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

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: OVERVIEW OF THE ROCK MECHANICS PROGRAM

PRESENTER: DR. THOMAS E. BLEJWAS

PRESENTER'S TITLE AND ORGANIZATION: TECHNICAL PROJECT OFFICER,
SANDIA NATIONAL LABORATORY
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REGISTRY HOTEL, DENVER, COLORADO
JUNE 25-27, 1991
RELATIONSHIP BETWEEN DATA ACQUISITION FOR ROCK PROPERTIES AND ISSUES REQUIRING THE DATA

**DESIGN AND PERFORMANCE ISSUES CALLING FOR DATA**

- ISSUE 1.8: PRE-WASTE-EMPLACEMENT GROUND-WATER TRAVEL TIME (8.3.5.12)
- ISSUE 1.11: CONFIGURATION OF UNDERGROUND FACILITY (POSTCLOSURE) (8.3.2.2)
- ISSUE 1.12: SHAFT AND BOREHOLE SEALS CHARACTERIZATION (8.3.3.2)
- ISSUE 2.7: RADIATION SAFETY DESIGN (8.3.2.3)
- ISSUE 4.2: NONRADIOPHILIC HEALTH AND SAFETY (8.3.2.4)
- ISSUE 4.4: REPOSITORY DESIGN AND TECHNICAL FEASIBILITY (8.3.2.5)

**SITE PROGRAM**

**ANALYSIS/INTEGRATION ACTIVITIES**

- DEVELOPMENT OF 3-D MODELS
  - STRATIGRAPHIC
  - THERMAL/MECHANICAL

**DATA COLLECTION ACTIVITIES**

- INVESTIGATION 8.3.1.18.1
  - BULK PROPERTIES (LABORATORY)
  - THERMAL PROPERTIES (FIELD)
  - MECHANICAL PROPERTIES (LABORATORY)
  - MECHANICAL PROPERTIES (FIELD)
  - IN SITU DESIGN VERIFICATION
  - AMBIENT TEMPERATURE CONDITIONS
  - AMBIENT STRESS CONDITIONS
  - GEOLOGIC FRAMEWORK
OVERALL OBJECTIVE

CHARACTERIZE THE THERMAL AND MECHANICAL PROPERTIES OF THE ROCK UNITS AT YUCCA MOUNTAIN
BOUNDARY ELEMENT PREDICTION OF PRINCIPAL STRESSES IN THE VICINITY OF THE VERTICAL EMBLACEMENT DRIFT, AT TIMES UP TO 100 YEARS AFTER WASTE EMBLACEMENT (ST. JOHN, 1987)

<table>
<thead>
<tr>
<th>Drift at time of Excavation</th>
<th>After 10yrs, Unventilated</th>
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<tbody>
<tr>
<td>After 35yrs, Unventilated</td>
<td>After 100yrs, Unventilated</td>
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<table>
<thead>
<tr>
<th>Mpa</th>
<th>PRINC. STRESS</th>
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<tbody>
<tr>
<td>0</td>
<td>50</td>
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<tr>
<th>meters</th>
<th>5</th>
<th>10</th>
<th>0</th>
<th>5</th>
<th>10</th>
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HGORTBSP.125.NWTRB/6-25,27-91
ISSUE RESOLUTION STRATEGY

PERFORMANCE ALLOCATION

DESIGN/CONDUCT EXPERIMENTS

REFERENCE INFORMATION BASE

VALIDATE MODELS

DESIGN/PERFORMANCE ANALYSES

ISSUE RESOLVED?

