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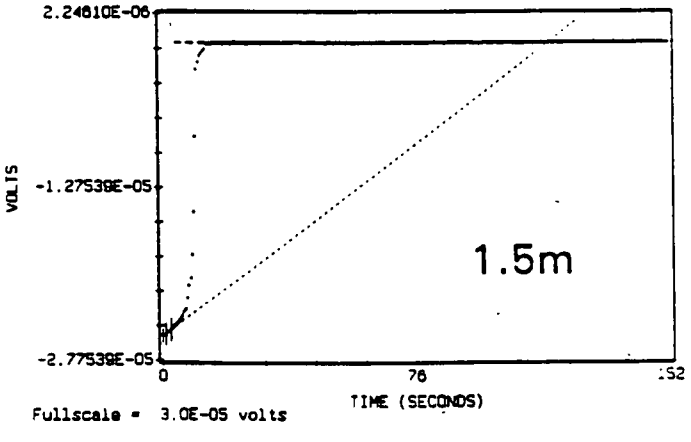
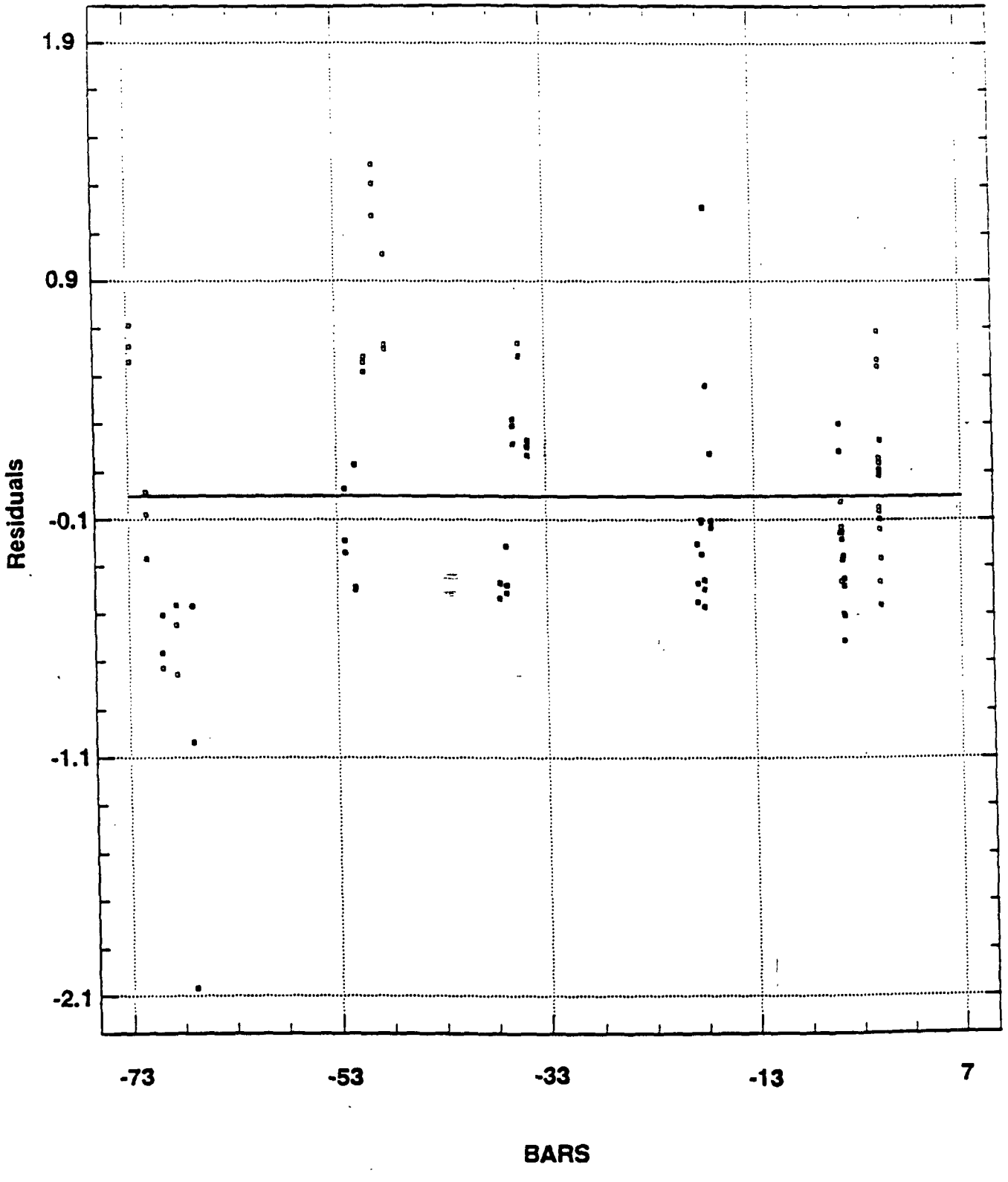
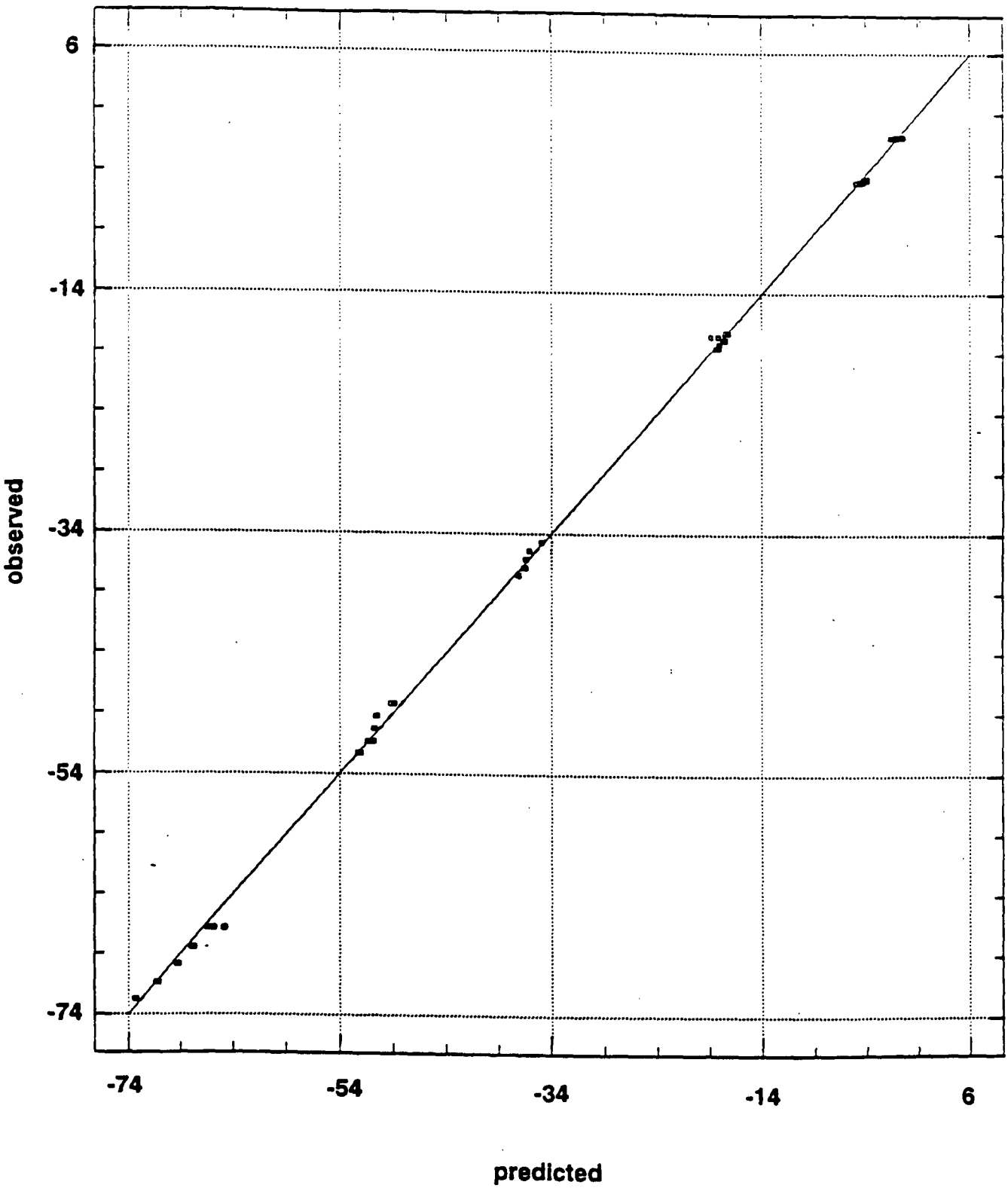


