General Training On Methodologies For Geological Disposal in North America

IAEA Network of Centers of Excellence

Session 17: Underground Exploratory Studies

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Underground Activities

- Characterize the URL rock mass
- Determine rock response to excavation
- Develop an understanding of contaminant transport through rock masses
- Understand the coupled Thermal-Mechanical-Hydraulic behaviour of the rock mass
- Demonstrate sealing system construction and conduct in situ tests of sealing system performance

Underground Characterization

- Hydrogeology / Hydrogeochemistry
  - Flow system monitoring
  - Groundwater sampling
- Geology / Geophysics
  - Mapping and photography
  - Borehole drilling and logging
  - Radar and crosshole ultrasonics
  - Acoustic emission / microseismic monitoring
- Geomechanics
  - Rock properties testing
  - Fracture properties testing
  - In situ stress determinations

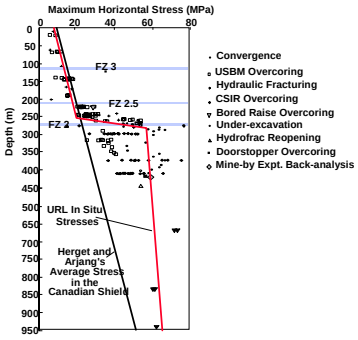
continued...

Underground Characterization (concluded)

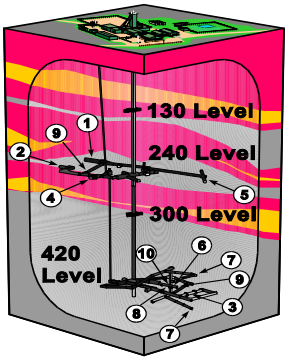
- Excavation Response
  - Mechanical and hydrogeological
- Careful Blasting
  - Blast design and quality control

In-Situ Stress Program

- Improve equipment, procedures and analytical methods for determining *in-situ* stresses in rock
- Improve under-standing of the influence of geology on stress
- Determine *in-situ* stresses for underground experiments



URL Experiment Locations



Experiment Locations

1. Buffer/Container
2. Quarried Block Radionuclide Migration
3. Tunnel Sealing
4. Solute Transport in Highly Fractured Rock
5. Solute Transport in Moderately Fractured Rock
6. Mine-by
7. Excavation Stability Study
8. Solute Transport Excavation Damage Zone
9. Connected Permeability Tests
10. Heated Failure Tests

Underground Experimental Program

Solute Transport
- Solute Transport in Highly Fractured Rock
- Solute Transport in Moderately- Fractured Rock
- *In Situ* Diffusion Experiment
- Quarried Block Fracture Migration Experiment
- Connected Permeability Tests

Excavation Response
- Mine-by Experiment
- Excavation Stability Study

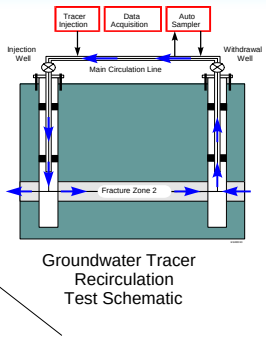
Sealing Experiments
- Buffer/Container Experiment
- Isothermal Test
- Tunnel Sealing Experiment

