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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
PANEL ON STRUCTURAL GEOLOGY & GEOENGINEERING

SUBJECT: AIRBORNE GOALS AND REQUIREMENTS FOR SELECTED SEALING COMPONENTS

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Scope of Presentation

MODIFIED PERMEABILITY ZONE (MPZ) MODEL

- STRESS RELIEF
- BLASTING EFFECTS

RADIONUCLIDE RELEASE MECHANISMS

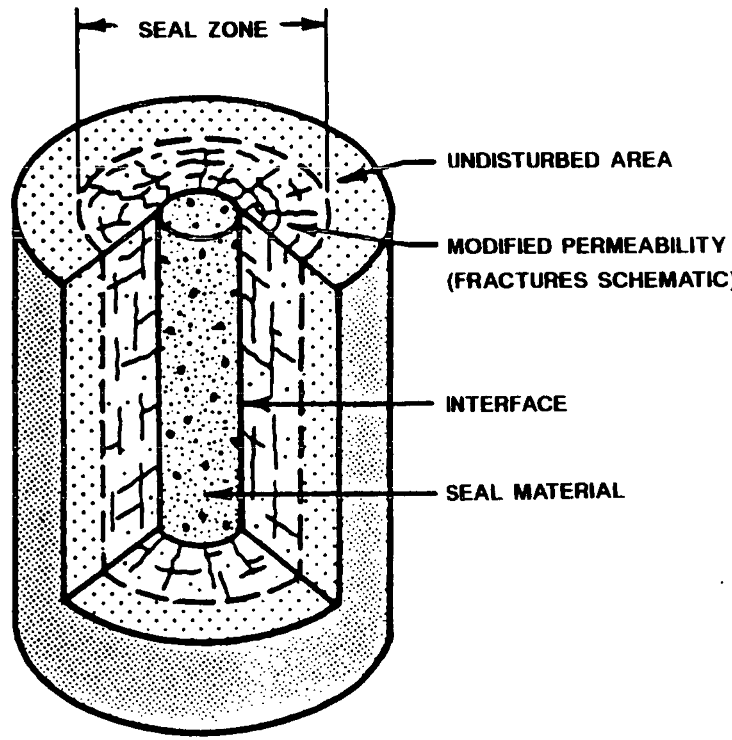
- CONVECTIVE AIRFLOW
- BAROMETRIC AIRFLOW

Outline of Modified Permeability Zone (MPZ) Presentation

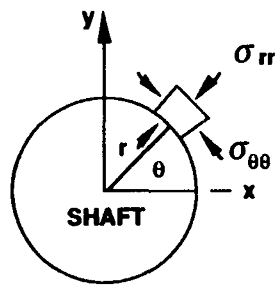
MPZ Model Required For Airflow and Water Flow Performance Calculations

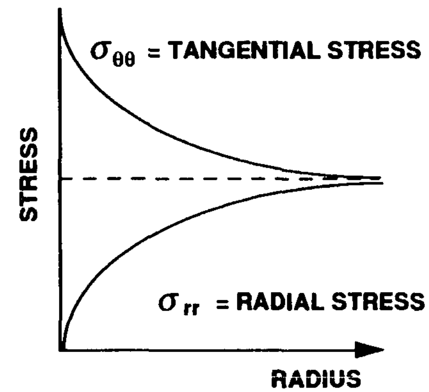
- Technical approach to developing MPZ modeling assumptions in fractured, welded tuff
- Elastic and elastoplastic stress analysis
- Stress-permeability relationships
- Modeling results and MPZ model

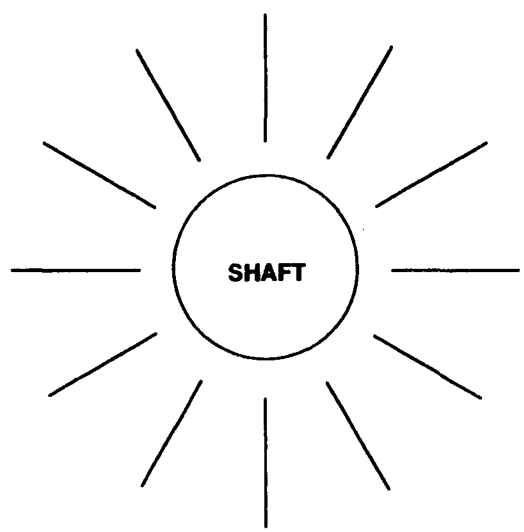
Flow Through Seal Components for Shafts and Boreholes



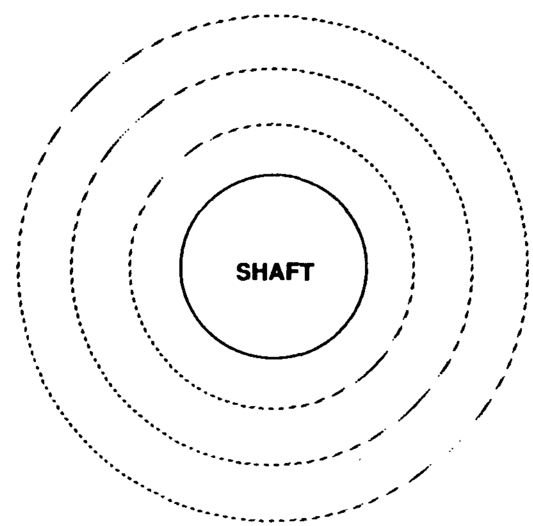
Stress Relief Mechanisms







RADIAL
SYSTEM OF FRACTURES



"ONION SKIN" OR
TANGENTIAL
SYSTEM OF FRACTURES

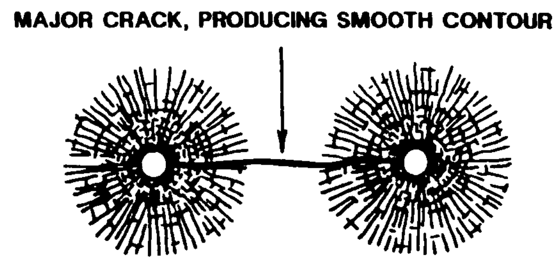
Mechanisms Involved in Creating a Modified Permeability Zone Include

- Opening and closing of existing fractures
- Creating new fractures due to blasting
  - Blasting
  - Stress relief

Technical Approach to Developing the MPZ

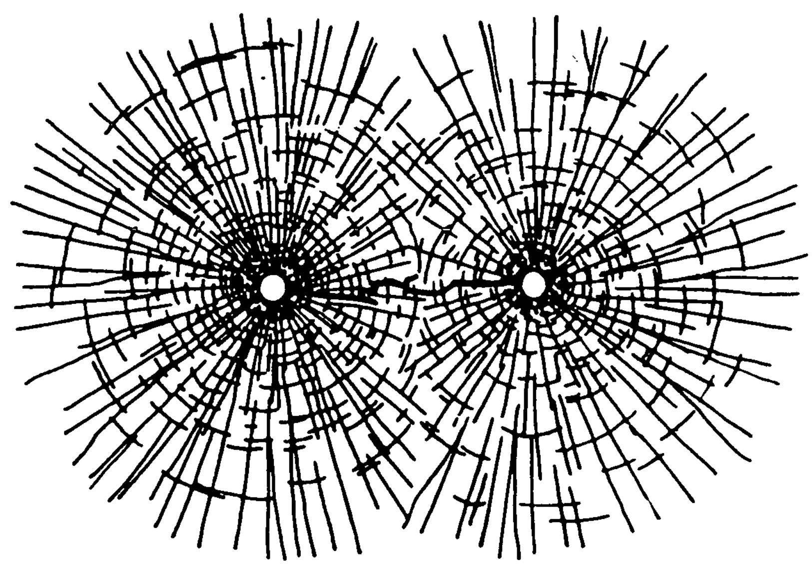
- Calculate stress changes around the shaft
- Relate permeability to stress field (field and laboratory tests)
- Calculate rock-mass permeability as a function of radius
- Estimate increased rock-mass permeability due to blasting