Fullscale = 3.0E-05 volts

Residuals for Psychrometer E6-0083



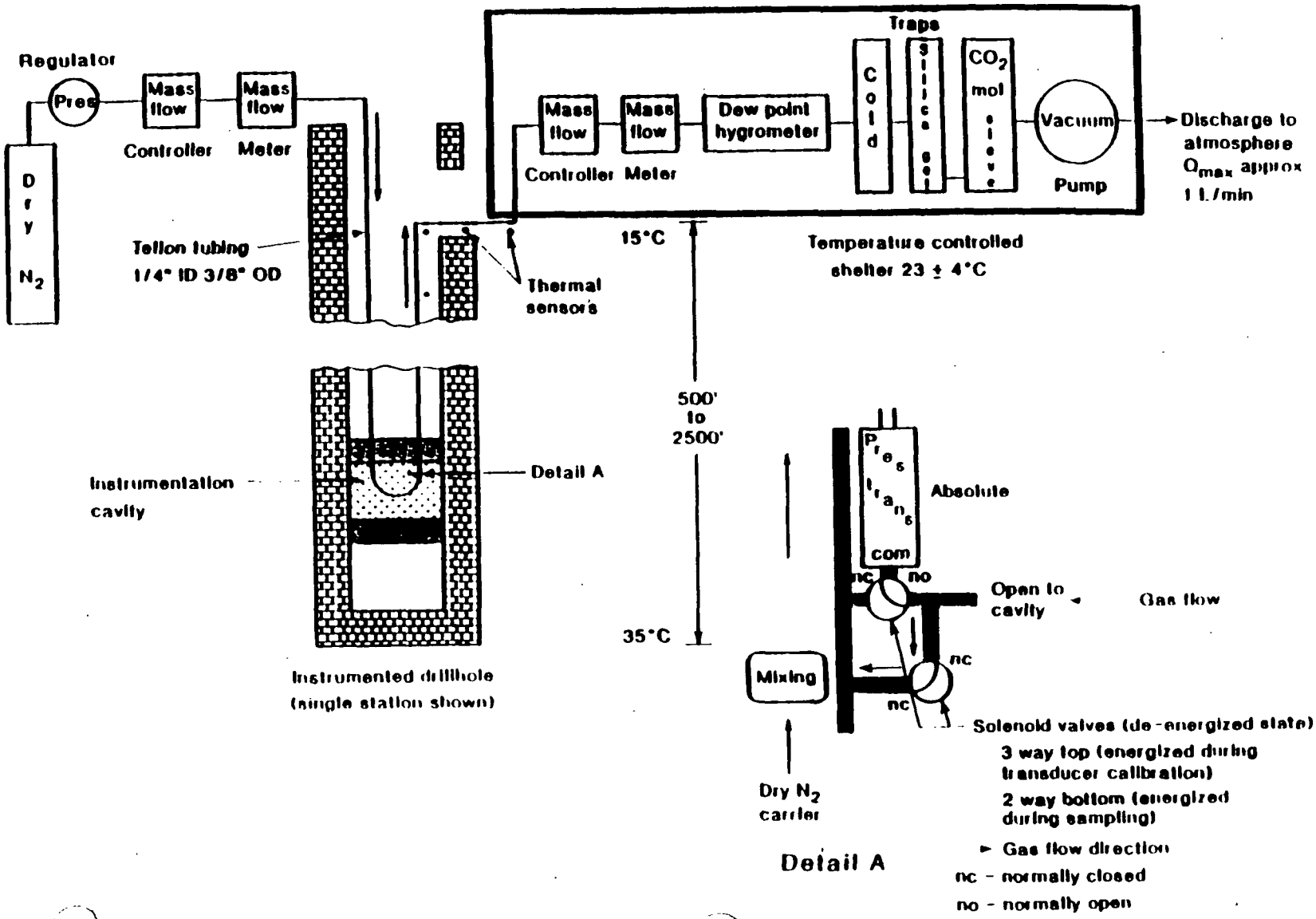
Measured vs Predicted Values



GAS SAMPLING

- ASSUMES CONSERVATION OF MASS (H_2O_V)
- PRODUCES CONTROLLED PERTURBATION
- AIR FLOW FROM MATRIX vs FRACTURES MAY BE DISCERNABLE
- STABILITY OF (H_2O_V) CONCENTRATOIN MAY BE USED TO EVALUATE DEGREE OF FRACTURE INTERCONNECTEDNESS
- EQUIVALENT TO A PUMPING TEST

