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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: IN SITU THERMOMECHANICAL PROPERTIES TESTING

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JUNE 25-27, 1991

IN SITU THERMOMECHANICAL INVESTIGATIONS STUDY

(STUDY PLAN 8.3.1.15.1.6)

PURPOSE:

- PROVIDE INFORMATION TO VALIDATE COMPUTER CODES USED IN HEAT TRANSFER AND THERMOMECHANICAL CALCULATIONS
- PROVIDE INFORMATION ON THE ROCK MASS THERMOMECHANICAL RESPONSE AT INCREASINGLY LARGER SCALE (UP TO ROOM SCALE)
- DEMONSTRATION OF THE RESPONSE OF A REPRESENTATIVE REPOSITORY DRIFT (REPRESENTATIVE SIZE, SHAPE, AND GROUND SUPPORT) TO EXPECTED THERMOMECHANICAL CONDITIONS

IN SITU THERMOMECHANICAL PROPERTIES

SCP APPROACH

- HEATER EXPERIMENT IN UNIT TSw1
- CANISTER-SCALE HEATER EXPERIMENT
- YUCCA MOUNTAIN HEATED BLOCK
- THERMAL STRESS MEASUREMENTS
- HEATED ROOM EXPERIMENT

IN SITU THERMOMECHANICAL PROPERTIES

(CONTINUED)

POST-SCP MODIFICATIONS

- **MINOR CONFIGURATION CHANGES**
  - HEATER TESTS IN VERTICAL MODE
  - THERMAL STRESS TEST
  - HEATER TEST IN TSw1 WILL BE FULL SCALE

IN SITU THERMOMECHANICAL PROPERTIES

(CONTINUED)

- PURPOSE AND RATIONALE
- DESCRIPTION
- EXPERIENCE
- ANALYSES

HEATER EXPERIMENTS

PURPOSE AND RATIONALE

PURPOSE:

- OBTAIN THERMAL AND THERMOMECHANICAL ROCK MASS DATA IN TSw1 AND TSw2 HORIZONS
- DETERMINE THE UPPER THERMAL LIMITS FOR BOREHOLE STABILITY
- CANISTER-SCALE MOCK-UP

RATIONALE:

- DATA WILL BE USED TO VALIDATE THERMAL AND THERMOMECHANICAL MODELS
- THERMAL OVERDRIVE WILL DEMONSTRATE THAT THE BOREHOLE TEMPERATURES CAN BE RAISED TO AND BEYOND THE UPPER DESIGN TEMPERATURE AND WILL BE USED BY DESIGNERS TO ASSESS RETRIEVABILITY

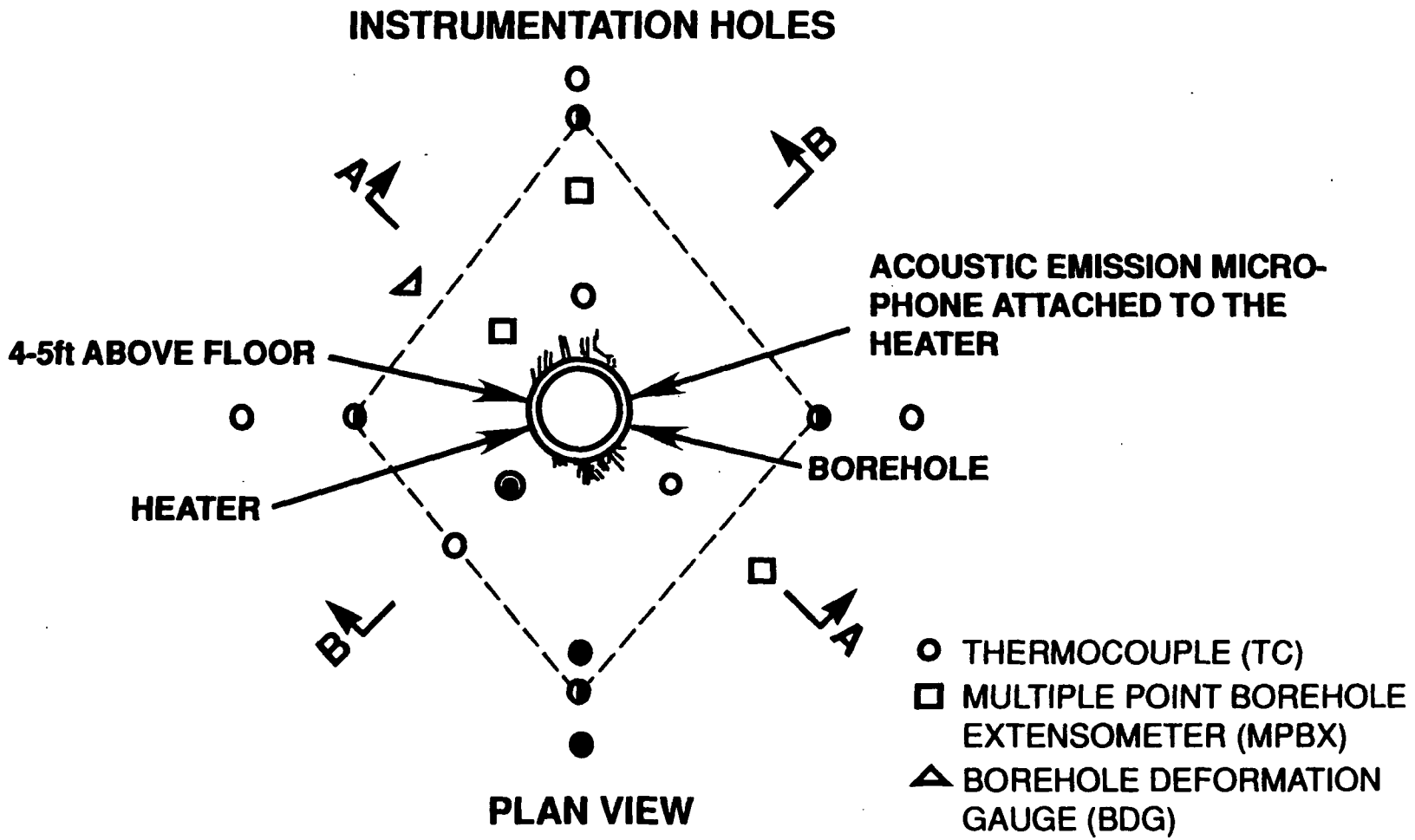
HEATER EXPERIMENTS

(CONTINUED)

TEST DESCRIPTION

- EXPERIMENT PRIMARILY INVOLVES DISPLACEMENT AND TEMPERATURE MEASUREMENTS (MPBX AND THERMOCOUPLE)
- ALSO MONITOR MOISTURE AND RADON EMANATION
- EXPERIMENT WILL BE RUN AT 3 kW FOR 9 MONTHS FOR MODEL VALIDATION
- OVERDRIVE WILL BE RUN IMMEDIATELY AFTER MODEL VALIDATION UP TO 12kW

PLAN VIEW SHOWING HEATER AND INSTRUMENTATION HOLES



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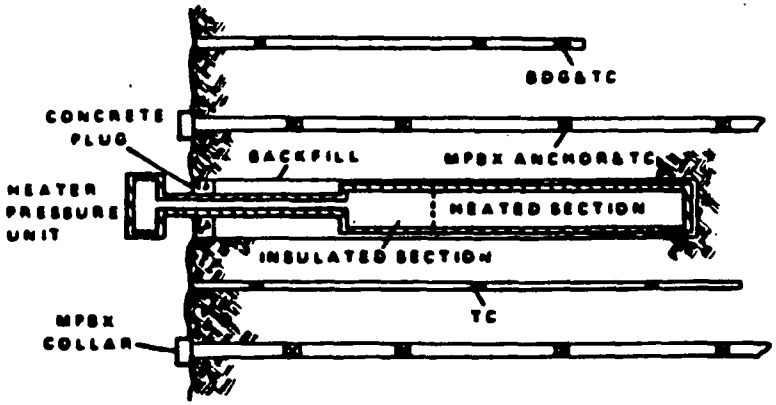
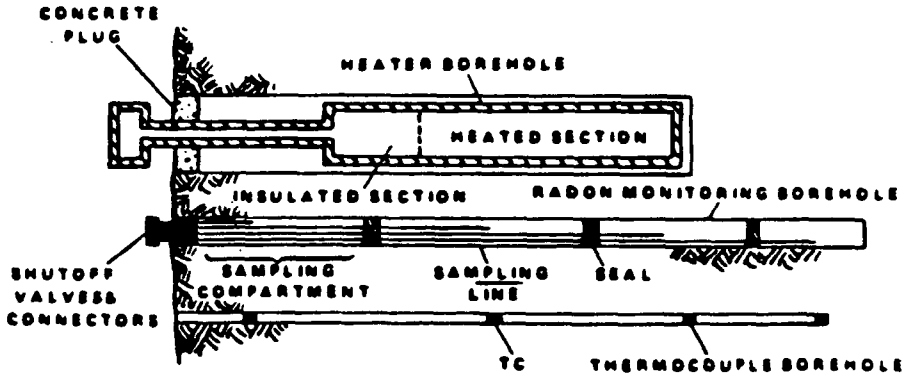
TYPICAL LAYOUT OF HEATER AND INSTRUMENTATION