Blasting Mechanism



SMOOTH BLASTING

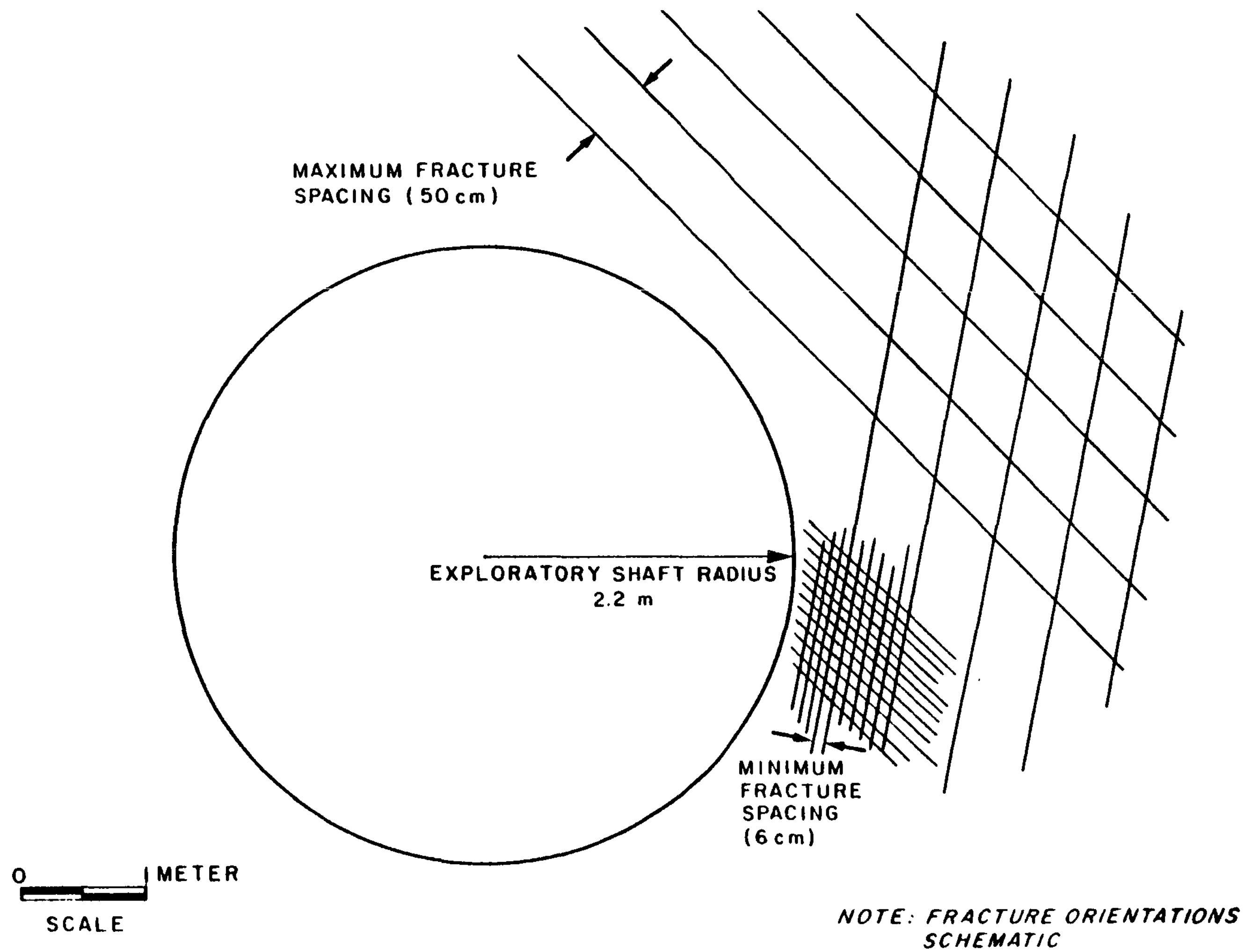
DAMAGE ZONE 5-10 TIMES LOADED
BOREHOLE DIAMETER



CONVENTIONAL BLASTING

DAMAGE ZONE 15-20 TIMES LOADED
BOREHOLE DIAMETER

Cross Section Through a Shaft in Welded Tuff Showing Fracture Spacing Relative to Shaft Radius



After Langkopf and Gnirk, 1986

Modeling Assumptions

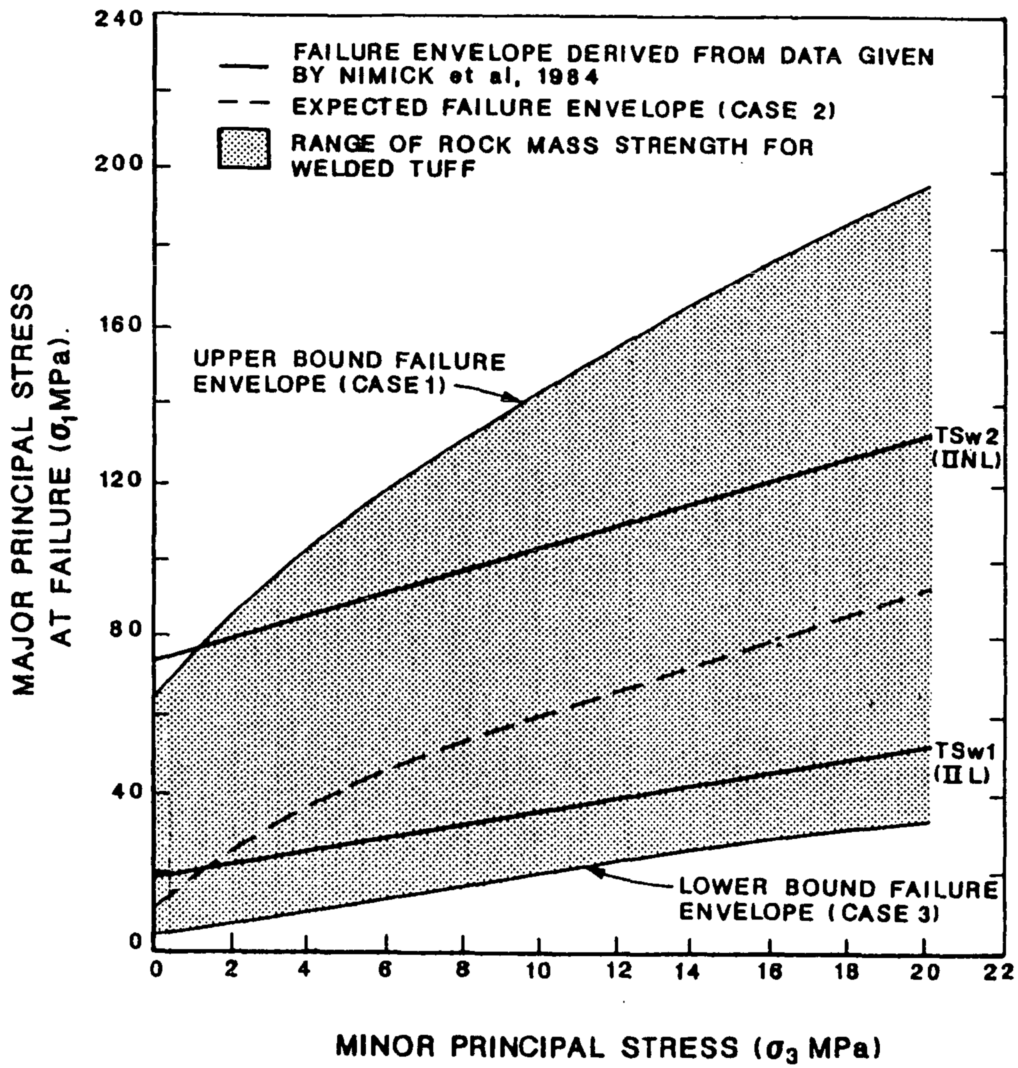
- In situ state of stress is isotropic
- Orient fracture normal to direction of maximum stress relief
- Calculate stress relief using closed form solutions
- Shaft liner support at time of excavation is neglected

Assessment of Rock Mass Strength

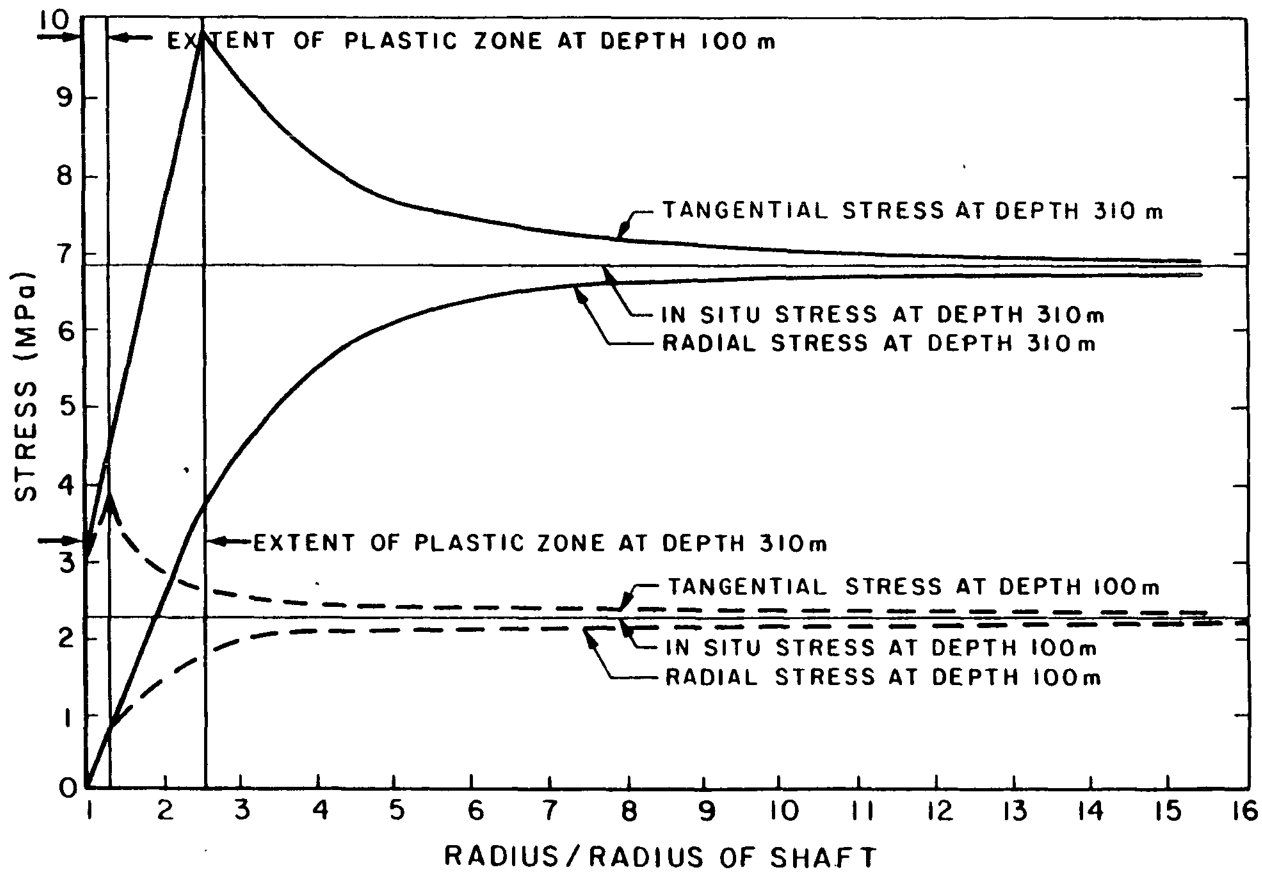
Rock Mass Rating (RMR) Ranged From 48 to 84