Experiments

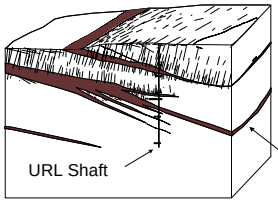
Solute Transport

Solute Transport in Highly Fractured Rock

Two borehole tracer recirculation tests in a permeable fracture zone

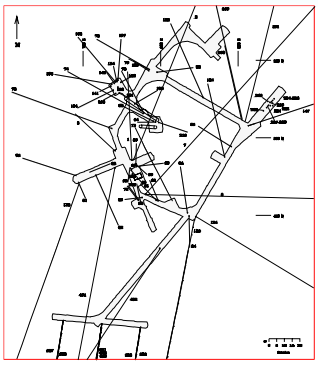


Groundwater Tracer Recirculation Test Schematic

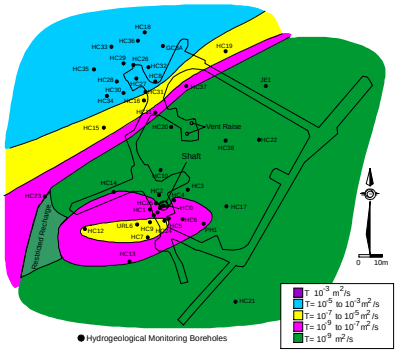


Fracture Zone 2

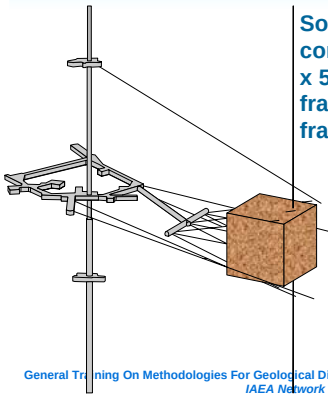
240-Level Hydrogeological Characterization



240-Level Hydraulic Transmissivity



Moderately Fractured Rock Solute Transport



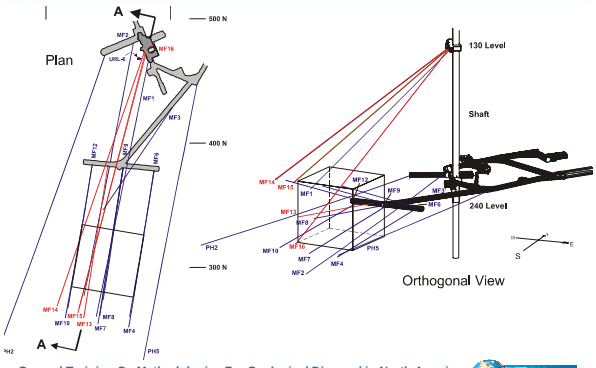
Solute transport studies conducted in 50 m x 50 m x 50 m block of moderately fractured rock (1 to 5 fractures per linear metre)

Test modelling approach for solute transport and verify its applicability at this scale of fracturing

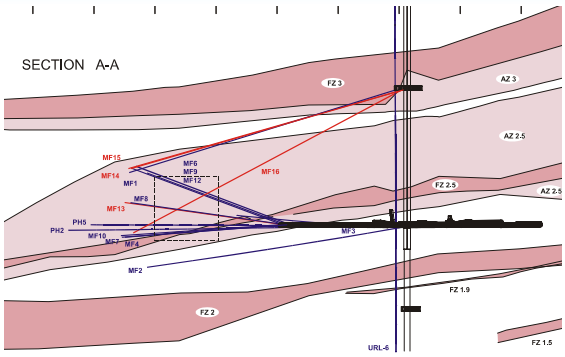
Objectives of MFR Experiment

- Determine the applicability of Equivalent Porous Media transport models to solute transport in MFR domain
- Develop and test site characterization models for moderately fractured rock