SECTION A–A

TYPICAL LAYOUT OF RADON-MONITORING BOREHOLE



SECTION B–B

HEATER EXPERIMENTS

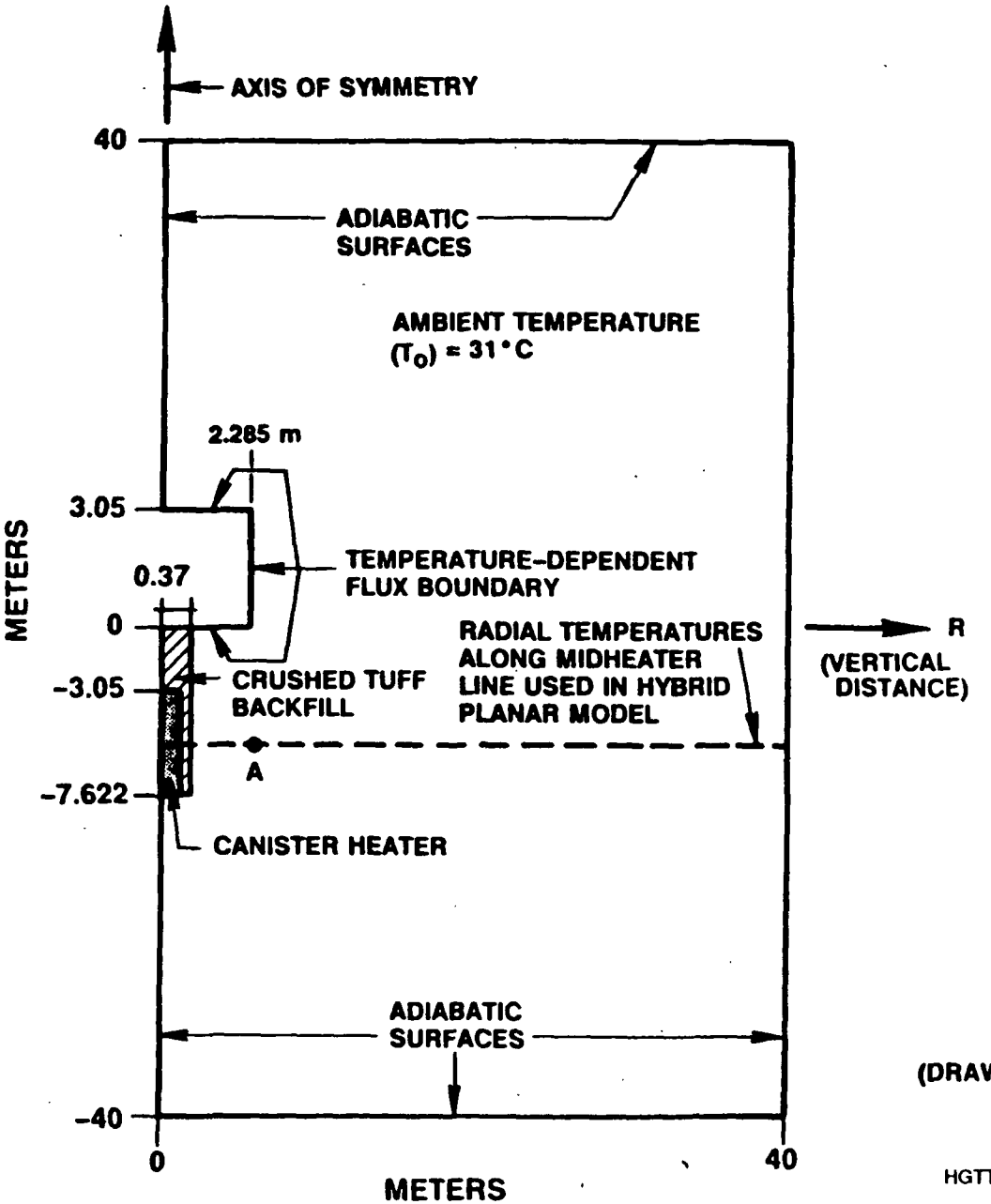
(CONTINUED)

EXPERIENCE

- PROTOTYPE TESTING IN G-TUNNEL CONFINED TO SMALL-SCALE HEATERS (EARLY 1980's)

- PRE-TEST ANALYSES OF THIS EXPERIMENT PERFORMED IN 1988. PROVIDED INFORMATION ON REQUIRED HEATER POWER TO ACHIEVE THERMAL OVERDRIVE. PROVIDED INFORMATION ON EXPECTED TEMPERATURE AND DISPLACEMENT FIELD

AXISYMMETRIC THERMAL MODEL



(DRAWING NOT TO SCALE)

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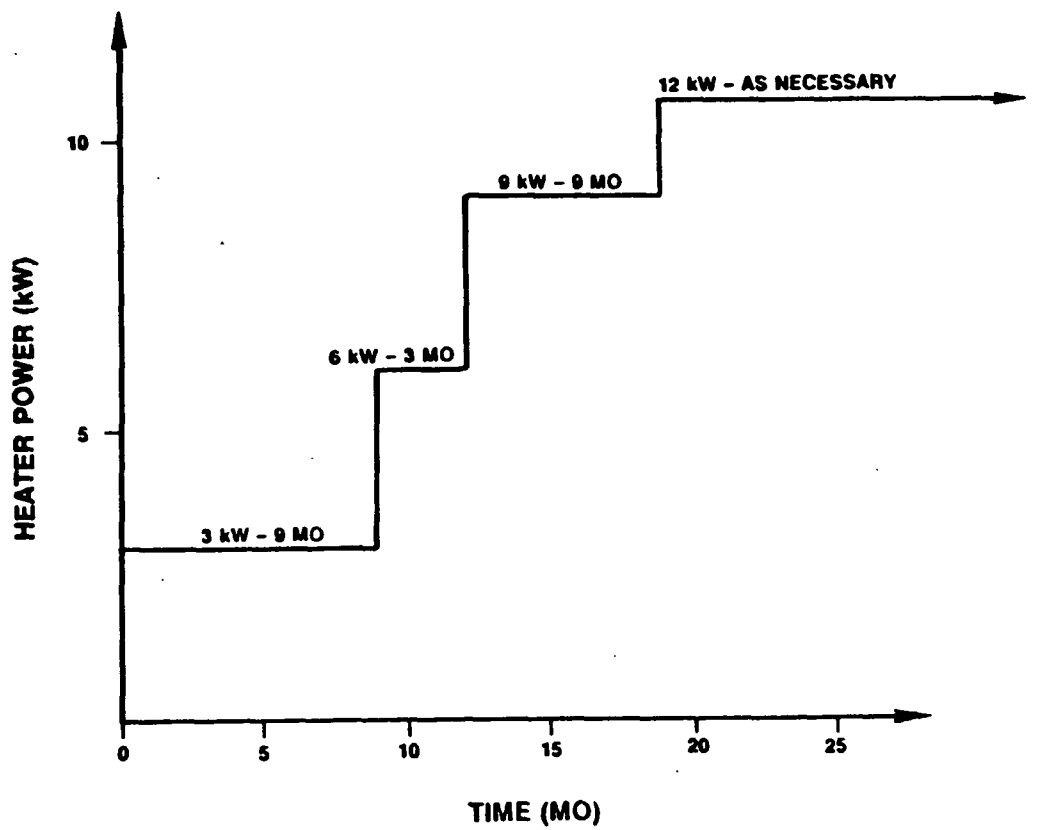
POWER SCHEDULE FOR THE CANISTER-SCALE HEATER TEST (FROM SCP)