- Unconfined Compressive Strength (UCS) 110 to 230 MPa
- Joint frequency 2 to 16 fractures per meter
- Joint condition
  - Lower bound slightly rough fractures
  - Upper bound very tough fractures
- Dry groundwater conditions

Rock Mass Failure Envelopes for Welded Tuff



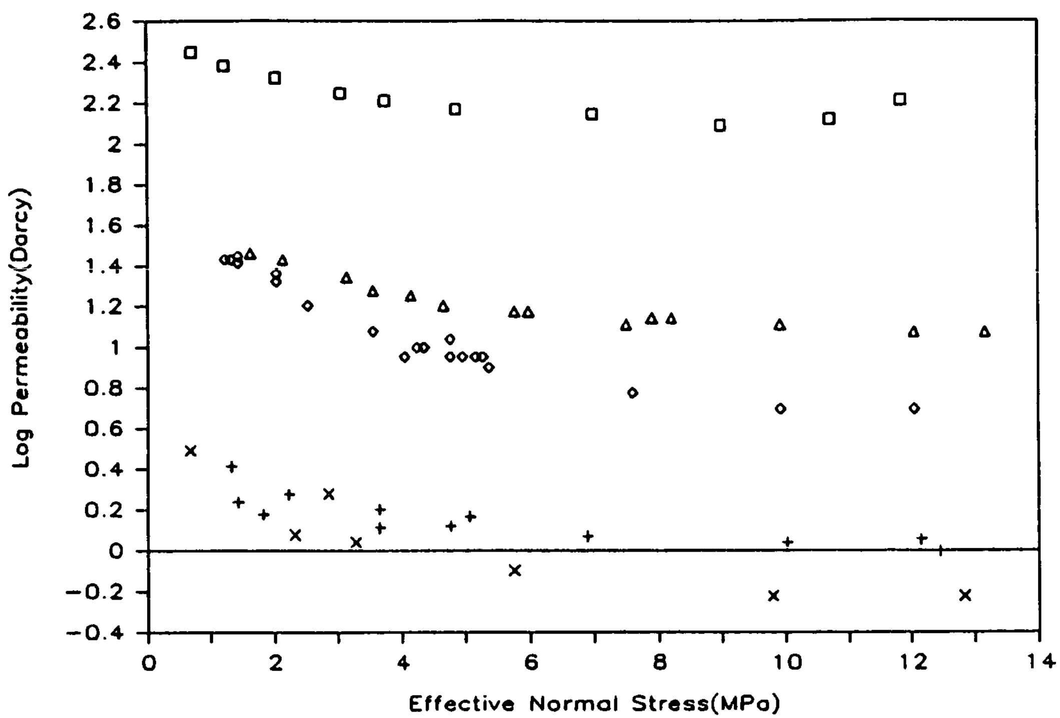
Development of a Plastic Zone in Welded Tuff for Assumptions of Lower Bound Strength and Upper Bound In Situ Stress



Laboratory Studies of Single Fractures in Welded and Nonwelded Tuff

- Constant flow rate permeameter
- Single fractures with various roughness
- Pore and confining pressure raised to about 3 MPa
- Confining pressure raised to 3.5 to 16 MPa
- Fracture permeability calculated using the smooth wall fracture aperture relationship

Permeability as a Function of Normal Stress From Laboratory Testing by Peters et al. (1984)

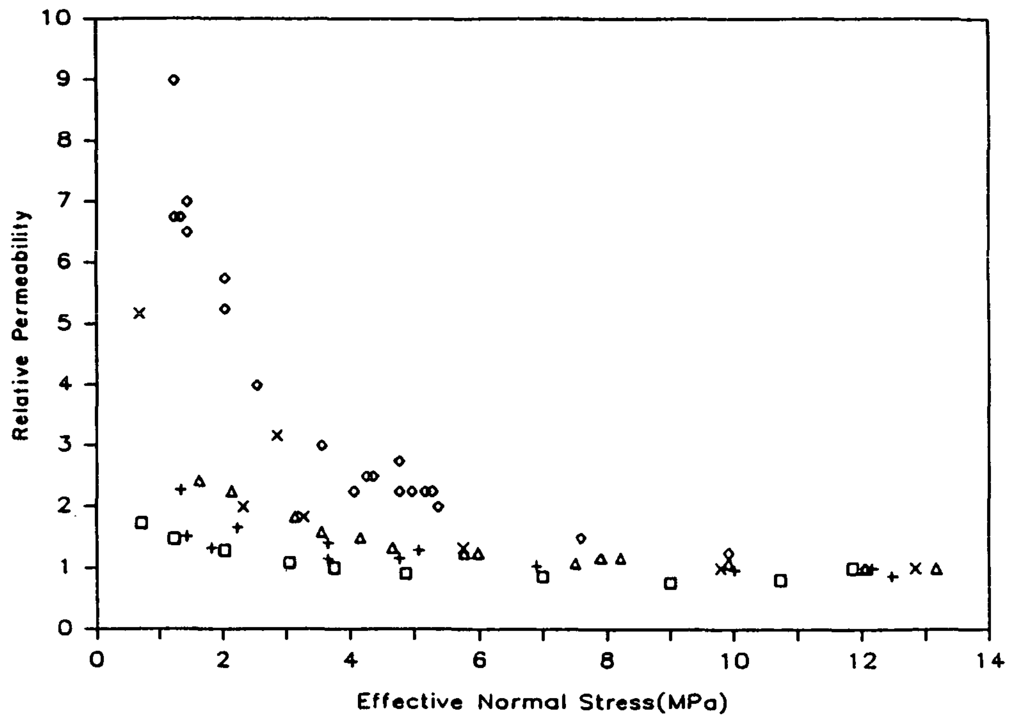


LEGEND

SAMPLES TAKEN FROM THE G4 SERIES:

- □ 1F HIGHLY WELDED, ROUGH
- + 2F HIGHLY WELDED, SMOOTH
- ◇ 3F WELDED, PLANAR
- △ 4F NONWELDED
- x 5F NONWELDED, PLANAR

Comparison of Relative Permeability Relationships From Laboratory Testing by Peters et al. (1984)



