PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: DEEP BOREHOLE TESTING FOR FLOW PROCESSES

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REGISTRY HOTEL, DENVER, COLORADO
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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

<table>
<thead>
<tr>
<th><strong>DRY DRILLING AND CONTINUOUS CORING</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- 19 VERTICAL BOREHOLES - 32,000 FEET</td>
</tr>
<tr>
<td>- 1 (+) HORIZONTAL BOREHOLE - 1,000 FEET</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>HYDRO INSTRUMENTATION OF 17 VERTICAL AND 1 (+) HORIZONTAL BOREHOLE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- PASSIVE IN-SITU MONITORING - 3 TO 5 YEARS</td>
</tr>
<tr>
<td>- ACTIVE IN-SITU TESTING - INTERMITTENT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>GEOPHONE INSTRUMENTATION OF 2 VERTICAL BOREHOLES</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- CROSS HOLE TOMOGRAPHY</td>
</tr>
<tr>
<td>- VERTICAL SEISMIC PROFILING (VSP)</td>
</tr>
</tbody>
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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
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
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

<table>
<thead>
<tr>
<th>DEGREE OF SIMPLIFICATION</th>
<th>SYSTEM DESCRIPTION</th>
<th>DOMINANT FLOW PROCESSES &amp; GEOMETRIES</th>
<th>CANDIDATE HYDROGEOLOGIC UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>Isothermal Flow, Homogenous Porous Media</td>
<td>Single phase, liquid flow, simple boundaries</td>
<td>Paintbrush, nonwelded vitric tuff</td>
</tr>
<tr>
<td></td>
<td>Isothermal Flow, Heterogeneous Porous Media</td>
<td>Single phase, liquid flow, REVs with simple boundaries</td>
<td>Calico Hills, nonwelded zeolitized tuff</td>
</tr>
<tr>
<td></td>
<td>Non-Isothermal Flow, Heterogeneous Porous Media</td>
<td>Liquid and gas flow, REV's with simple to complex boundaries</td>
<td>Calico Hills, nonwelded vitric tuff</td>
</tr>
<tr>
<td>low</td>
<td>Non-Isothermal Flow, Heterogeneous Fractured, Porous Media</td>
<td>Liquid and gas flow, continuum approach with simple to complex boundaries</td>
<td>Topopah Spring densely welded tuff</td>
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<td></td>
<td>Liquid and gas flow, discrete fracture systems, complex boundaries, transients</td>
<td>Liquid and gas flow, discrete fractures with internal and external boundaries, complex circulation systems, perched water, transients</td>
<td>Tiva Canyon densely welded tuff</td>
</tr>
<tr>
<td></td>
<td>Liquid and gas flow, discrete fractures with internal and complex circulation systems, perched water, transients</td>
<td>Faults, topographic features and surface drainages</td>
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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: > ± 0.005 PSIA - 2 + σ (SEMICONDUCTOR STRAIN GAUGE)
  - TEMPERATURE: > ±0.005°C - 2 + σ (THERMISTOR)
  - WATER POTENTIAL (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

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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
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
SUPPORT EQUIPMENT
- KEITHLEY 181 NANOVOLTTRMETER
- 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]

Water potential range is approximately 1 to 72 bars
REGRESSION EQUATION FOR MODELING PSYCHROMETER OUTPUT

CUBIC FORM:

\[ \text{BARS} = A + B(\text{MICROVOLTS}) + C(\text{MICROVOLTS}^2) + D(\text{MICROVOLTS})(\text{TEMP}) + E(\text{TEMP}^2) + F(\text{MICROVOLTS})(\text{TEMP}^2) \]

STANDARD ERROR = 0.815
E3-0110 CALIBRATIONS AT 20 DEG C

0.02m

0.1m

0.4m

0.8m

1.1m

1.5m

Fullscale = 4.0E-07 volts

Fullscale = 8.0E-07 volts

Fullscale = 9.0E-06 volts

Fullscale = 2.0E-05 volts

Fullscale = 3.0E-05 volts

Fullscale = 3.0E-05 volts
Residuals for Psychrometer E6-0083

Residuals

BARS

-73 -53 -33 -13 7
Measured vs Predicted Values

predicted

observed
GAS SAMPLING

- Assumes conservation of mass \((H_2O_v)\)
- Produces controlled perturbation
- Air flow from matrix vs fractures may be discernable
- Stability of \((H_2O_v)\) concentration may be used to evaluate degree of fracture interconnectedness
- Equivalent to a pumping test
GENERALIZED SCHEMATIC DIAGRAM FOR GAS SAMPLING IN DRILL HOLES

Regulator

Press

Mass flow

Mass flow

Controller

Meter

Teflon tubing
1/4" ID 3/8" OD

15°C

Temperature controlled shelter 23 ± 4°C

500' to 2500'

35°C

Detail A

Instrumented drillhole (angle station shown)

Instrumentation cavity

Detail A

Discharge to atmosphere

O_{max} approx 11 l/min

Dry N₂
carrier

Solenoid valves (de-energized state)
3 way top (energized during transducer calibration)
2 way bottom (energized during sampling)

Gas flow direction

nc - normally closed
no - normally open
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

Y SCALES

A
1.6800E+01
1.6700E+01
1.00E-01

B
-1.8000E-06
-2.8000E-06
1.00E-06

T2
1.6800E+01
1.6700E+01
1.00E-01

≈ 0.3 Bars
≈ 0.01°C

T1

T1 = 16.705°C
ψ1 = -4.31 bars
ΔT = 0.075°C

T2 = 16.780°C
ψ2 = -5.25 bars

Δψ = 0.94 BARS - FROM CUBIC EQUATION
Δψ = 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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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