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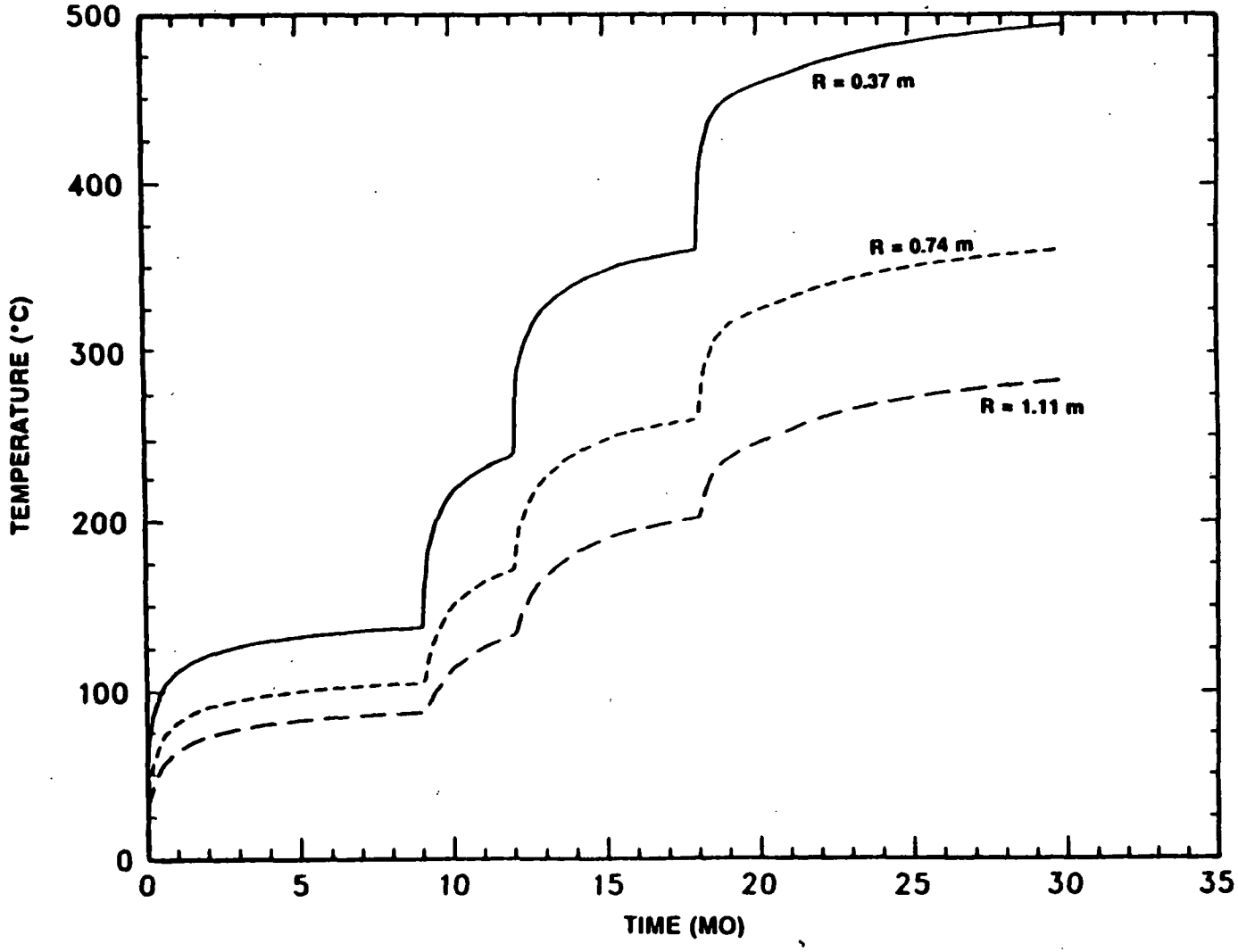
TEMPERATURE HISTORIES AT SELECTED RADII (R) AT HEATER MIDHEIGHT



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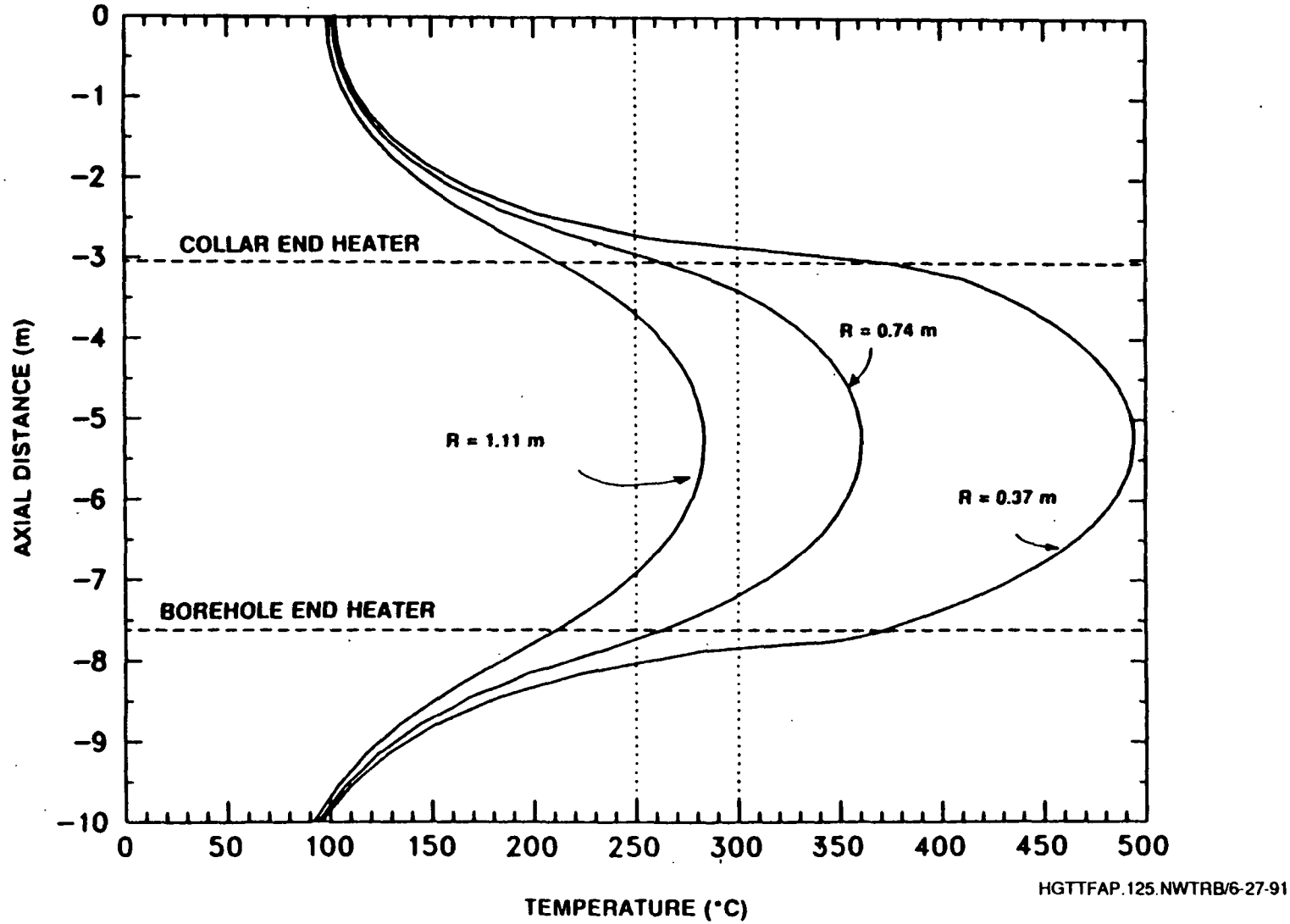
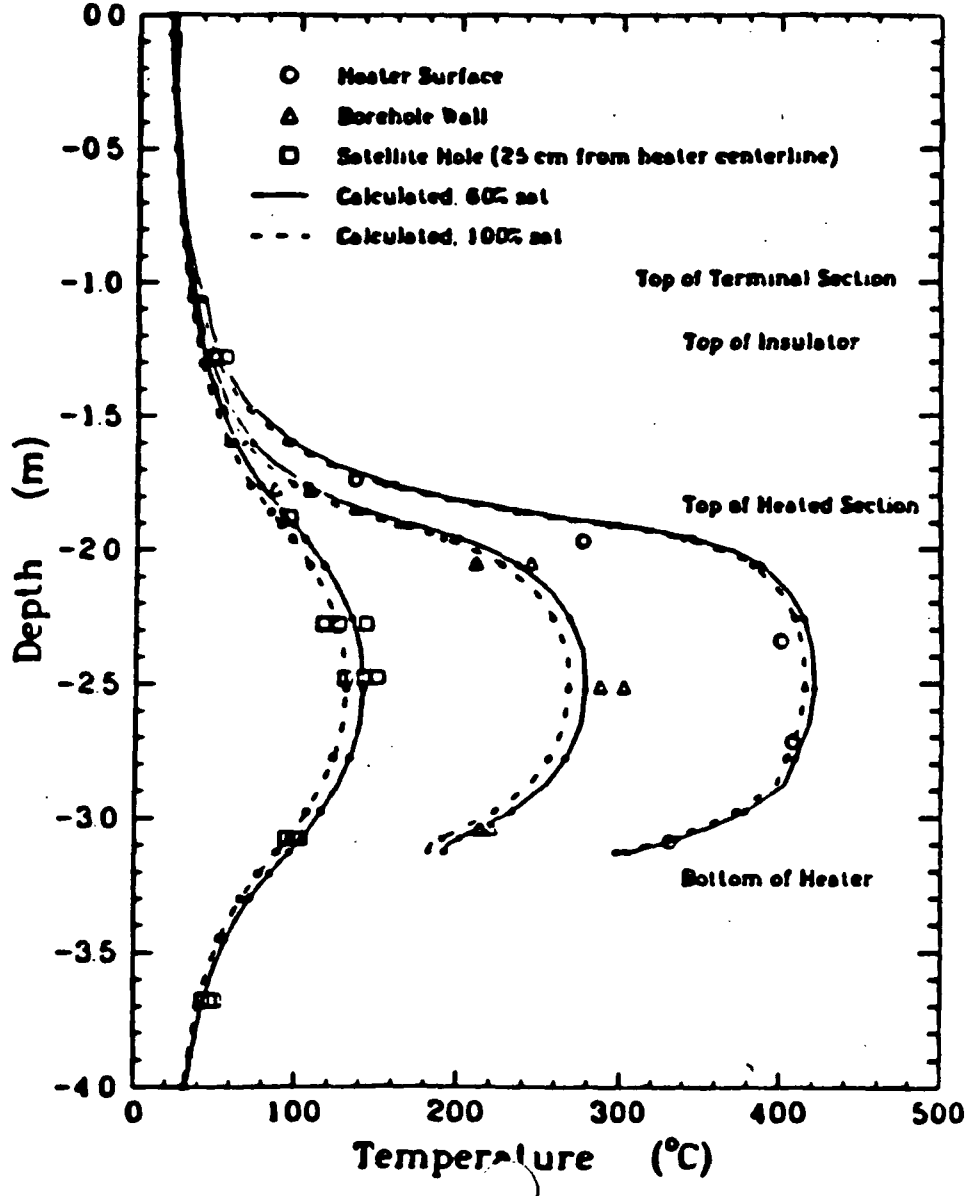
AXIAL TEMPERATURE PROFILES AFTER 30 MONTHS OF HEATING FOR THE AXISYMMETRIC MODEL AT SELECTED RADIAL DISTANCES (R)