LEGEND

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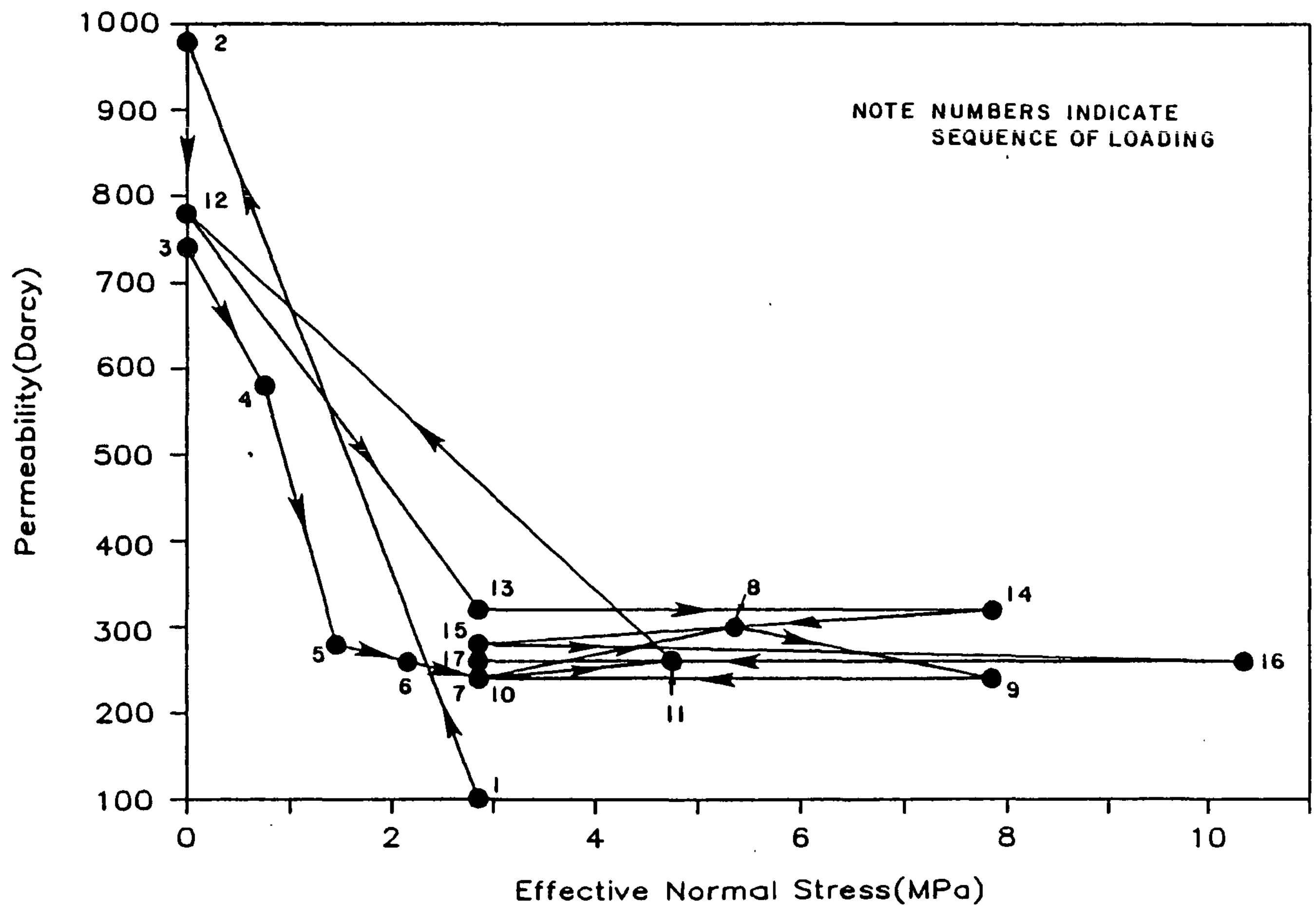
- X 5F NONWELDED, PLANAR

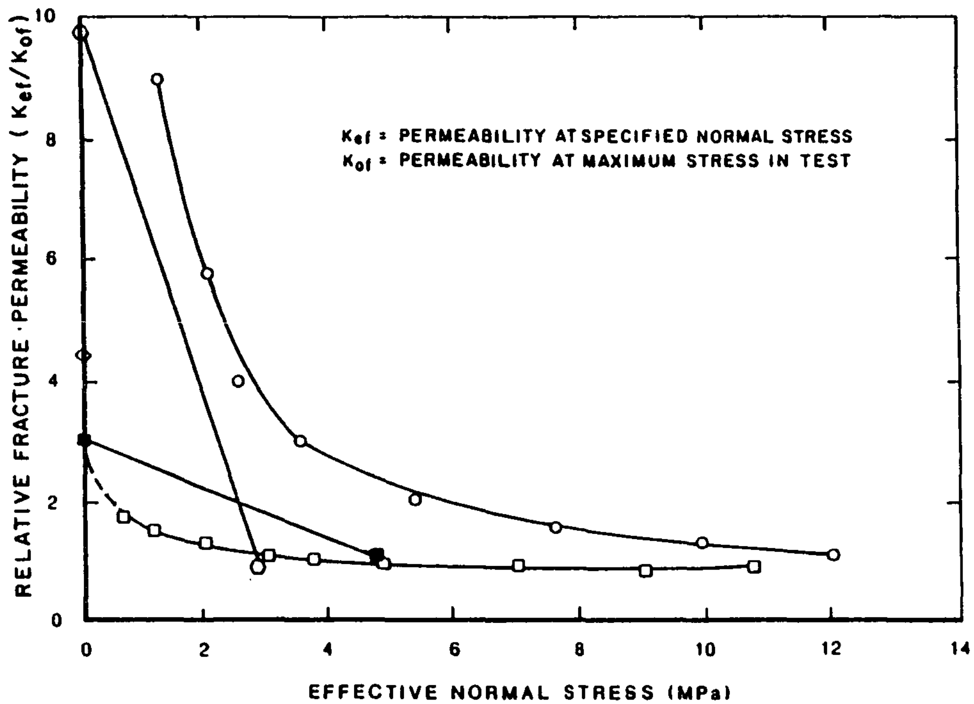
Field Studies of Single Fractures in Welded Tuff

- Heated block test in G Tunnel
- Tests performed by injecting water into a near-vertical fracture
- Monitor flow rate in two observation holes
- Fracture permeability calculated using the smooth wall fracture aperture relationship

Permeability vs. Effective Normal Stress, G Tunnel Block Test - Path 21 (After Zimmerman et al., 1985)



Comparison of Field and Laboratory Results



LEGEND

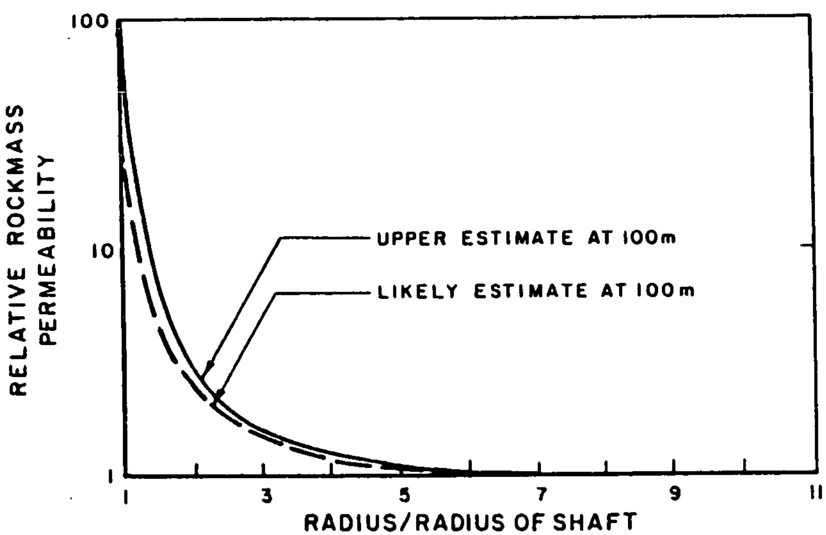
LABORATORY TESTING (AFTER PETERS ET AL., 1984)

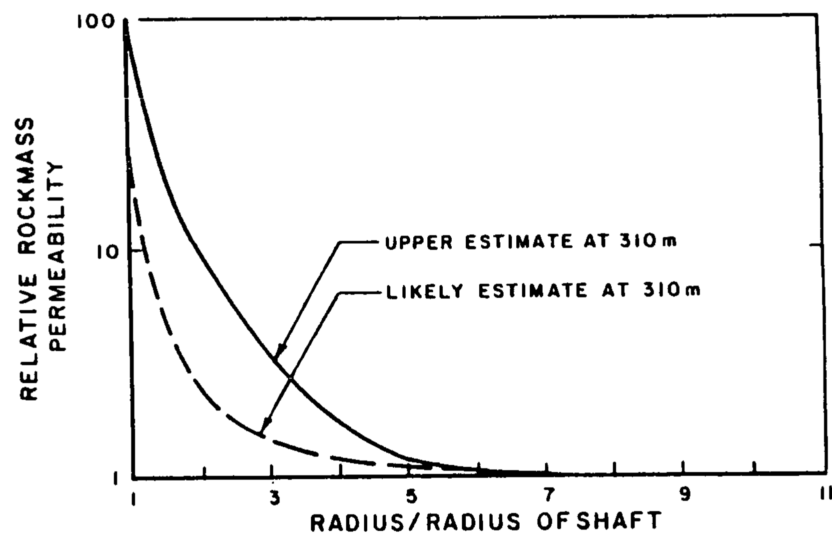
- □ ROUGH FRACTURE WITH POORLY MATED SURFACES (SAMPLE G4-1F, WELDED)
- ○ PLANAR FRACTURE WITH WELL MATCHED SURFACES (SAMPLE G4-3F, WELDED)

FIELD TESTING (AFTER ZIMMERMAN ET AL., 1985)