GENERALIZED SCHEMATIC DIAGRAM FOR GAS SAMPLING IN DRILL HOLES

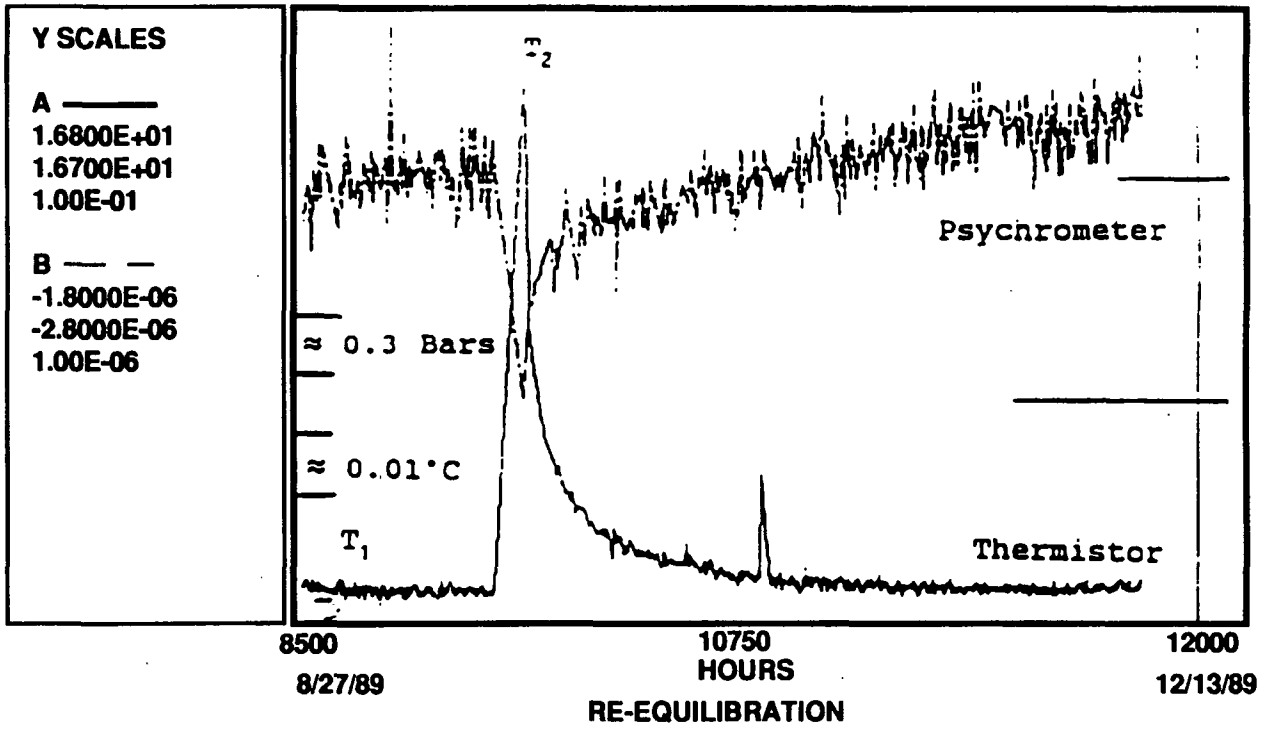


PHOTOGRAPH OF THE DISA (DOWNHOLE INSTRUMENT STATION APPARATUS DISASSEMBLED)

CLOSE UP OF THE DISA SHOWING GAS MIXING AND SOLENOID VALVE CONTROLS

PHOTOGRAPH OF THE DISA ASSEMBLED AND MOUNTED TO CONTROL STEMMING ROD

G TUNNEL DISPLAY PROGRAM VERSION 1.003



CURVE A THMD.ENG
CURVE B TCPD.Q

T_1 = 16.705°C T_2 = 16.780°C
ψ_1 = -4.31 bars ψ_2 = -5.25 bars

ΔT = 0.075°C

$\Delta\Psi$ = 0.94 BARS - FROM CUBIC EQUATION
$\Delta\psi$ = 1.09 BARS - FROM SENSITIVITY OF PSYCHROMETER

TEMPERATURE PERTURBATION DUE TO OPERATION OF 2 WATT SOLENOID VALVE DURING IN-SITU RECALIBRATION OF PRESSURE TRANSDUCER

- NOTE EFFECT ON PSYCHROMETER
- NOTE DURATION OF TIME NEEDED TO RE-EQUILIBRATE T AND ψ > 750 HOURS (30+ DAYS)