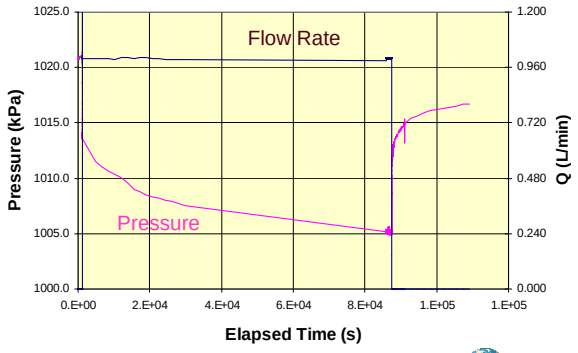
Location of MFR Experiment



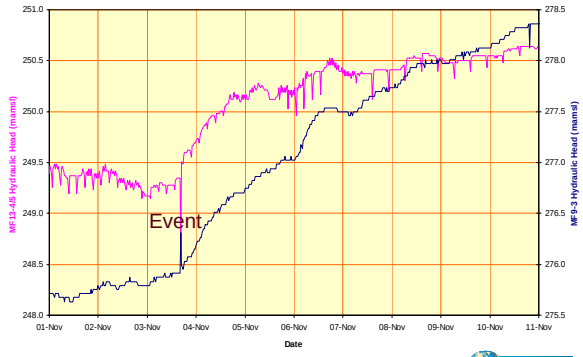
Geology of the MFR Experiment Area



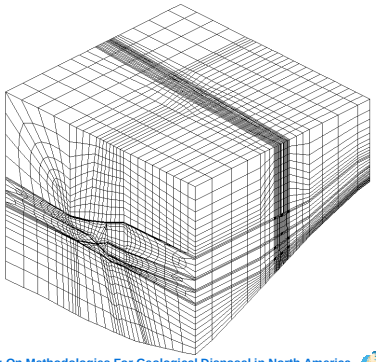
Example of Hydraulic Pump Test



Hydraulic Response to Earthquake



Finite Element Mesh for Tracer Test TT4



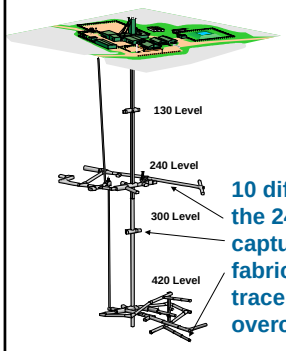
Flow and Transport Model Calibration

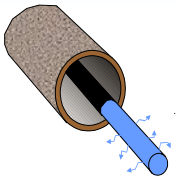
- Each single-hole pumping test was independently calibrated used MOTIF/PEST
- Horizontal permeabilities were the parameters to be optimized
- Vertical permeability was tied to the horizontal permeability by a fixed ratio of two
- Optimization considered complete when the objective functions (sum of squared weighted residuals) were within a relative distance of each other for three iterations

Experiments

In-Situ Diffusion

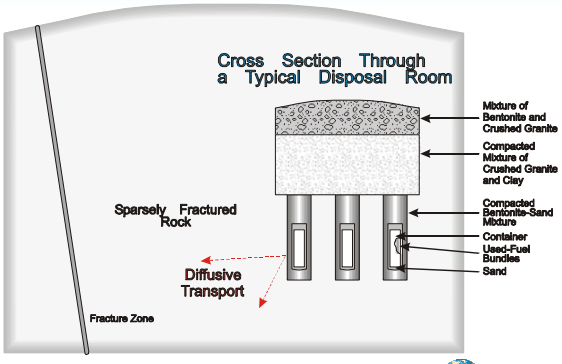
In-Situ Diffusion Experiment





10 diffusion boreholes located on the 240, 300 and 420 Levels to capture effects of stress and rock fabric on diffusion. I, Br, Li and Rb tracers used and the boreholes overcored after 12 to 14 months.

Importance of Diffusion



Sparsely Fractured Granite

- Extremely low permeability: 10^{-19} to 10^{-21} m^2
- Very low porosity: 0.003
- Locally highly stressed ($\sigma_1 \approx 60$ MPa)
- Mass transport dominated by diffusion

Approaches To Estimating Diffusivity

<u>Laboratory tests with rock samples</u>
- More experimental options
- Less expensive
- Can use radioactive tracers
- Sample alteration during drilling

<u>Field-scale *in-situ* experiments</u>
- Maintain *in-situ* stress conditions
- In-situ chemistry & temperature
- No sample alteration
- Effect of borehole-rock interface
- Expensive and limited field sites
- Less experimental options