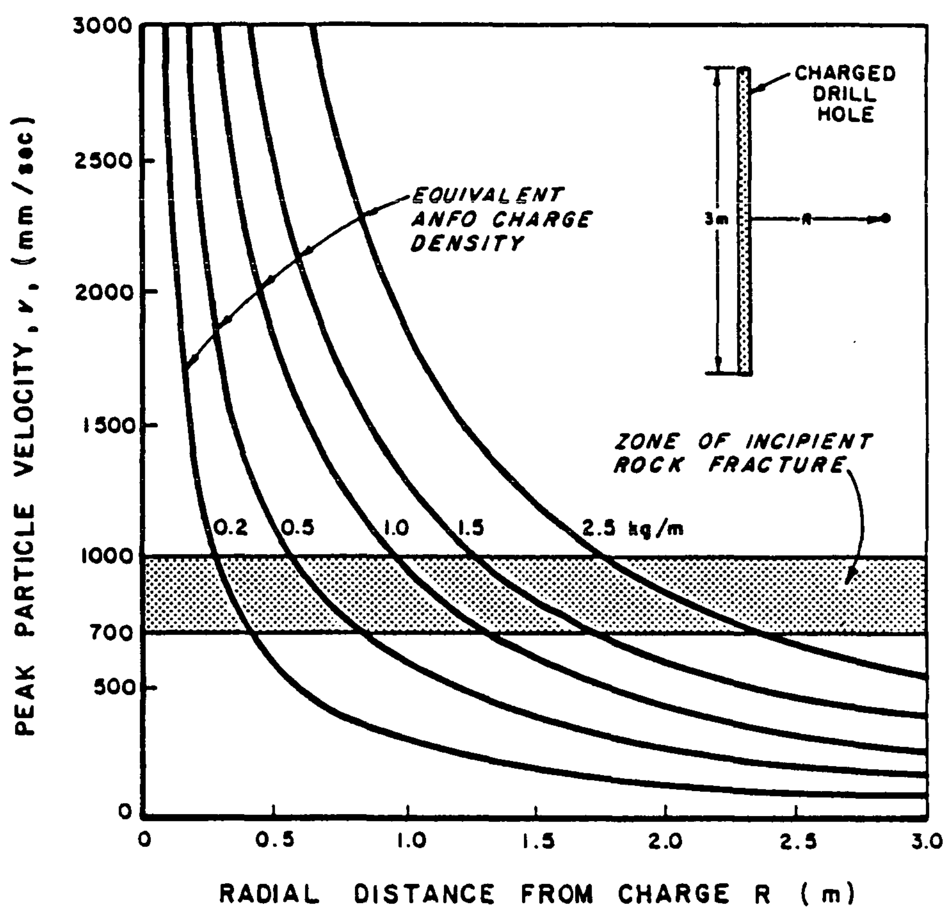
- ⬡ FRACTURE IN G TUNNEL BLOCK TEST FOR PATH 21 UNLOADED BY SLOT CREATION
- ■ FRACTURE IN G TUNNEL BLOCK TEST FOR PATH 21 AFTER SUBSEQUENT LOADING CYCLE

Estimated Change in Axial Rock Mass Permeability at 100 m and 310 m Depths Resulting From Stress Relief





Method For Estimating Thickness of Blast-Damaged Zone in Relation to Explosive Charge Density

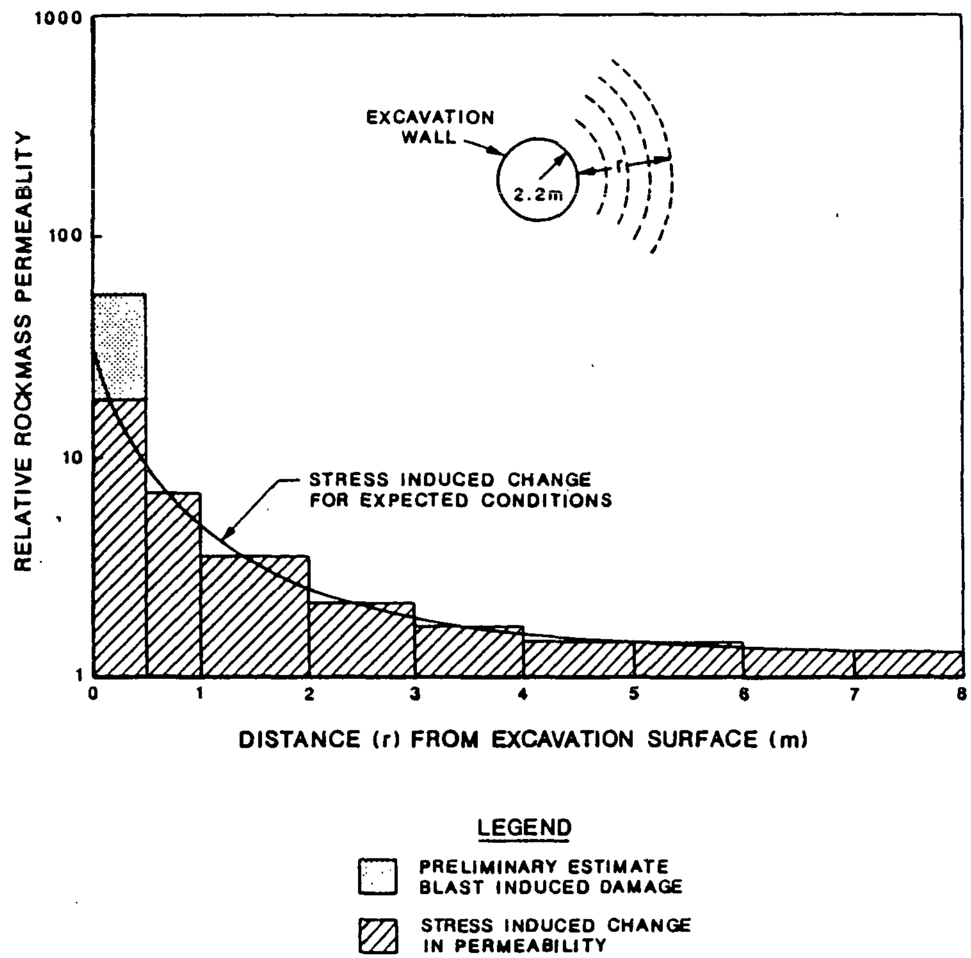


From Holmberg and Persson (1980)

Preliminary Model of the Modified Permeability Zone

- Expected case--increase in permeability of 20 over one radius
- Upper bound case--increase in permeability of 40 to 80 depending on depth (100 m vs. 310 m)
- Significant contrast in elastic vs. elastoplastic response

Modified Permeability Zone Model for Topopah Spring Welded Tuff for Expected Conditions at 310 m Depth



Scope of Presentation

MODIFIED PERMEABILITY ZONE (MPZ) MODEL

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RADIONUCLIDE RELEASE MECHANISMS

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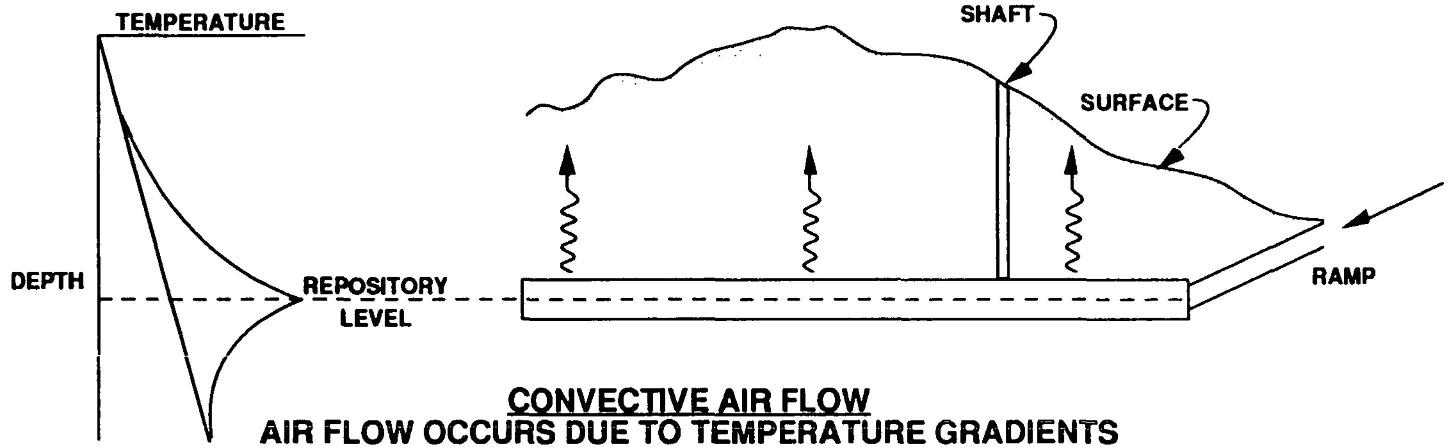
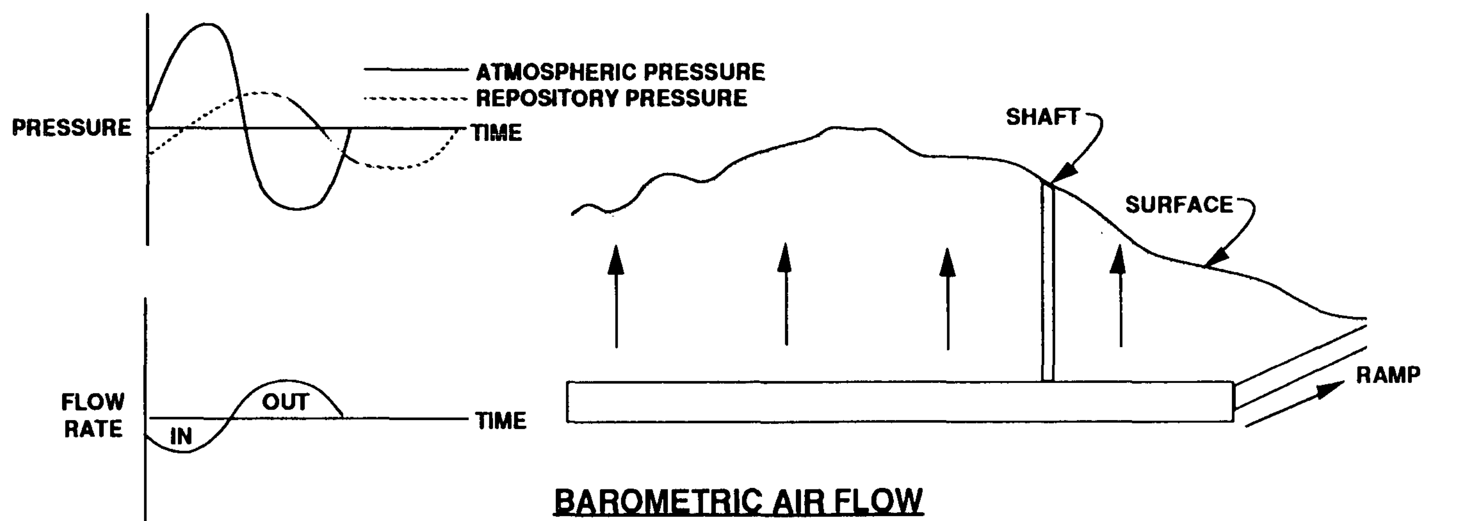
Radionuclide Release Mechanisms