YES

LICENSE APPLICATION

NO
DATA NEEDS

- PARAMETERS FOR THE DESIGN AND ANALYSIS OF THE REPOSITORY
- DATABASE FOR EMPIRICAL DESIGN METHODS
- VALIDATION OF ADVANCED ANALYTICAL METHODS
- CRITERIA FOR ACCEPTABILITY OR FAILURE OF OPENINGS
- DEMONSTRATIONS OF OPENING BEHAVIOR
POTENTIAL DATA USERS

- REPOSITORY DESIGNERS
- ANALYSTS OF PRE-CLOSURE PERFORMANCE
- ANALYSTS OF POST-CLOSURE PERFORMANCE
- STATE OF NEVADA INVESTIGATORS
- NUCLEAR REGULATORY COMMISSION STAFF
DESIGN ANALYSIS AND MODELING

ELASTIC ANALYSIS WITH POSTPROCESSING

ROCK STRUCTURE ISOTROPIC

NO

JOINT SPACING CLOSE

YES

JOINT PATTERN BLOCKY & COHESION LOW

YES

DISCONTINUUM DISTINCT BLOCK MODELING

NO

EQUIVALENT-CONTINUUM UBIQUITOUS JOINT MODELING

DISCONTINUUM DISCRETE JOINT MODELING

EQUIVALENT-CONTINUUM ELASTO-PLASTIC MODELING
ROCK MECHANICS
EXPERIMENTAL PROGRAM

TRY TO COLLECT DATA OF SUFFICIENT BREADTH TO SUPPORT A WIDE RANGE OF ANTICIPATED AND UNANTICIPATED ANALYTICAL AND EMPIRICAL ACTIVITIES
PROGRAM HISTORY

~ 1980
SCOPING EXPERIMENTS BEGIN IN LABS AND IN G-TUNNEL

1982
CONCEPTS FOR SUITE OF ESF TESTS

1983
EXPLORATORY SHAFT TEST PLAN (ESTP) FIRST APPEARS IN DRAFT FORM

1986
PERFORMANCE ALLOCATION CONDUCTED. INTERNAL REVIEW OF PLANNED TESTS

1986 - 1988
SCP WRITTEN, REVIEWED, AND ISSUED

1987
EXTERNAL REVIEW OF THE ESTP

1985 - 1989
SIGNIFICANT ADDITIONS AND TURNOVER OF PERSONNEL

1989 - PRESENT
PEER REVIEW PANEL FORMED AND REVIEWS CONDUCTED

1990 - 1991
LACK OF FUNDING LEADS TO ABSENCE OF FIELD-TEST SITE AND STAFF TRANSFERS

1991
REVISION OF SOME TESTS FOR ALTERNATE ESF DESIGNS
STEPS IN PERFORMANCE ALLOCATION

1. SELECT SYSTEMS
2. DETERMINE REQUIRED SYSTEM PERFORMANCE
3. SELECT PARAMETERS TO SHOW PERFORMANCE
4. DETERMINE PARAMETER "GOALS" AND "CONFIDENCE"
5. DESIGN SITE-CHARACTERIZATION EXPERIMENTS
EXAMPLE OF THE PERFORMANCE - ALLOCATION PROCESS

- NNWSI PROJECT ISSUE 2.4: "WILL THE REPOSITORY PRESERVE THE OPTION OF WASTE RETRIEVAL . . . ?

- ISSUE- RESOLUTION STRATEGY: SHOW THAT ACCESS TO WASTE CAN BE MAINTAINED WITH NORMAL MAINTENANCE, i.e., DRIFTS ARE GENERALLY STABLE WHILE THE REPOSITORY IS HEATED BY THE WASTE

- MUST KNOW THE STRESS FIELD AROUND OPENINGS - PRELIMINARY ANALYSES SUGGEST STRESSES MAY BE HIGH (~50 MPa)

- MODULUS OF DEFORMATION FOR THE ROCK MASS MUST BE KNOWN WITH HIGH CONFIDENCE

- COMPLEX APPROACH TO DETERMINING MODULUS INCLUDING:
  - LABORATORY TESTING OF SAMPLES
  - PLATE BEARING TESTS
  - ANALYSES OF JOINTED ROCK MASS
  - VALIDATION EXPERIMENTS (LABORATORY & FIELD)
PLANNING DOCUMENT HIERARCHY

SITE CHARACTERIZATION PLAN (SCP)

STUDY PLANS (SP)