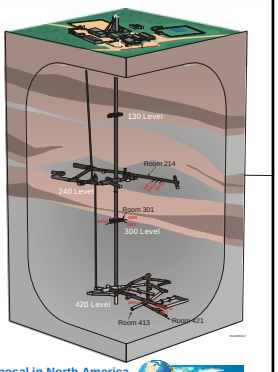
In-Situ Diffusion Experiment Locations

Situated on the 240-m, 300-m and 420-m Levels

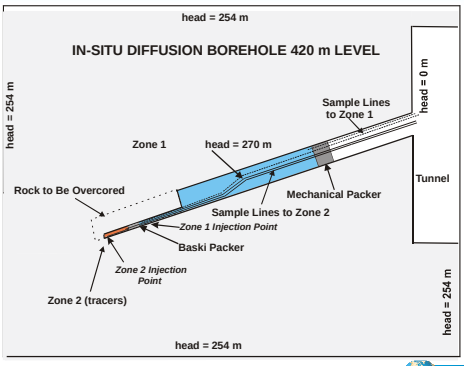
Maximum stress: 14 to 60 MPa

Sparsely fractured rock textures:

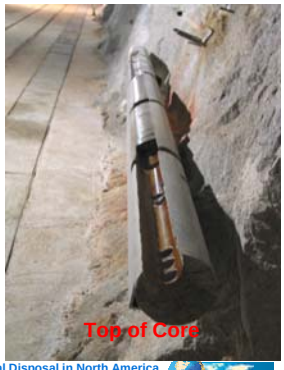
- fine grained granodiorite
- medium grained gneissic gray granite
- coarse grained leucocratic granite segregations and pegmatite dykes



In-Situ Diffusion Experiment Borehole Installation



Diffusion Core after Removal from Hole



Experiments

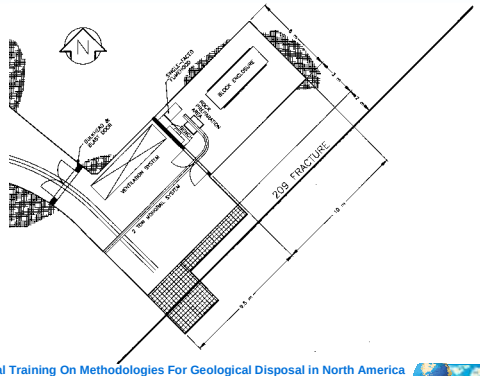
Quarried Block Fracture Migration

Quarried Block Fracture Migration Experiment

Objectives

- **Increase understanding of mass transport along a single, natural fracture in granite**
- **Investigate influence on groundwater flow and contaminant migration by**
  - **fracture geometry**
  - **aperture distribution/correlation**
  - **aperture structure/closure**
  - **fracture roughness**
  - **mineralogy**

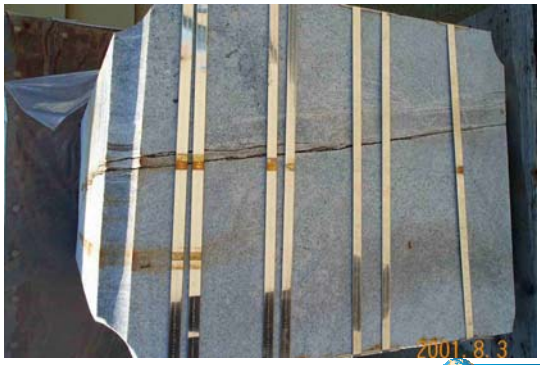
Quarried Block Radionuclide Migration Facility



Block Removal Area

Quarried Block

Close-up of Typical Joint Set



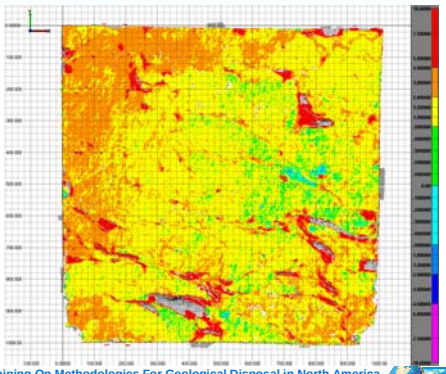
Fracture Opened

Fracture Characterization

- White light profilometry
- Fracture surfaces scanned with white light
- Digitized maps of surface obtained from different locations
- Images "electronically stitched together"
- "Point clouds" generated for both fracture surfaces
- Resolution ~ 0.5 mm
- Accuracy ~0.1 mm