COMPARISON OF MEASURED AND CALCULATED TEMPERATURE PROFILES FOR THE WELDED TUFF SMALL-DIAMETER HEATER EXPERIMENT



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YUCCA MOUNTAIN HEATED BLOCK TEST

OBJECTIVES

- **PREDICT ROCK MASS THERMOMECHANICAL BEHAVIOR**
  - INTERMEDIATE SCALE BLOCK ($8m^3$)
  - CAPTURE REPRESENTATIVE FRACTURES IN WELDED TUFF
  - USE TEMPERATURES AND PRESSURES PERTINENT TO WASTE REPOSITORY
- **PROVIDE FIELD MEASUREMENTS OF PROPERTIES**
  - ONE DIMENSIONAL HEAT FLUX
  - UNIAXIAL AND BIAXIAL STRESS STATES
  - STRESS-TEMPERATURE VARIATIONS
- **PROVIDE GEOMETRY FOR MODELING**

YUCCA MOUNTAIN HEATED BLOCK TEST

(CONTINUED)

DESCRIPTION

- ISOLATE 2 x 2 x 2 m BLOCK
- USE FLATJACKS IN SLOTS FOR STRESS APPLICATION
- PLACE LINES OF HEATERS ON TWO SIDES OUTSIDE OF FLATJACKS
- APPLY PRESSURE AND TEMPERATURE CYCLES
  - AXIAL AND LATERAL DEFORMATION MEASUREMENTS
  - ASSESS THERMAL EXPANSION
  - ASSESS THERMAL CONDUCTIVITY AND HEAT CAPACITY
  - MOISTURE CHANGE

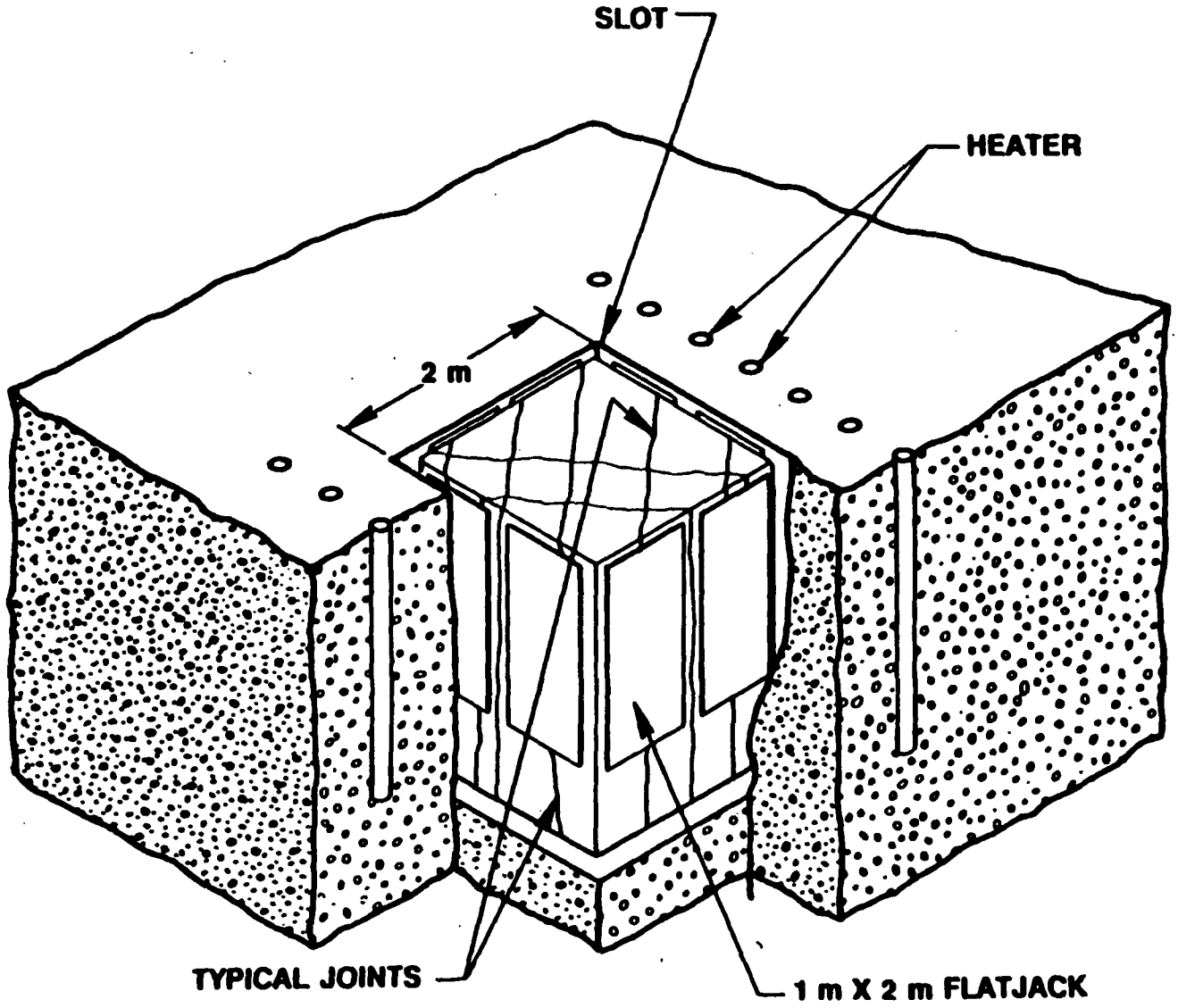
YUCCA MOUNTAIN HEATED BLOCK TEST

(CONTINUED)

PREVIOUS EXPERIENCE

- G-TUNNEL HEATED BLOCK (STARTED 1981)
  - RESULTS IN SAND84-2620
- ANALYSES BY COSTIN AND CHEN, SAND87-2699
  - COMPLIANT JOINT MODEL
  - PARAMETER VARIATION SENSITIVITY STUDY
- COMBINATION OF PROTOTYPE EXPERIENCE AND ANALYSES TO GUIDE ESF PLAN

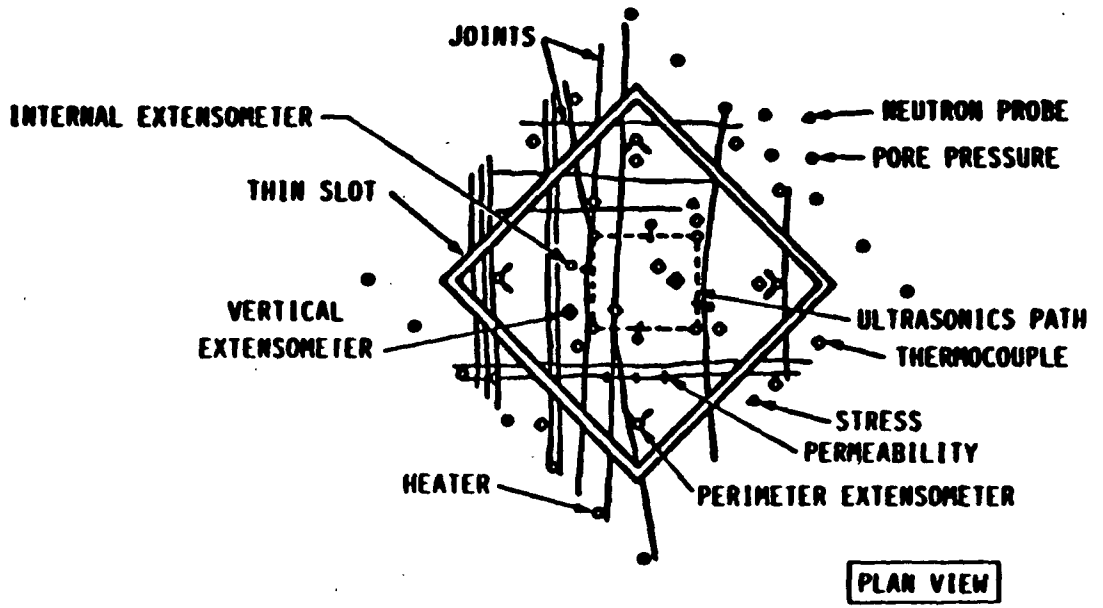
G-TUNNEL HEATED BLOCK EXPERIMENT



YUCCA MOUNTAIN HEATED BLOCK TEST

(CONTINUED)