* DATA FROM G-TUNNEL UNDERGROUND FACILITY - PROTOTYPE DRILLHOLE INSTRUMENTATION TEST

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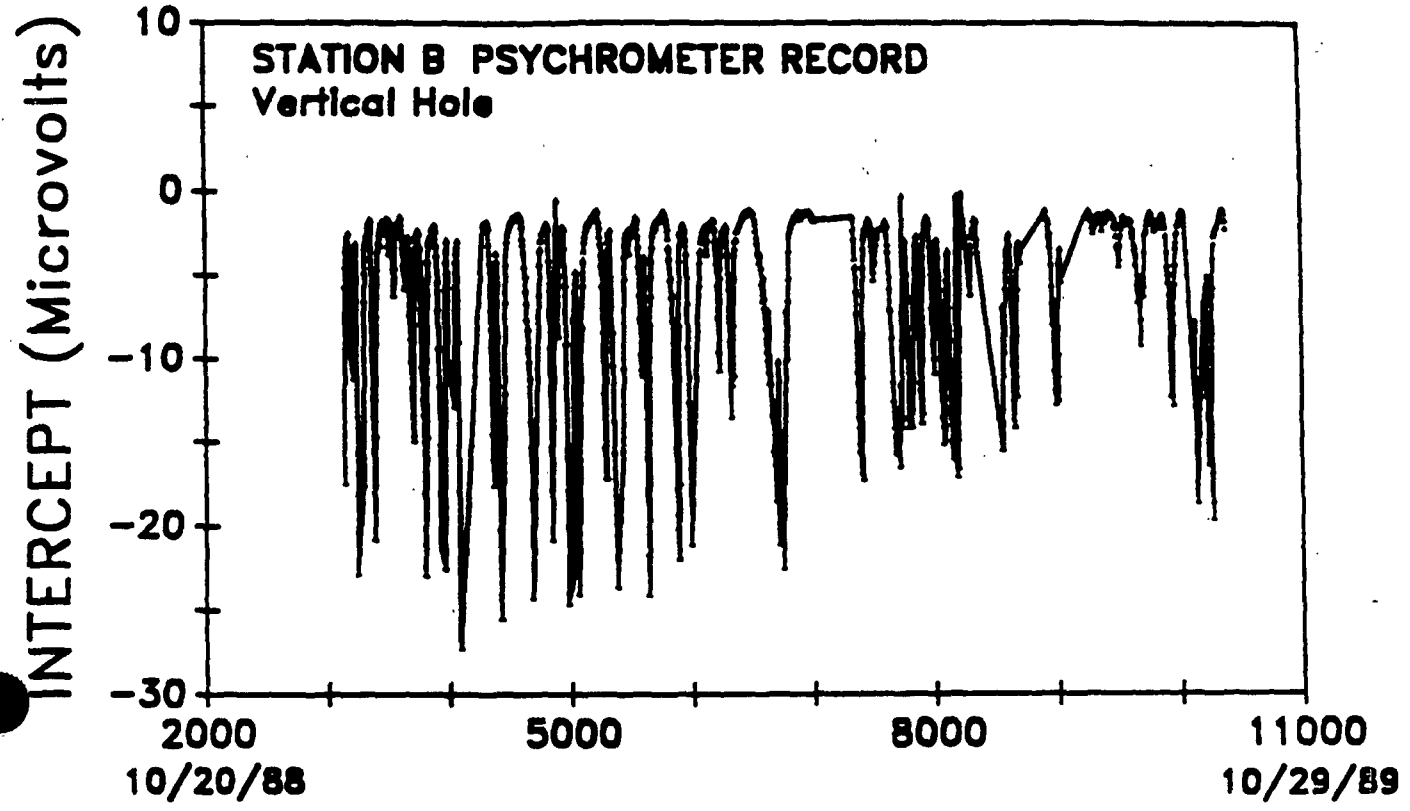
BOREHOLE DI-1 STATION B