White Light Profilometry

Fracture Aperture Width Distribution

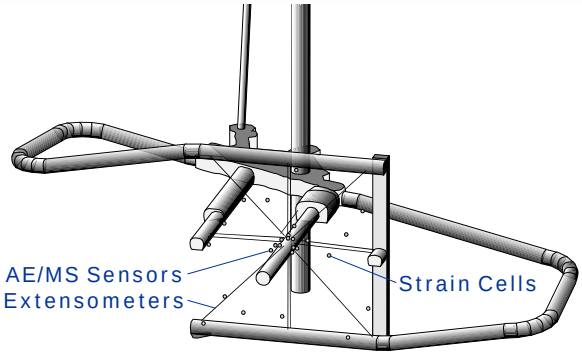


Experimental Set-up

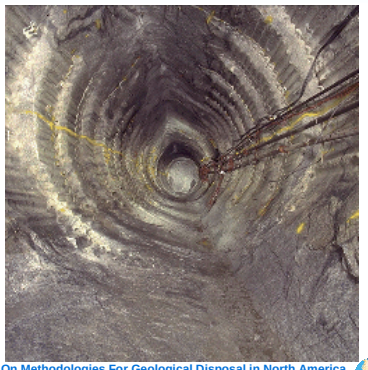
Experiments

Excavation Response

Mine-by Experiment

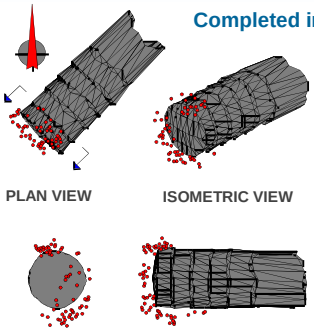


Mine-by Experiment Test Tunnel



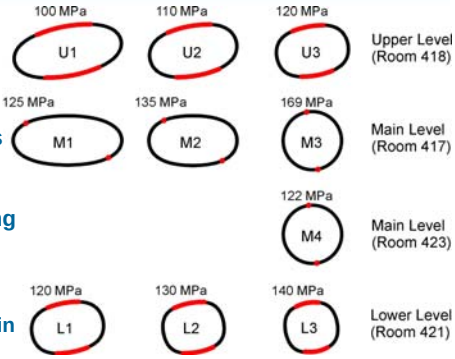
Acoustic Emission/Microseismic Response

Completed in 1996



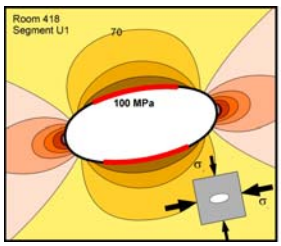
Excavation Stability Study

Excavation of nine different shaped excavations to test methods for designing stable openings

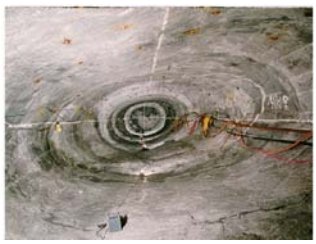


Completed in 1997

Excavation Stability Study

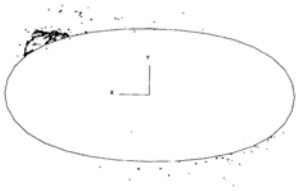


Linear elastic model

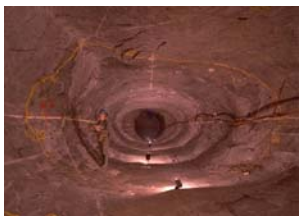


Stable excavation

Excavation Stability Study



Discrete element damage model



Rock failure

Experiments

Sealing System Studies

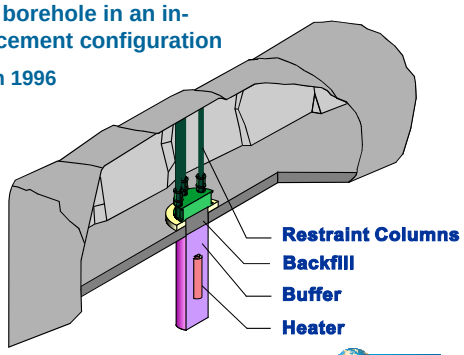
Buffer/Container Experiment and Isothermal Test