G-TUNNEL INSTRUMENTATION ARRANGEMENT



YUCCA MOUNTAIN HEATED BLOCK TEST

(CONTINUED)

DATA ANALYSES

- **MEASUREMENT OF ROCK MASS PROPERTIES**
  - ROCK MASS MODULUS
  - POISSON'S RATIO
- **ASSESS VALIDATION AND PREDICTION OF CODES**
  - PROVIDE A BETTER ESTIMATE OF ROCK MASS PROPERTIES
  - ANALYZE THERMAL AND MECHANICAL EFFECTS
  - EVALUATE COMPLIANT JOINT MODEL WITH ORTHOGONAL JOINT SETS
  - PROVIDE IMPROVEMENTS IN EXPERIMENTAL TECHNIQUES

YUCCA MOUNTAIN HEATED BLOCK TEST

(CONTINUED)

MODELING
(COSTIN AND CHEN, 1988, SAND87-2699)

- JAC - MECHANICAL RESPONSE (BIFFLE, 1984)
  - MATERIAL MODEL - CONTINUUM FOR JOINTED ROCK WITH ORTHOGONAL JOINTS (CHEN, 1987)

- COYOTE - THERMAL ANALYSIS (GARTLING, 1982)

- MODELING RESULTS PROVIDED MANY SUGGESTIONS FOR IMPROVEMENT OF THE BLOCK TEST IN ESF

YUCCA MOUNTAIN HEATED BLOCK TEST

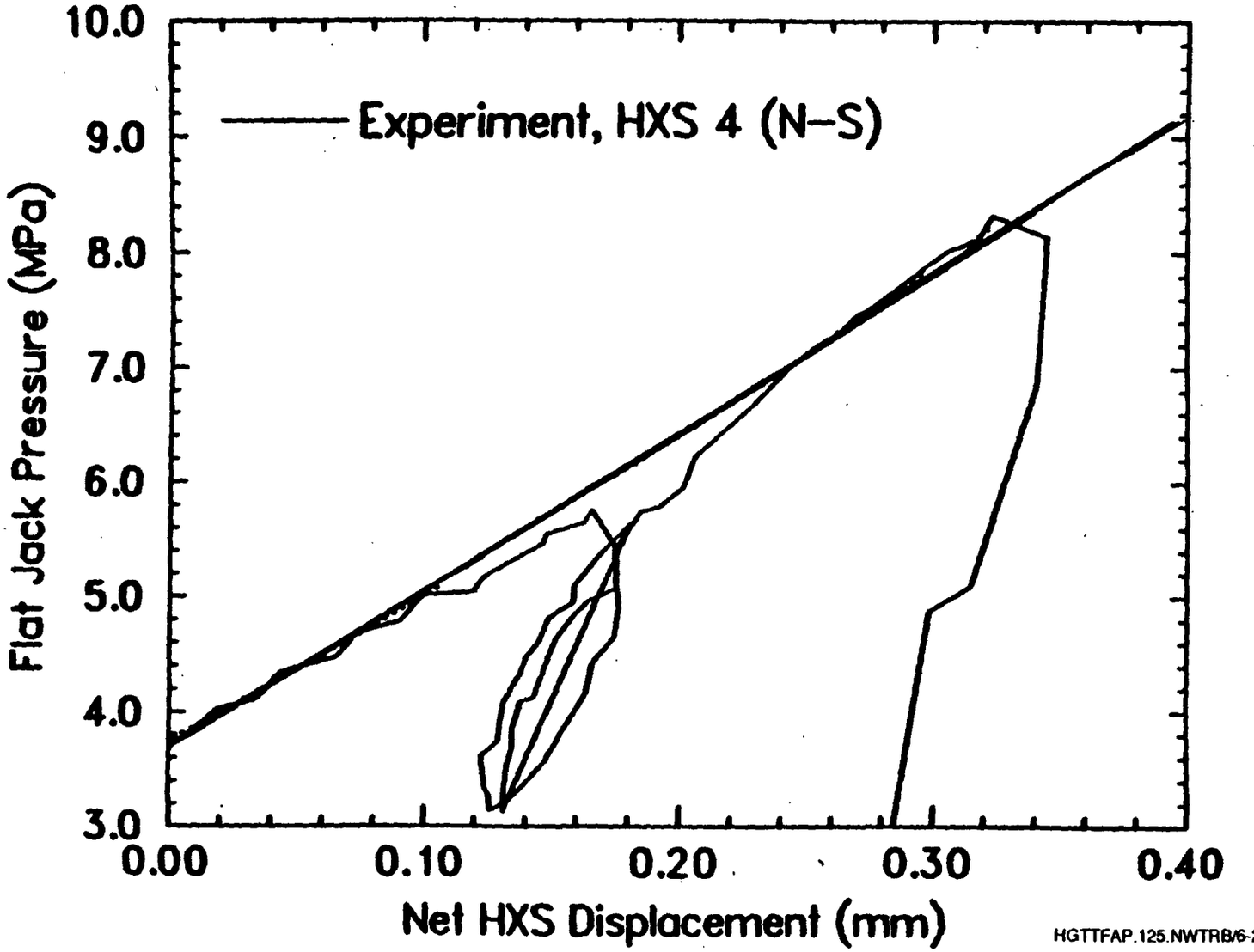
(CONTINUED)

MODELING RESULTS

- **BIAXIAL LOADING**
  - PERMANENT DEFORMATION UPON UNLOADING NOT MODELED
  - LOADING vs DISPLACEMENT MATCHED BY PARAMETER VARIATION
  - STRESSES TOO LOW TO TEST MODEL CAPABILITIES
- **UNIAXIAL LOADING**
  - DOMINATED BY JOINT SHEAR
  - POORLY CONSTRAINED EXPERIMENT

MODELING RESULTS

Biaxial Cycle 1 – 2 – 3



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YUCCA MOUNTAIN HEATED BLOCK TEST

(CONTINUED)

MODELING RESULTS

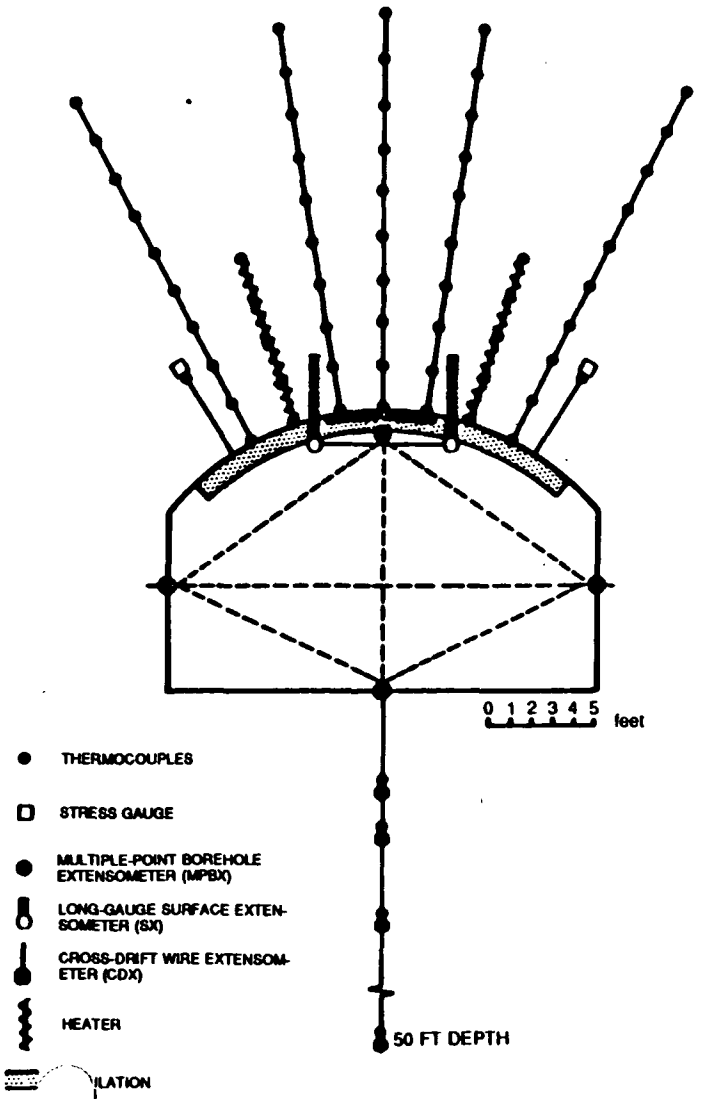
- **THERMAL**
  - HEAT LOSS CORRECTION
- **CONCLUSIONS**
  - NUMEROUS SUGGESTIONS FOR FUTURE TEST(S) (COSTIN AND CHEN, 1988)