CONVECTIVE AIR FLOW
AIR FLOW OCCURS DUE TO TEMPERATURE GRADIENTS



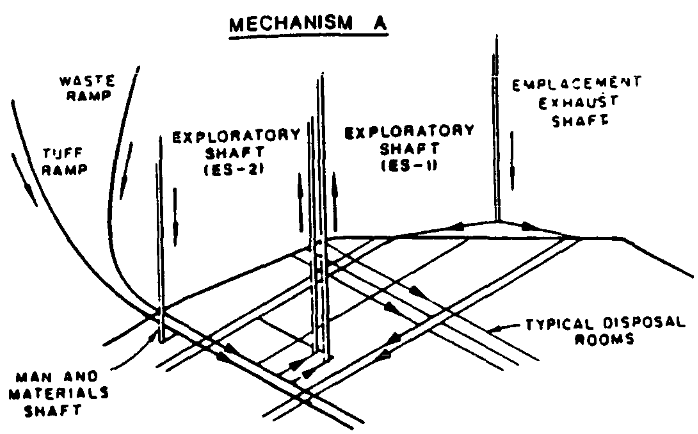
BAROMETRIC AIR FLOW
AIR FLOW OCCURS DUE TO DIFFERENCE IN AIR PRESSURE

Modeling Assumptions

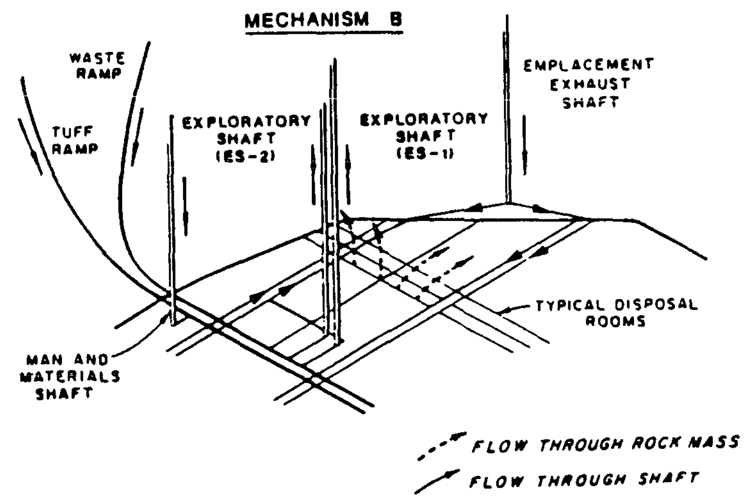
- Darcy's Law is valid
- Rock and air are at the same temperature at the same location
- Air is dry and flow is incompressible
- Air circulation occurs along specified paths
- Air in repository obeys ideal gas law (barometric)

Mechanisms For Convective Air Flow
(a) Through Shafts Only and
(b) Through Shafts and Rock

(a)



(b)