- Installed in 1.24-m-dia. by 6-m-deep boreholes drilled with high-pressure water
- Reference buffer material (RBM) (50% bentonite clay, 50% silica sand) compacted in situ to dry density of 1.7 Mg/m^3
- B/C Experiment operated at 85°C heater temperature for ~900 days; Isothermal Test operated at ambient temperature (~12°C) for ~2500 days
- >660 sensors (16 different types) installed and monitored remotely. Overall instrument survival rate for both experiments >80%

Buffer/Container Experiment

One heated borehole in an in-floor emplacement configuration

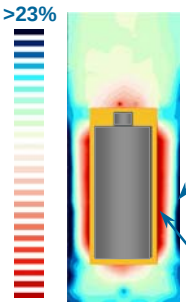
Completed in 1996



Buffer/Container Experiment

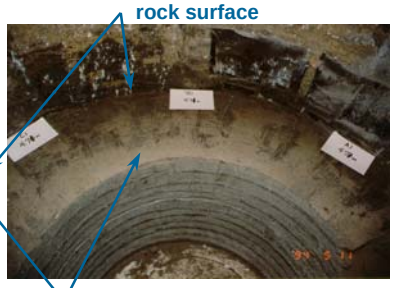
In-situ compaction of sand-bentonite buffer material

Thermally-Driven Water Redistribution



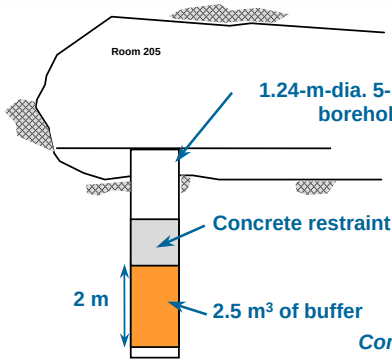
Water contents

Low permeability saturated seal near rock surface



Very dry near heater cavity

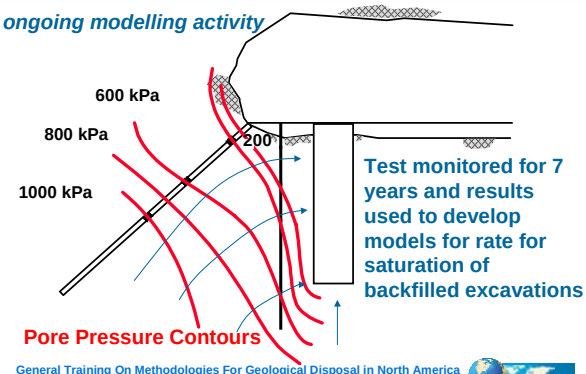
Isothermal Test



Completed in 2001

Saturation of Backfilled Excavations

ongoing modelling activity

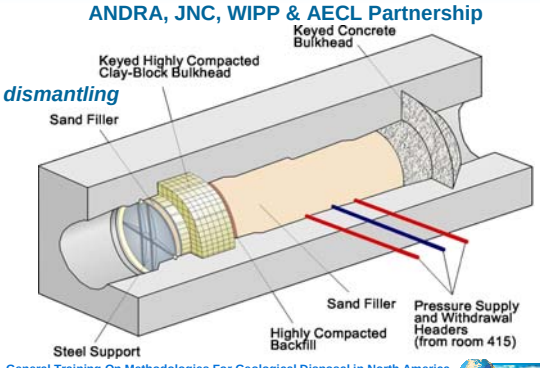


Test monitored for 7 years and results used to develop models for rate for saturation of backfilled excavations