THERMAL STRESS EXPERIMENT

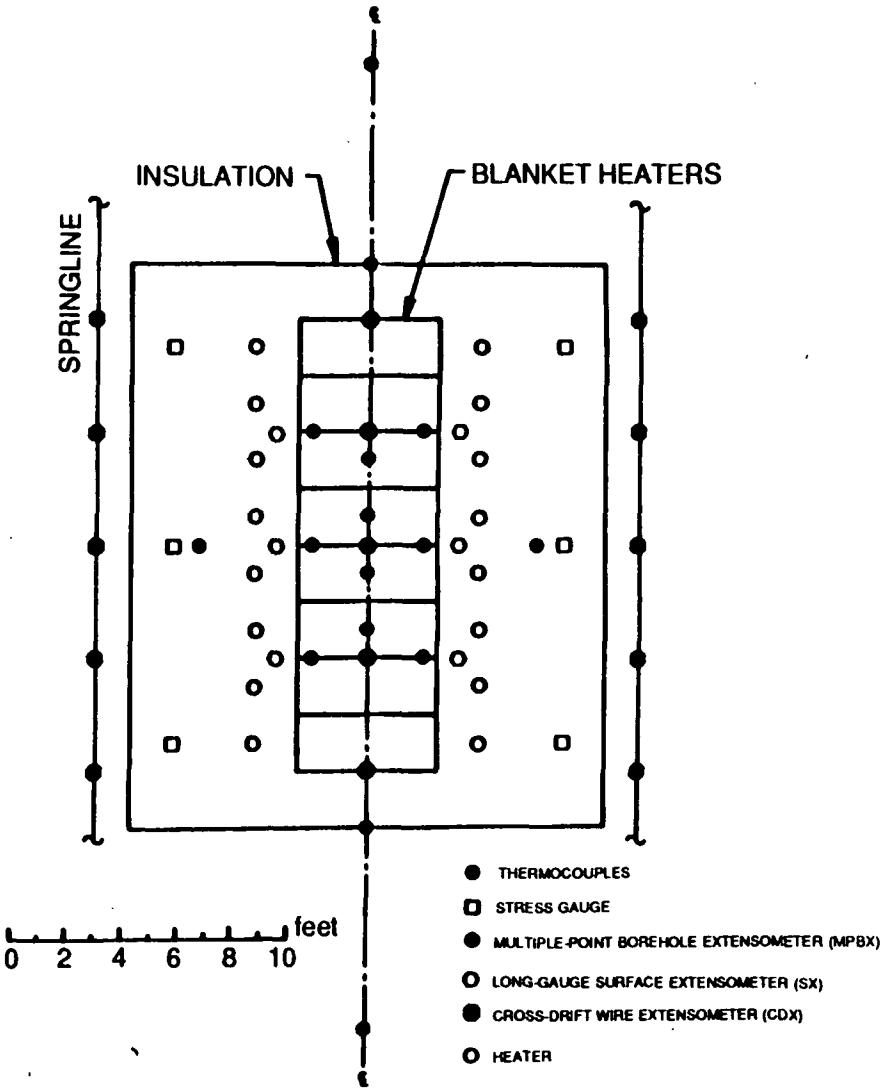
OBJECTIVES

- **ESF TEST**
  - DEMONSTRATE STABILITY OF REPOSITORY-SCALE OPENING SUBJECTED TO THERMAL AND MECHANICAL LOADS
  - PROVIDE DATA TO VALIDATE CONSTITUTIVE MODELS USED TO PREDICT THERMOMECHANICAL BEHAVIOR AS WELL AS FAILURE CRITERIA USED TO ASSESS STABILITY
- **PROTOTYPE TEST**
  - ASSESS THERMAL STRESS EXPERIMENT
  - EVALUATE INSTRUMENTS
  - CONTRIBUTE TO MODEL VALIDATION

PROTOTYPE THERMAL STRESS TEST LAYOUT: SECTION VIEW



PROTOTYPE THERMAL STRESS TEST LAYOUT: PLAN VIEW



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THERMAL STRESS EXPERIMENT

(CONTINUED)

DATA ANALYSES

2-D THERMOMECHANICAL MODELS HAVE BEEN RUN

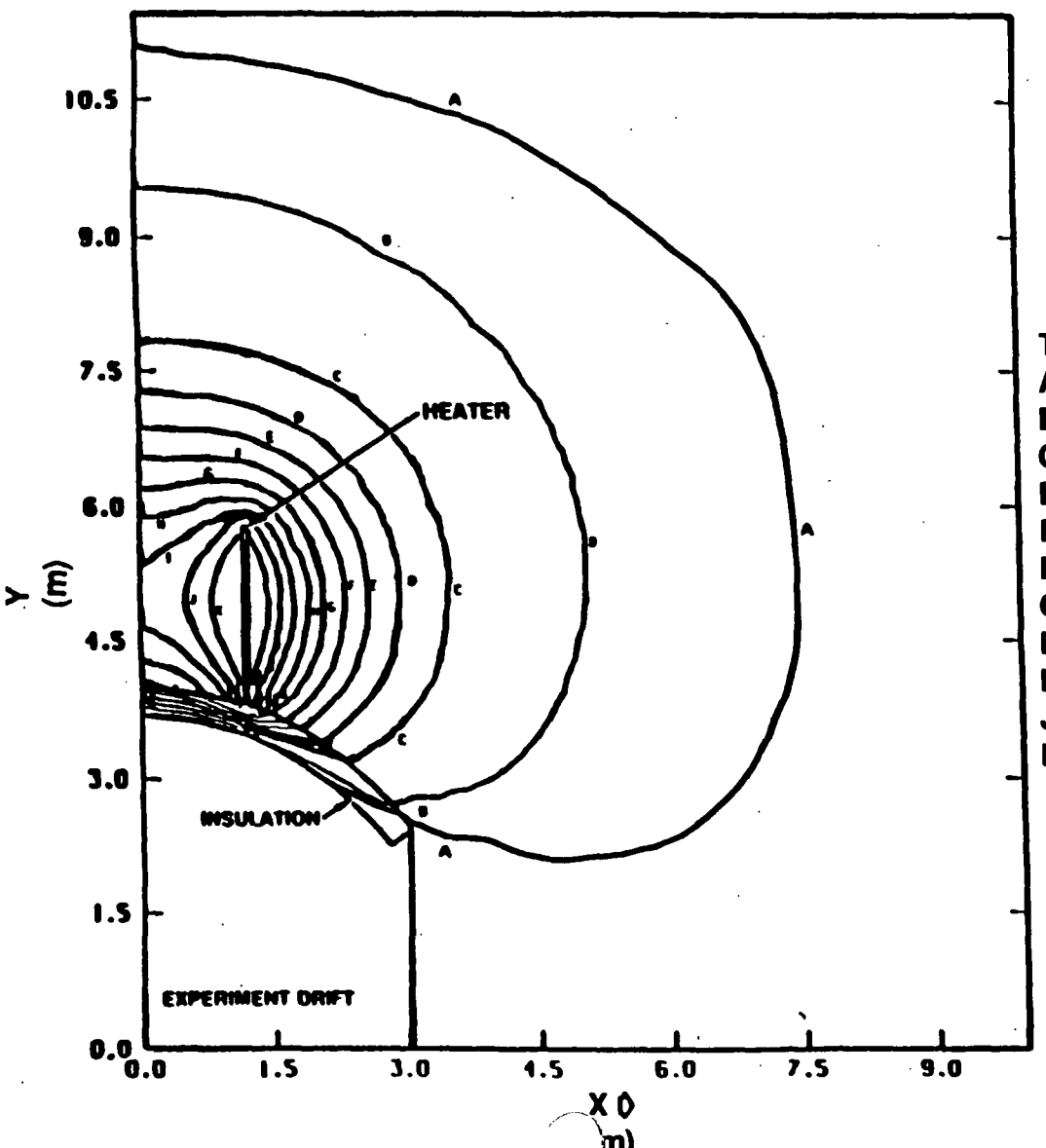
- INPUT
  - VARIOUS THERMAL LOADS
  - VARIOUS DURATIONS
  - VARIOUS INSULATION BOUNDARY CONDITIONS
- OUTPUT
  - STRESS CONTOURS; MAGNITUDES AND DIRECTIONS
  - TEMPERATURE PROFILES
  - DISPLACEMENTS

ANALYSES USED FOR EXPERIMENT DESIGN

- GEOMETRY
- LOCATION AND ORIENTATION OF INSTRUMENTS
- INSULATION
- POWER TO HEATERS
- SAFETY

PREDICTIONS WILL BE COMPARED TO TEST RESULTS

TEMPERATURE CONTOURS AT 90 DAYS OF HEATING



TEMPERATURE (°C)