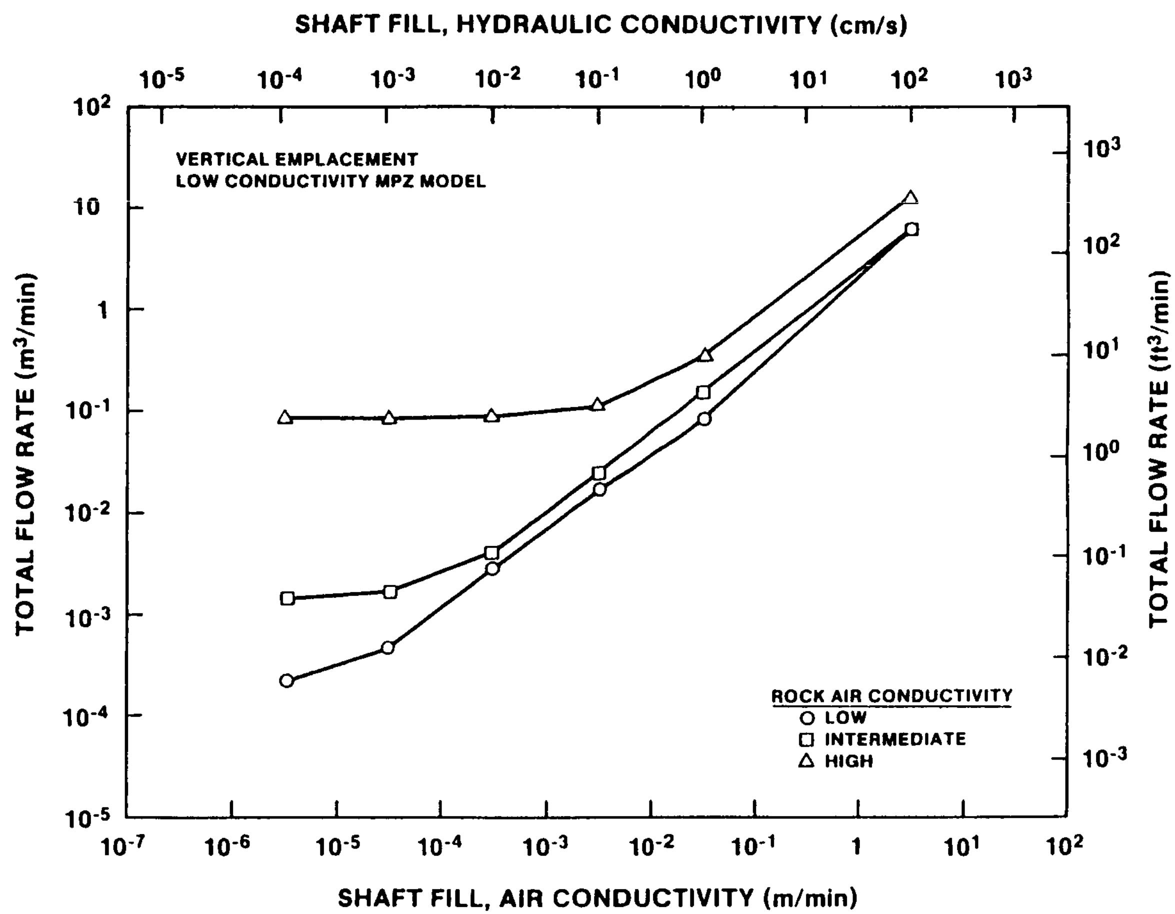


Convective Air Flow Model Description

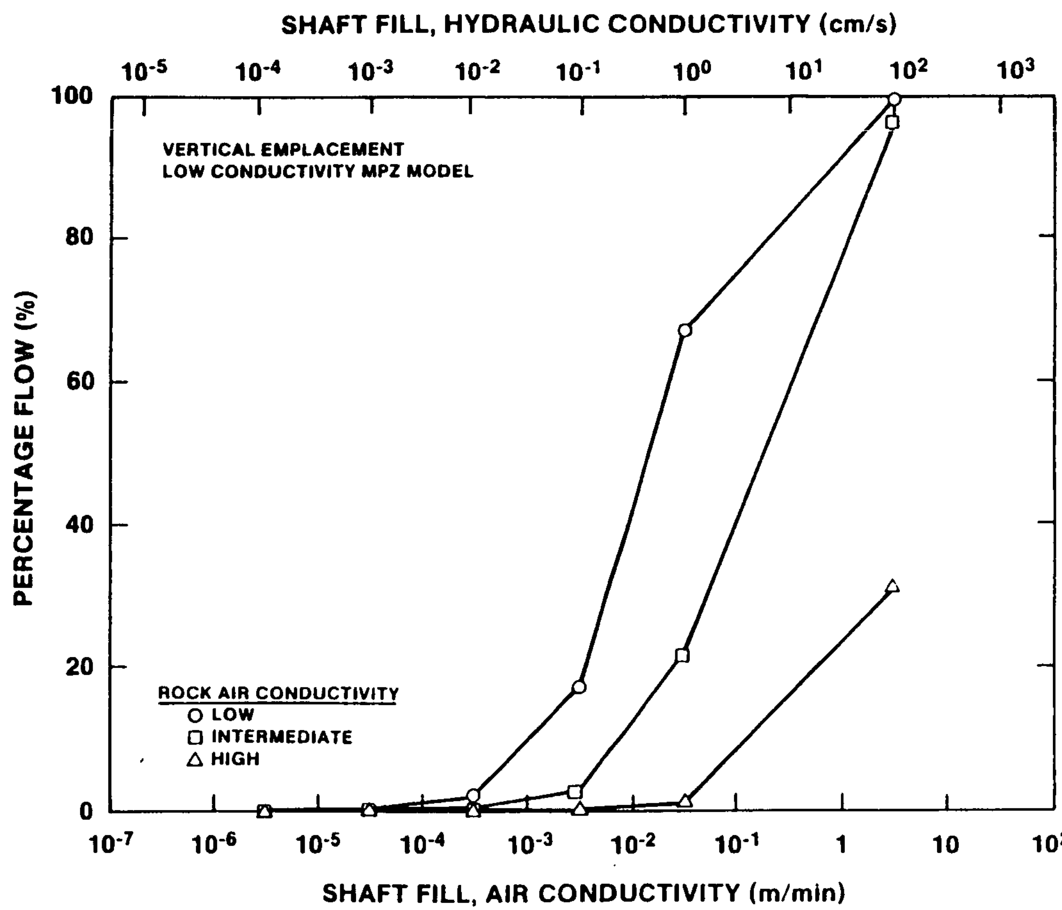
- Draft air pressure of 0.35 kPa (1.4 in. of water gage)
- Flow paths (ES-1, ES-2, MM, EES, waste ramp, and tuff ramp)
- Flow through rock (plan area and average depth of repository)

THREE COMBINATIONS OF ROCK MASS CONDUCTIVITY		
	NONWELDED (cm/s)	WELDED (cm/s)
COMBINATION 1	10^{-5}	10^{-5}
COMBINATION 2	10^{-5}	10^{-2}
COMBINATION 3	10^{-3}	10^{-2}

Total Flow Rate as a Function of Shaft Fill, Air Conductivity



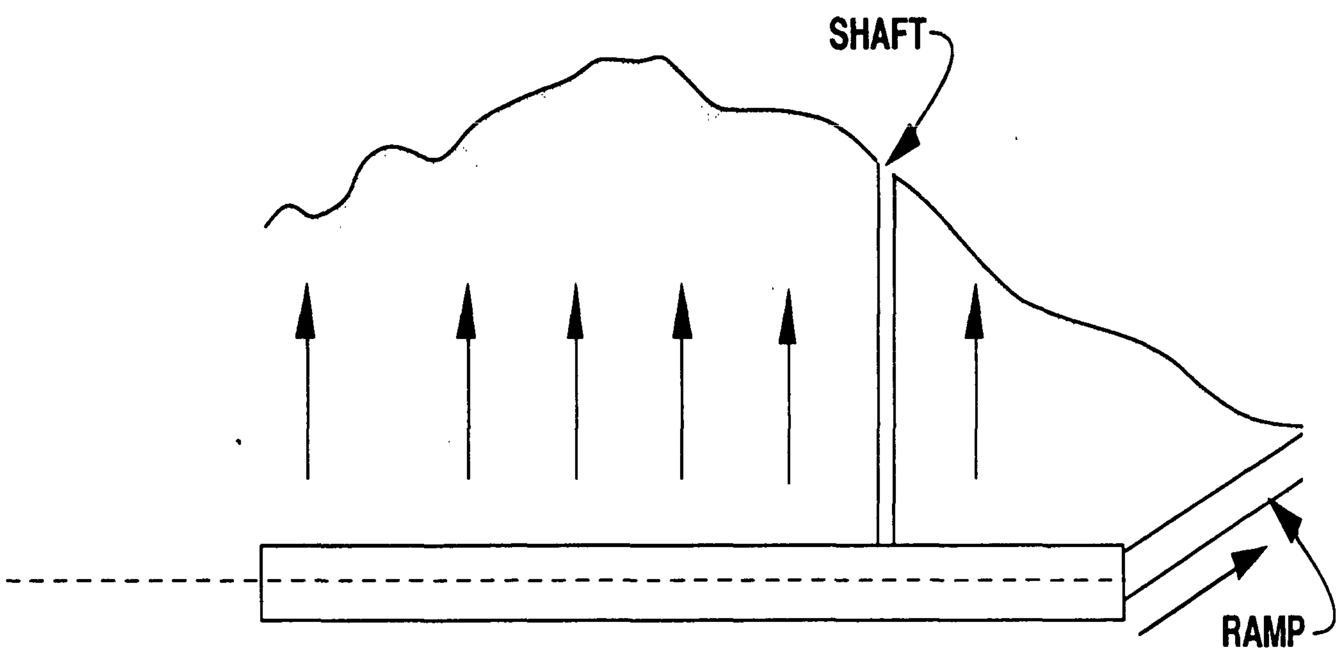
Air Flow Through ES-1 and ES-2 (Shaft Fill and MPZ Flows Included) as a Percentage of Flow Through the Rock Over the Repository Area



Convective Air Flow Model Results

- Air flow occurs dominantly through backfilled shafts for seal conductivities of $\geq 10^{-4}$ cm/s
- Air flow occurs dominantly through MPZ for low seal conductivities ($<10^{-4}$ cm/s)
- Conservative analysis based upon maximum temperature contrast
- Seal conductivity of 10^{-2} cm/s satisfies performance goal

Repository Used in Barometric Pressure Model



Barometric Air Flow Model Description

- Repository pressure ODE

$$\frac{cPr}{dt} + C\,(Pr - Pa) = 0$$

$$C = \frac{\eta r\, RTr}{\rho g\, Vr^2} \sum_{i=1}^{n} \frac{Ki\, Ai}{Li}$$

- Variation of air pressure follows a sinusoid

$$Pa = Pao + m \sin(wt)$$

- Thunderstorm
- Tornado
- Seasonal fluctuation

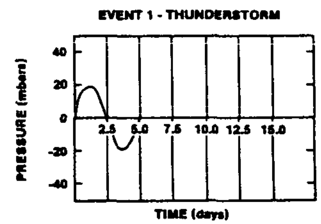
$$V = \sum_{i=1}^{n} \frac{2\, Ki\, Ai}{\rho g\, Li} \frac{m}{\sqrt{c^2 + w^2}}$$

Barometric Air Flow Model Description

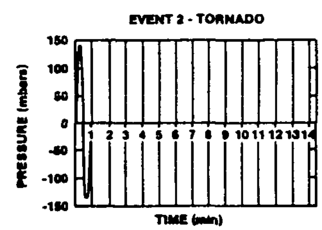
- Repository pressure ODE
- Barometric pressure events variation of air pressure follows a sinusoid