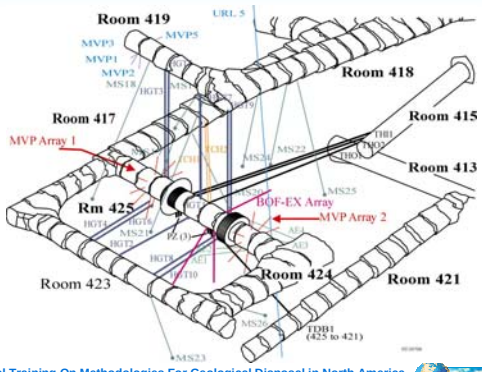
Tunnel Sealing eXperiment (TSX)

ANDRA, JNC, WIPP & AECL Partnership

dismantling



Tunnel Sealing eXperiment (TSX)

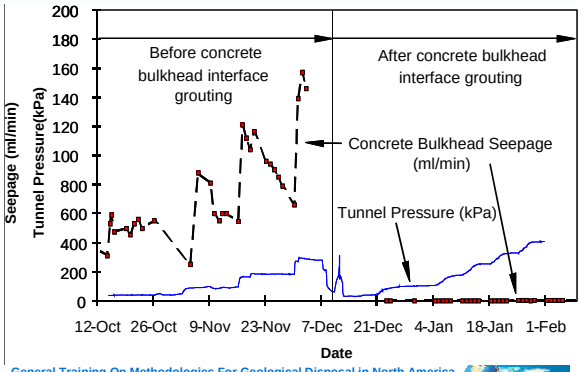


TSX - Construction of Keys Through EDZ

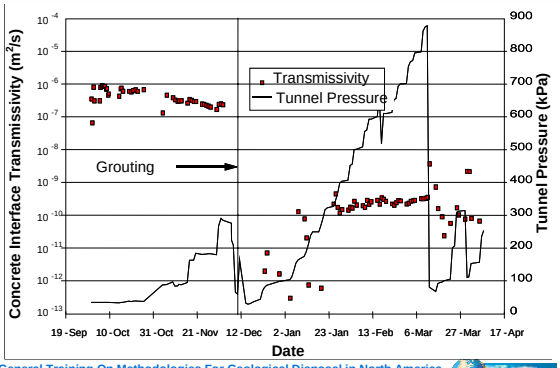
TSX - Pre-compacted Clay Block Tunnel Seal

AE Installation and Concrete Pour

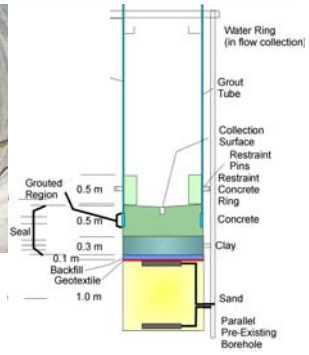
TSX Concrete Bulkhead Interface Seepage



TSX Concrete Bulkhead Interface Transmissivity

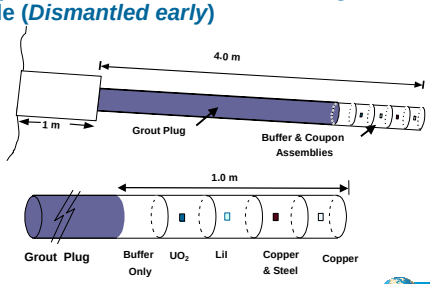


Composite Seal Experiment



Buffer-Coupon Long-term Test

Long-term installations (3 to 20 years) of copper and uranium coupons and a chemical tracer surrounded by compacted sand-bentonite and in a granite borehole (*Dismantled early*)



Comments

- **Numerous *in-situ* tests and measurements of coupled thermal, hydraulic, mechanical, chemical and microbiological processes have been performed**
- **Many studies have shown unexpected responses due to initial oversimplification of phenomena and to the effects of the construction process**
- **Much information has been produced from URL experimental studies that have application to other radioactive waste management programs**

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