EXPERIMENT PROCEDURES (EP)

TECHNICAL PROCEDURES (TD)
ROCK MECHANICS STUDIES

8.3.1.15.1.1 LABORATORY THERMAL PROPERTIES

8.3.1.15.1.2 LABORATORY THERMAL EXPANSION TESTING

8.3.1.15.1.3 LABORATORY DETERMINATION OF MECHANICAL PROPERTIES OF INTACT ROCK

8.3.1.15.1.5 EXCAVATION INVESTIGATIONS

8.3.1.15.1.6 IN SITU THERMOMECHANICAL PROPERTIES

8.3.1.15.1.7 IN SITU MECHANICAL PROPERTIES

8.3.1.15.1.8 IN SITU DESIGN VERIFICATION
## BUILDING BLOCK APPROACH

<table>
<thead>
<tr>
<th>EXPERIMENTS</th>
<th>PHYSICAL SCALE:</th>
<th>LABORATORY</th>
<th>CANISTER ROOM</th>
<th>FAR-FIELD</th>
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<tbody>
<tr>
<td>LOADING:</td>
<td>IN SITU</td>
<td>EXCAVATION</td>
<td>THERMAL</td>
<td>(SEISMIC)</td>
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<tr>
<td>TIME:</td>
<td>&quot;INSTANTANEOUS&quot;</td>
<td>WEEKS</td>
<td>MONTHS</td>
<td>YEARS</td>
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</table>

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<thead>
<tr>
<th>ANALYSES</th>
<th>MODELS:</th>
<th>LINEAR</th>
<th>ELASTO-PLASTIC</th>
<th>UBIQUITOUS JOINTS</th>
<th>DISCRETE JOINTS</th>
</tr>
</thead>
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**COMPLEXITY**
PLANNED LAB PROPERTIES TESTS

- LABORATORY DETERMINATION OF MECHANICAL PROPERTIES OF INTACT ROCK
  - COMPRESSIVE MECHANICAL PROPERTIES AT BASELINE EXPERIMENT CONDITIONS
  - EFFECTS OF VARIABLE ENVIRONMENTAL CONDITIONS

- LABORATORY DETERMINATION OF MECHANICAL PROPERTIES OF FRACTURES
  - MECHANICAL PROPERTIES AT BASELINE EXPERIMENT CONDITIONS
  - EFFECTS OF VARIABLE ENVIRONMENTAL CONDITIONS

- LABORATORY THERMAL PROPERTIES
  - DENSITY AND POROSITY
  - VOLUMETRIC HEAT CAPACITY
  - THERMAL CONDUCTIVITY

- LABORATORY THERMAL EXPANSION TESTING
SAMPLING FOR THERMAL AND MECHANICAL PROPERTIES

- SURFACE
- COREHOLE
- UNIT CONTACT
- NO CORE
- SAMPLE
- n EVENLY SPACED INTERVALS
- FRACTURES
PHOTOGRAPH OF TRIAXIAL COMPRESSION APPARATUS
PHOTOGRAPH OF SONIC VELOCITY MEASUREMENT APPARATUS
PHOTOGRAPH OF CORE SAMPLE FROM TSw1
LABORATORY EXPERIENCE

INFORMATION FOR SOME UNITS OBTAINED ON:

- INTACT MECHANICAL PROPERTIES
  - COMPRESSION TESTS
    * DRY AND SATURATED
    * VARIOUS CONFINING PRESSURES
    * STRAIN-RATE EFFECTS
    * SAMPLE-SIZE EFFECTS
  - TENSILE TESTS

- FRACTURE PROPERTIES

- THERMAL EXPANSION

- THERMAL CONDUCTIVITY

- BULK PROPERTIES

- MINERALOGY AND PETROLOGY
JOINT TRACES - WELDED TUFF
TOPOPAH SPRING MEMBER

0 1 5 10 cm
JOINT SHEAR IDEALIZATION

\[ K = cE \]

\[ \Delta \tau = cE \Delta h \tan (\phi_\mu + i) \]
SCP ESF CONFIGURATION

ES-1 12 FT DIA. SHAFT

ES-2 12 FT DIA. SHAFT

SHAFT CONVERGENCE STATIONS 13 ELEVATIONS

MAIN TEST LEVEL (MTL)