A	=	23
B	=	40
C	=	60
D	=	120
E	=	160
F	=	200
G	=	240
H	=	280
I	=	320
J	=	360
K	=	400

HEATED ROOM EXPERIMENT

OBJECTIVES

- **THERMALLY AND MECHANICALLY LOAD A REPOSITORY-SCALE OPENING**
  - EXTENDED PERIOD (~40 MO)
  - EXPECTED REPOSITORY CONDITIONS
- **MEASURE TEMPERATURES AND DISPLACEMENTS**
  - DATA BASE FOR DESIGN ANALYSES AND METHODS
- **SOME INFORMATION FOR LICENSING BUT MOST FOR PERFORMANCE CONFIRMATION**
  - PREDICT DRIFT RESPONSE
  - PREDICT SUPPORT/ROCK MASS INTERACTION

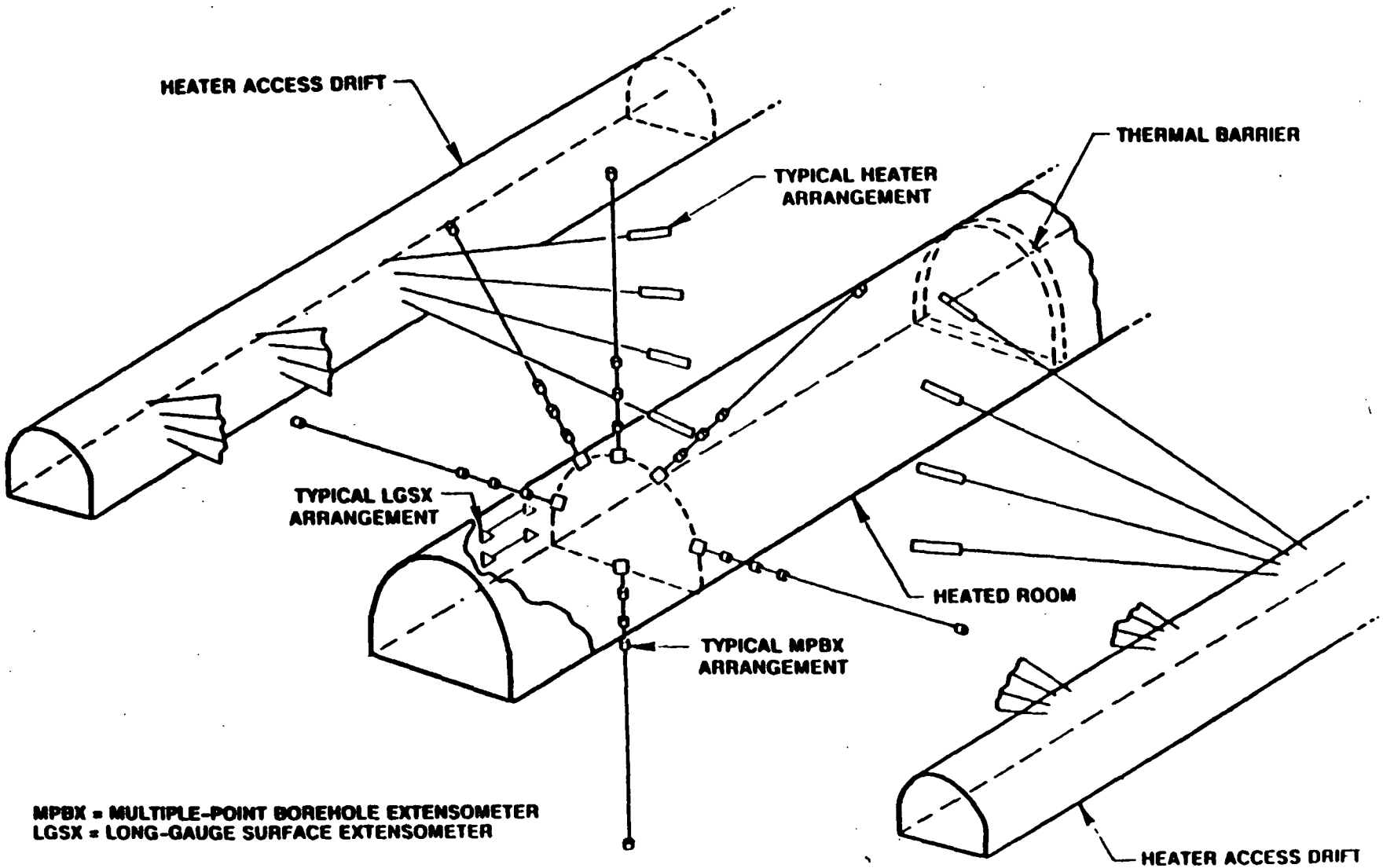
HEATED ROOM EXPERIMENT

(CONTINUED)

DESCRIPTION OF TEST

- EXCAVATE TWO PARALLEL OBSERVATION DRIFTS
  - SAME DRIFTS AS SEQUENTIAL DRIFT MINING EXPERIMENT
- INSTRUMENT ROCK MASS BETWEEN DRIFTS
- HEAT PILLARS OF CENTRAL DRIFT
  - TO REPOSITORY OPERATING TEMPERATURES
  - LENGTH AND PLACEMENT OF HEATERS NOT FINALIZED
  - DISTANCE BETWEEN DRIFTS TO FACILITATE ACCELERATED SCHEDULE

CONCEPTUAL ARRANGEMENT OF HEATED ROOM TEST



MPBX = MULTIPLE-POINT BOREHOLE EXTENSOMETER
LGSX = LONG-GAUGE SURFACE EXTENSOMETER

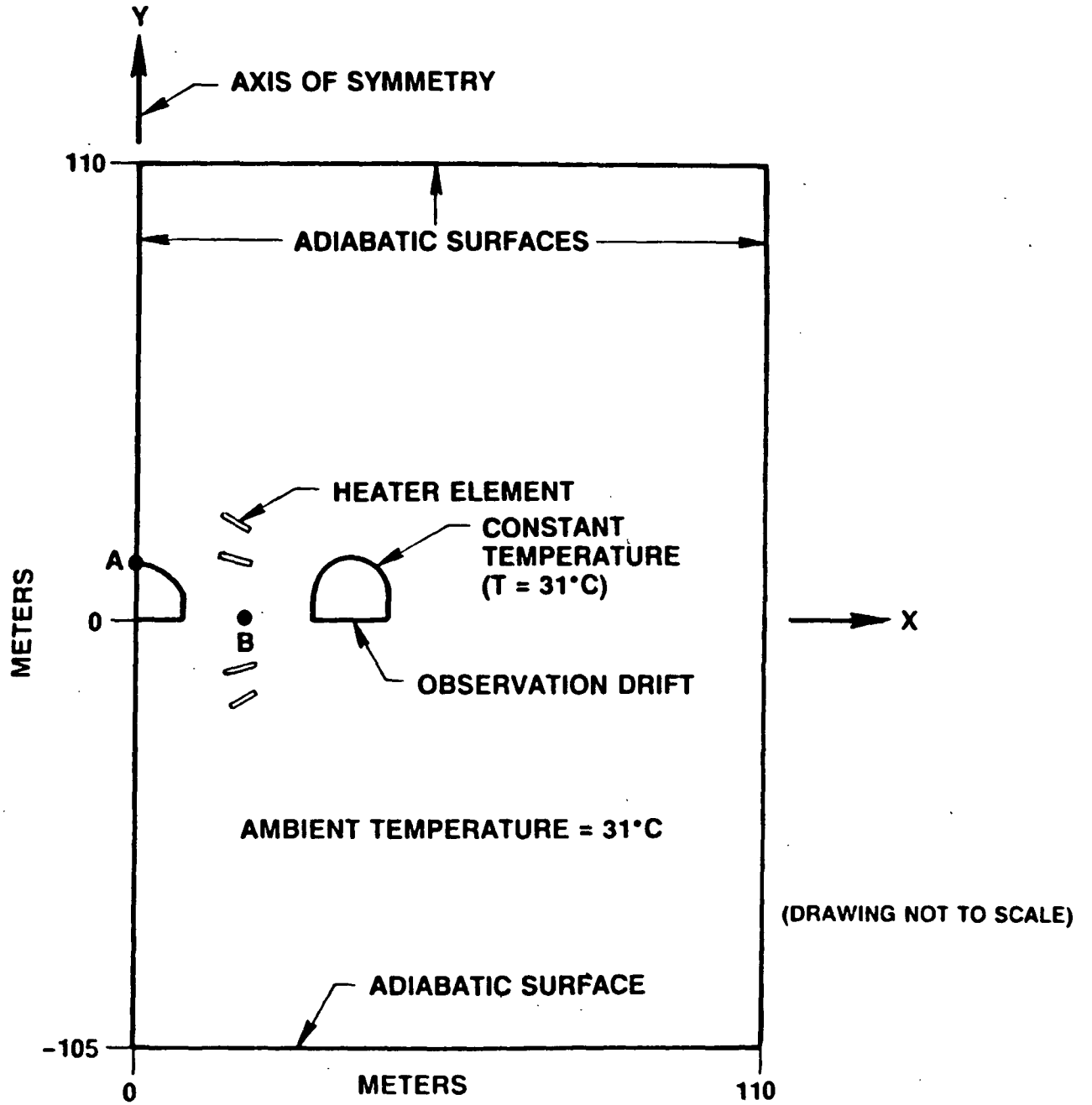
HEATED ROOM EXPERIMENT

(CONTINUED)