Barometric Pressure Events

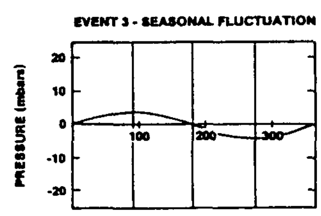
  - Thunderstorm



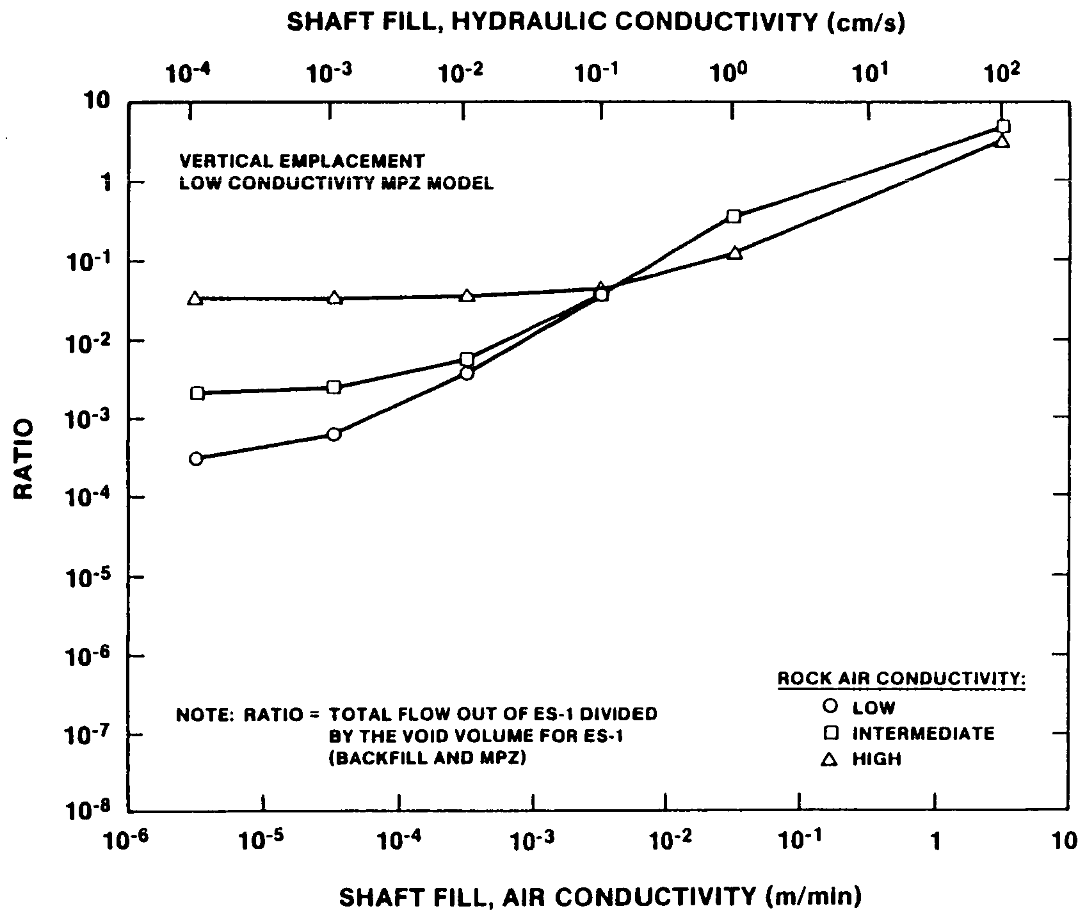
  - Tornado



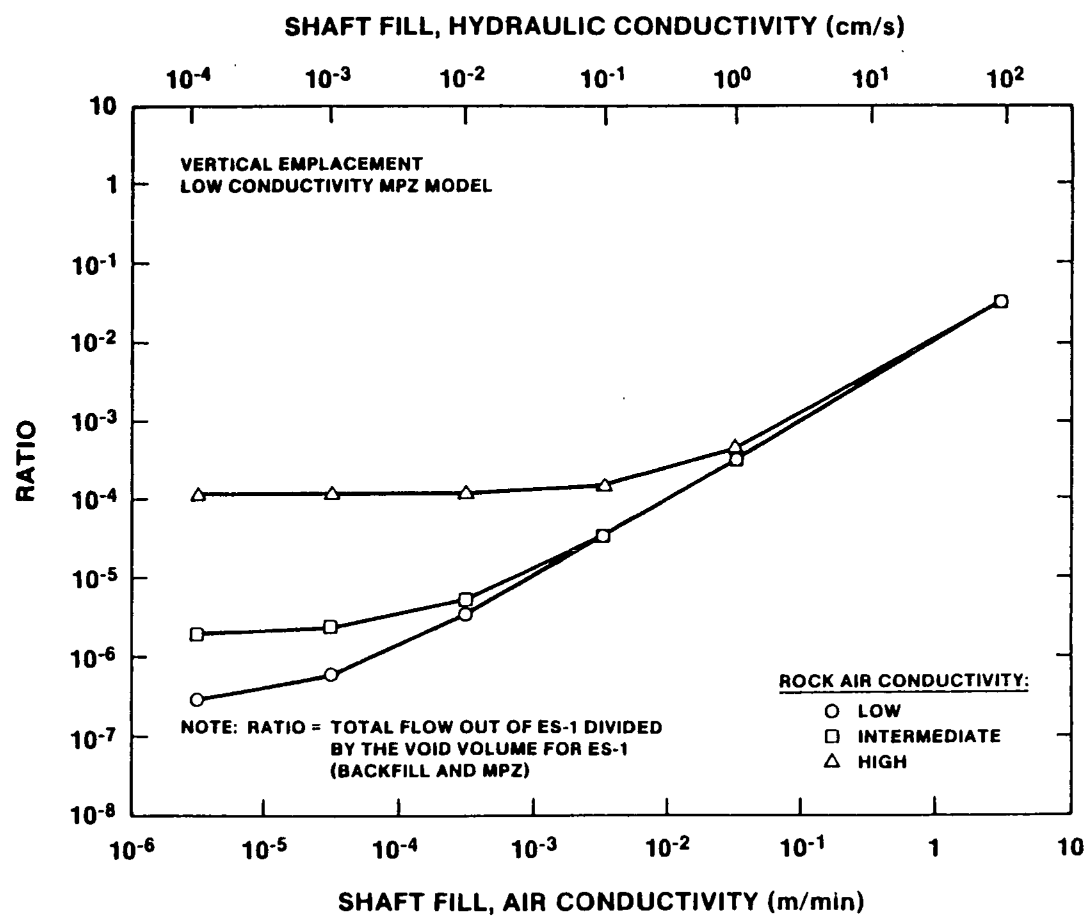
  - Seasonal fluctuation



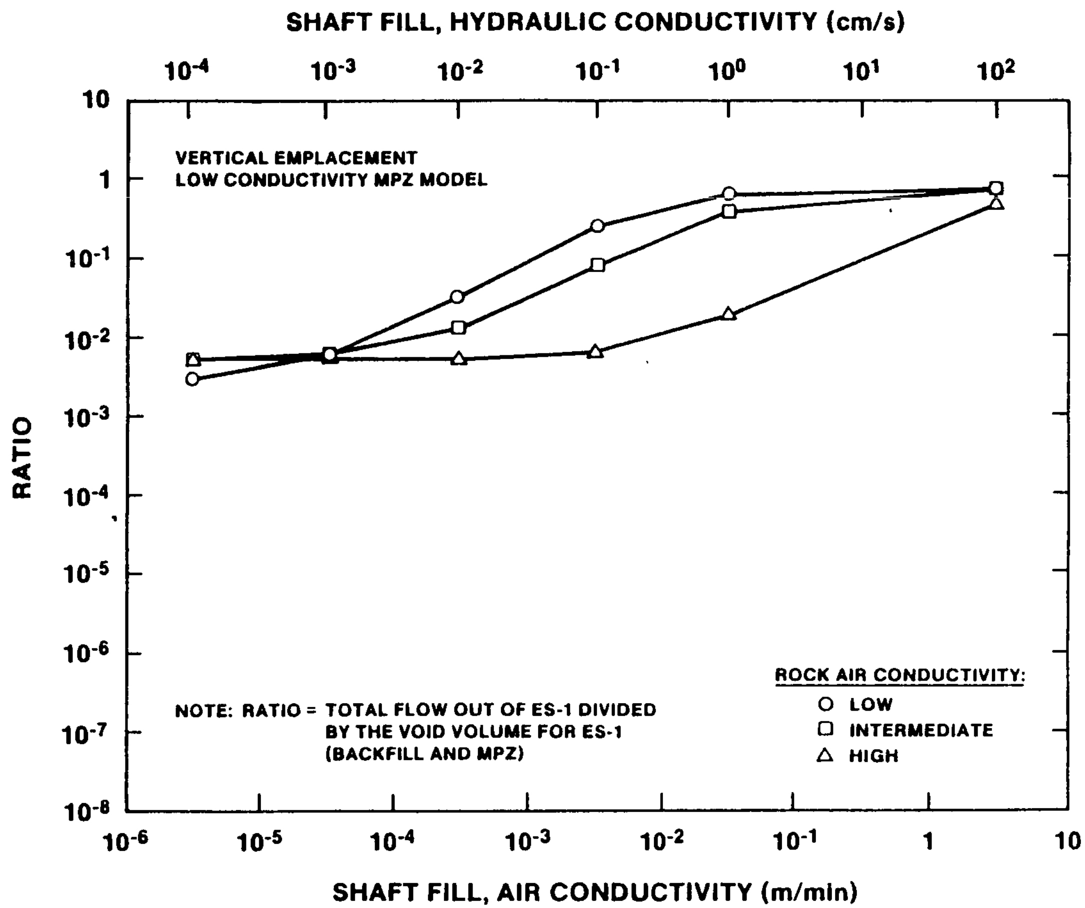
Ratio of Displaced Air Volume To Void Volume for ES-1 for a Severe Thunderstorm Event



Ratio of Displaced Air Volume To Void Volume for ES-1 for a Tornado Event



Ratio of Displaced Air Volume To Void Volume for ES-1 for a Seasonal Event



Barometric Air Flow Results

- Displaced air volume 1/10,000 to 1/10 the shaft air volume during a thunderstorm
- Air flow occurs dominantly through backfilled shafts for high-seal conductivities. Air flows through MPZ for low-seal conductivities
- Seasonal and tornado events of less significance
- For high-seal conductivity, displaced air volume approaches an asymptote, as can be seen from the displaced air relationship

Conclusion: Displaced air volume due to atmospheric events can be controlled by emplacement of a backfill with a conductivity less than 10^{-2} cm/s