TO TUPA MAIN GHOST CRACK FAULT 
DRILL HOLE WASH

LOWER DEMONSTRATION BREAKOUT ROOM

HEATER TEST

HEATER BLOCK

CAMBER SCALE

HEATER TEST

3025'

3075'

4130'

4130'
G-TUNNEL UNDERGROUND FACILITY (GTUF)

- LOCATED ABOUT 25 MILES FROM YUCCA MOUNTAIN
- PROVIDED ACCESS TO A THIN UNIT OF WELDED TUFF
- OVERBURDEN (~1400 FT) SIMILAR TO YUCCA MOUNTAIN
- ABOVE THE WATER TABLE
- PROVIDED SUFFICIENT UNDERGROUND OPENINGS FOR MANY EXPERIMENTS
- PROVIDED READILY AVAILABLE NTS SUPPORT
CROSS-SECTION OF RAINIER MESA
PHOTOGRAPH OF DEMONSTRATION DRIFT IN G-TUNNEL
G-TUNNEL EXPERIENCE

- HEATER TESTS IN WELDED AND NONWELDED TUFFS
- HEATED BLOCK EXPERIMENT
- MINING EVALUATIONS (MINE-BY)
- SLOT TESTS
- STRESS MEASUREMENTS
- EQUIPMENT AND INSTRUMENT EVALUATION
PHOTOGRAPH OF G-TUNNEL HEATED BLOCK EXPERIMENT
PHOTOGRAPH
G-TUNNEL SLOT TEST
SCHEMATIC OF THERMAL STRESS TEST

- THERMOCOUPLES
- STRESS GAUGE
- MULTIPLE-POINT BOREHOLE EXTENSOMETER (MPBX)
- LONG-GAUGE SURFACE EXTENSOMETER (SX)
- CROSS-DRIFT WIRE EXTENSOMETER (CDX)
- HEATER
- 50 FT DEPTH
- INSULATION

0 1 2 3 4 5 FEET

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FLOW OF DATA

TEST OR EXPERIMENT

COMPLETE DATA RECORDS

ARCHIVE

INTERPRETIVE REPORTS

DATA REPORTS

SITE AND ENGINEERING PROPERTIES DATA BASE

REFERENCE INFORMATION BASE

OTHER SOURCES

PERFORMANCE AND DESIGN ANALYSES

SPECIAL STUDIES

ISSUE RESOLUTION

REFERENCES FOR THIS REPORT

SPECIAL STUDIES

ISSUE RESOLUTION
ROCK MECHANICS REVIEW PANEL

DICK BIENIAWSKI - PENN STATE UNIVERSITY

STEVE CROUCH - UNIVERSITY OF MINNESOTA

HOWARD PINCUS - CONSULTANT

JIM RUSSELL - TEXAS A&M UNIVERSITY

CHRIS SCHOLZ - LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

HANS SWOLFS - USGS
EQUIPMENT AND INSTRUMENT DEVELOPMENT AND EVALUATION

- CHAIN SAWS
- HIGH-PRESSURE FLATJACKS
- IMPRESSION FLATJACK
- MULTI-POINT BOREHOLE EXTENSOMETER (MPBX)
- DATA ACQUISITION SYSTEM
- LASER INTERFEROMETER FOR DRIFT/SHAFT CONVERGENCE
PHOTOGRAPH OF ROCK CUTTING CHAIN SAW
PHOTOGRAPH OF IMPRESSION BLADDER FOR THIN SLOTS
1989 VIEW OF NEAR-TERM FIELD ACTIVITIES

- Prototype Thermal Stress Experiment
- Scoping Rock-Mass "Strength" Tests
- Equipment and Instrument Checkout
- Unheated Block