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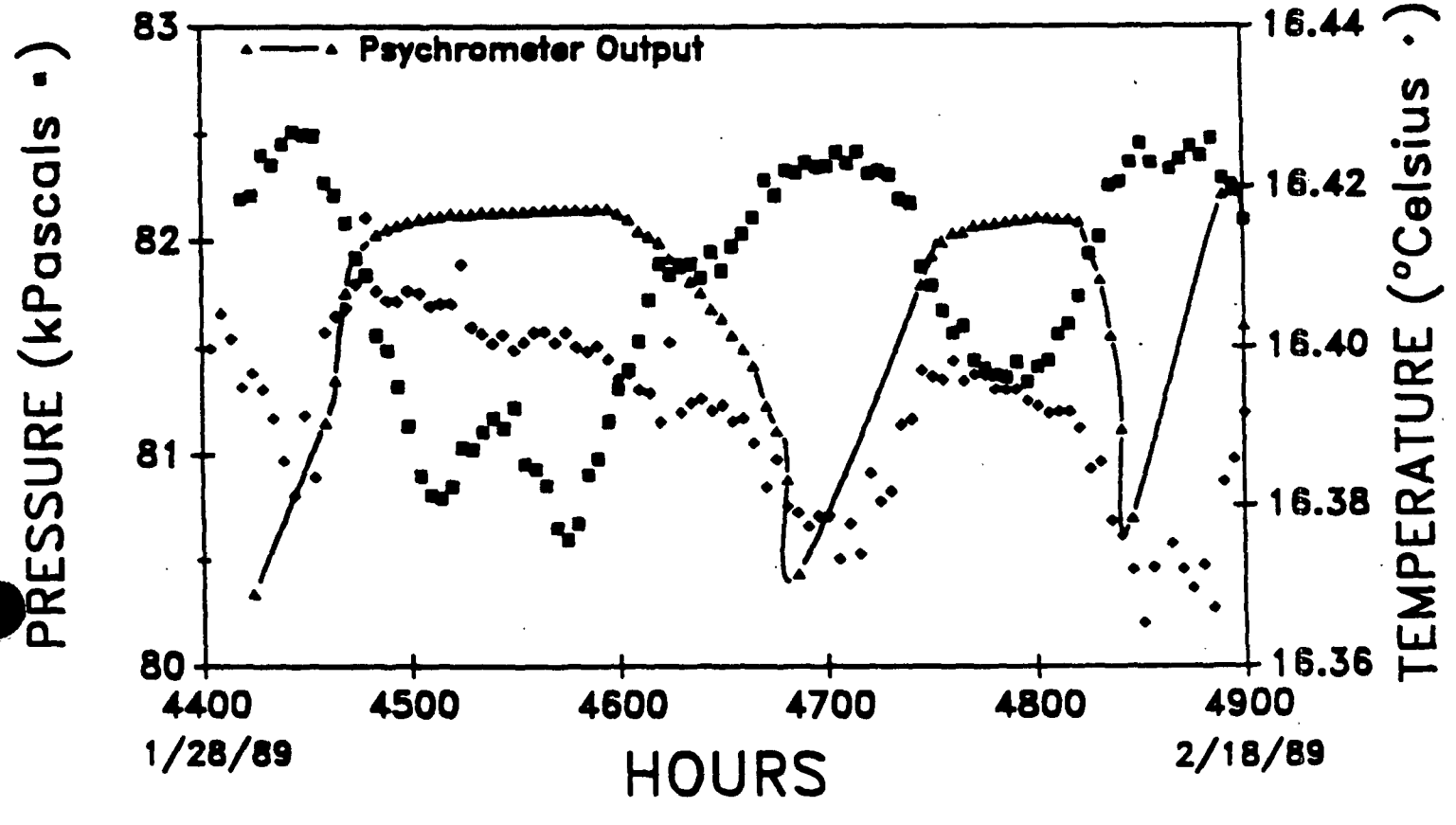

BENEFITS OF IN SITU MONITORING

- **OBSERVE THE DYNAMICS OF THE SYSTEM**
  - IMPACT OF EPISODIC EVENTS
  - IMPACT OF DIURNAL, SEASONAL, AND ANNUAL HARMONICS
- **OBTAIN PNEUMATIC PRESSURE AND TEMPERATURE MEASUREMENTS**
- **EVALUATE EQUILIBRIUM PROCESSES**
- **ISOLATE DISCRETE INTERVALS OF INTEREST**
  - FRACTURE ZONES
  - STRATIGRAPHIC AND STRUCTURAL CONTACTS
  - HYDROGEOLOGIC BOUNDARIES
- **PROVIDE A PLATFORM FOR ISOLATION OF ROCK GASES FOR GEOCHEMICAL SAMPLING**

FUTURE PLANS
HYDROLOGIC RESEARCH FACILITY (HRF)
BOREHOLE PROGRAM

PURPOSE

- **EVALUATION OF LONG -TERM (5-10 YEARS) SENSOR DRIFT CHARACTERISTICS**

- **TEST BED FACILITY FOR:**
  - **GAS SAMPLING**
  - **IN SITU PRESSURE TRANSDUCER RECALIBRATION**
  - **WATER INJECTION TESTING**
  - **GAS TRACER TESTING**

- **TRAINING**

FUTURE PLANS
HYDROLOGIC RESEARCH FACILITY (HRF) BOREHOLE PROGRAM

(CONTINUED)

SCOPE

- 3 - 40 ft. DEEP AUGERED BOREHOLES
- 4 - INSTRUMENT STATIONS/BOREHOLE (12 INSTRUMENT STATIONS TOTAL)
- SOLID STEMMING DESIGN
- REMOVABLE SENSOR PACKAGES