PREVIOUS EXPERIENCE

- INSTRUMENTATION
- HEATERS
- DATA ACQUISITION

SCHEMATIC FOR THE FINITE ELEMENT ANALYSIS



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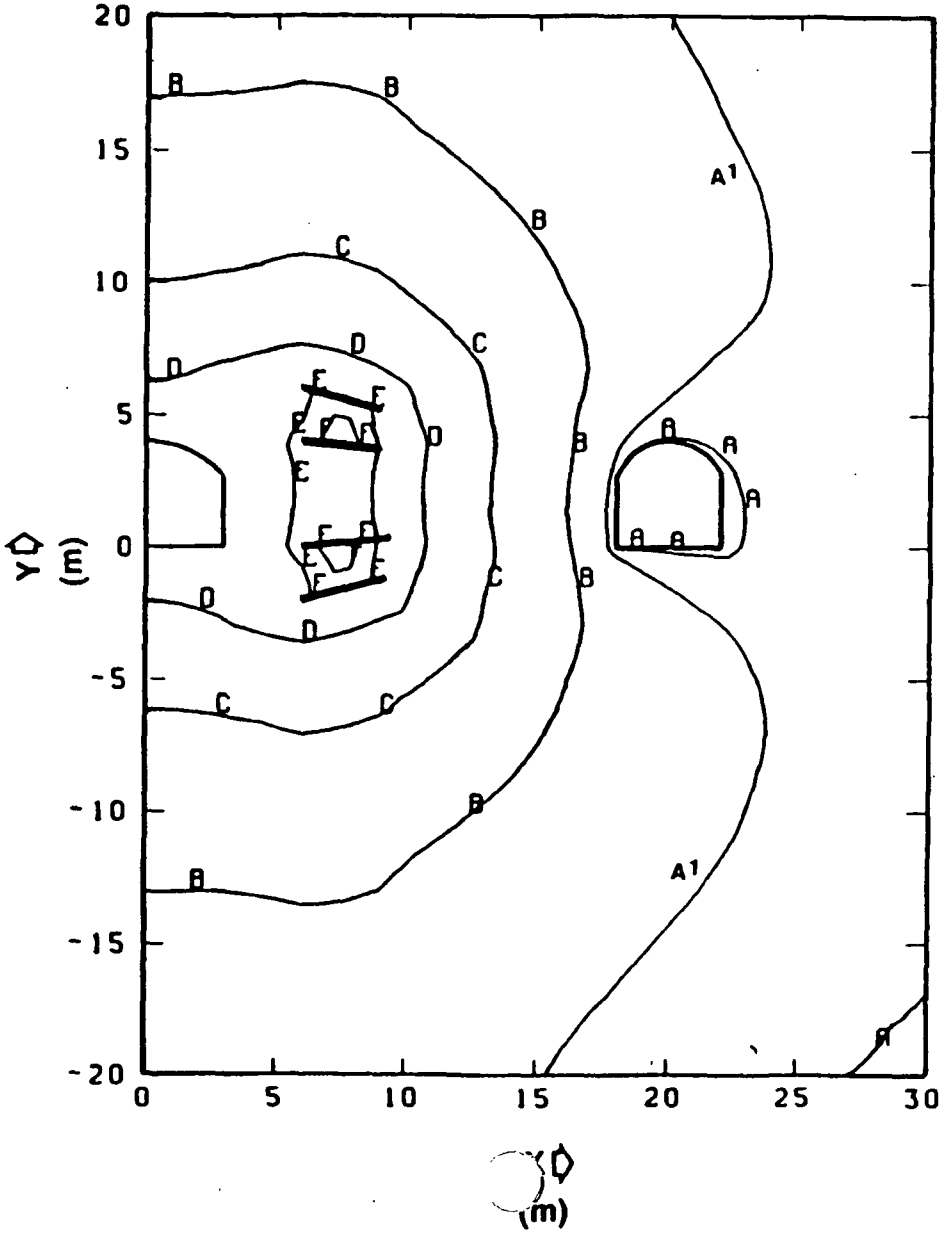
TEMPERATURE CONTOUR PLOT: 40.0 MO

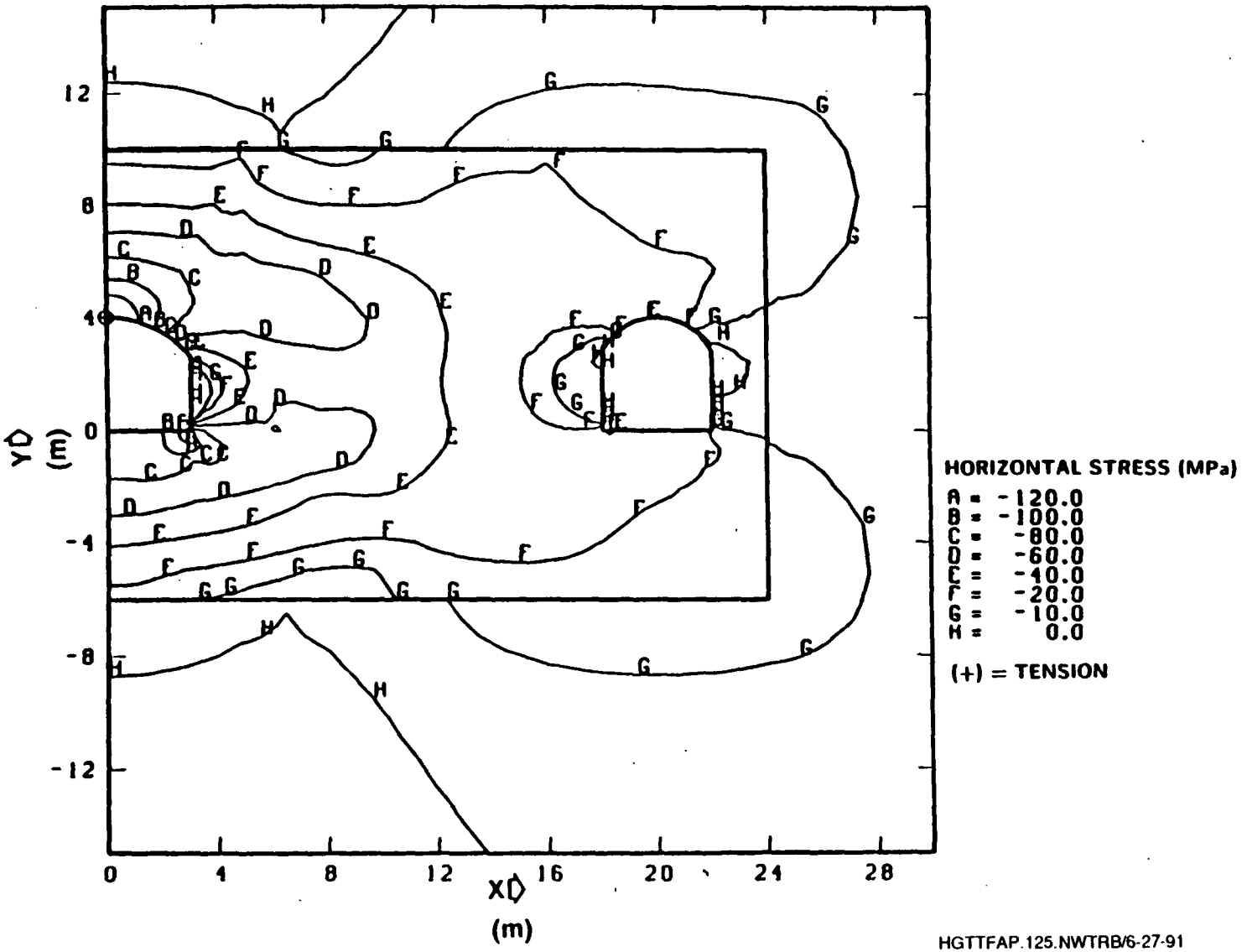


POWER = 50 kW

TEMPERATURE (°C)

A = 32.0
A1 = 36.0
B = 60.0
C = 100.0
D = 150.0
E = 200.0
F = 230.0

HORIZONTAL STRESS CONTOURS AT 40 MO



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NECESSITY FOR THERMAL MODELING

- SPENT FUEL GENERATES HEAT
- REPOSITORY OPENINGS WILL EXPERIENCE SIGNIFICANT THERMAL LOADS
- THERMALLY-INDUCED MECHANICAL STRESS/STRAIN PRINCIPAL COMPONENT OF DEFORMATION LOADS
- REGULATORY CONSTRAINTS TO DEMONSTRATE LONG-TERM OPENING STABILITY REQUIRES MECHANICAL MODELS OF ROCK MASS