

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

**PRESENTATION TO  
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD**

**SUBJECT:            FRACTURE/MATRIX INTERACTION:  
                         ANALYTICAL MODEL**

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# Fracture/matrix interaction

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- **What is the QUANTITY and CHEMISTRY of water contacting the waste packages?**
- **Where can it come from?**
  - **perched water**
  - **construction/drilling fluids**
  - **vapor condensation during heating**
  - **rainfall events**
  - **seismic pumping of the water table**
- **How is it getting there?**
  - **fracture-dominated flow**
  - **matrix-dominated flow**

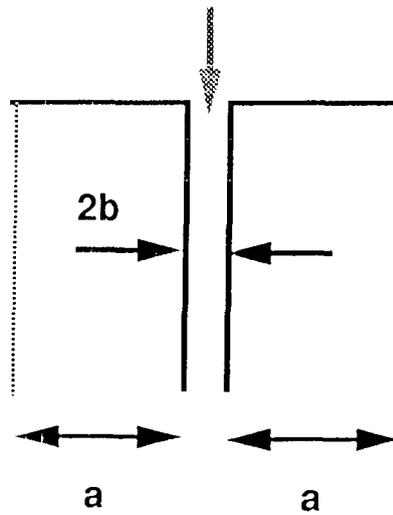
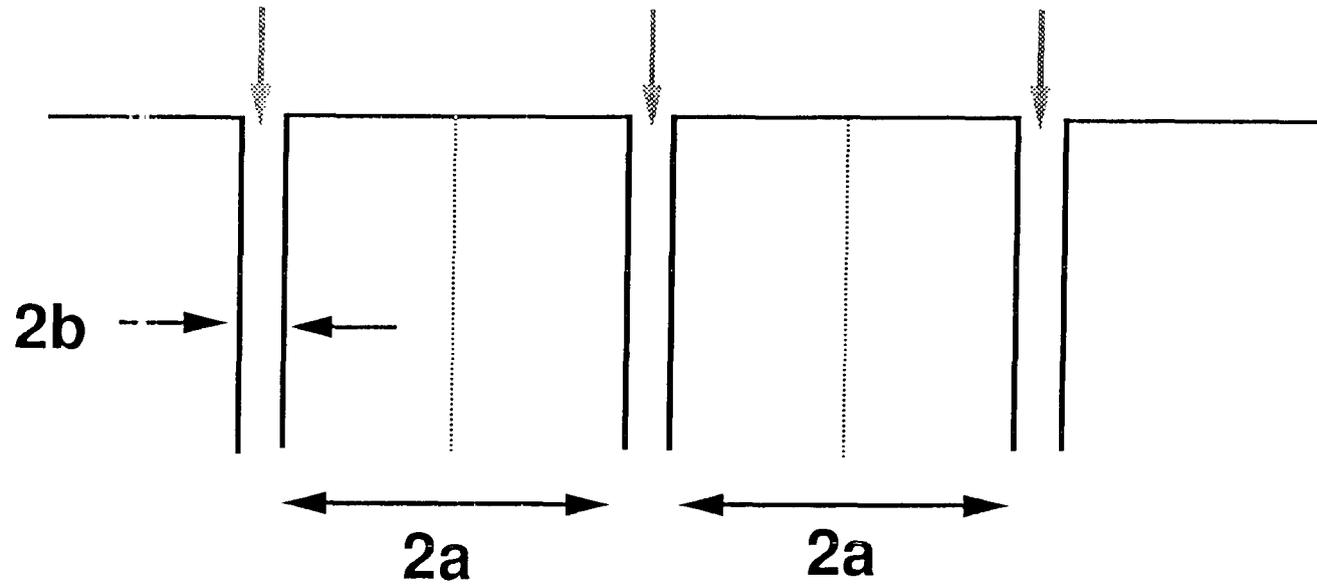
# Analysis of Fracture-Matrix Flow

- System of parallel fractures
- 2D numerical simulations and theoretical analysis
- Derived dimensionless groups and found criteria for matrix vs. fracture dominated flow conditions
- Treated both fracture and matrix dominated flow systems
- Approximate formulas predicting travel of water front
- Dependence of fracture flow on hydrological parameters
- Physical understanding and interpretation based on flow regimes
- Comparison with numerical solutions
- Application

## **When does fracture flow occur ?**

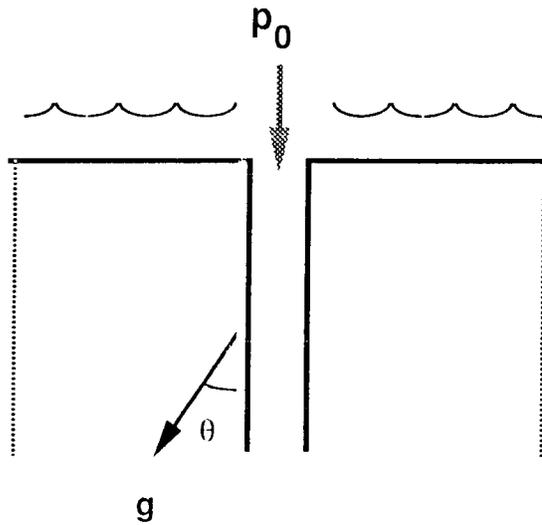
- **Determine dimensionless groups for flow in fracture-matrix systems**
- **Found critical values for fracture flow to dominate**
- **Criteria for validity of equivalent continuum approximation**

# Parallel Fracture System



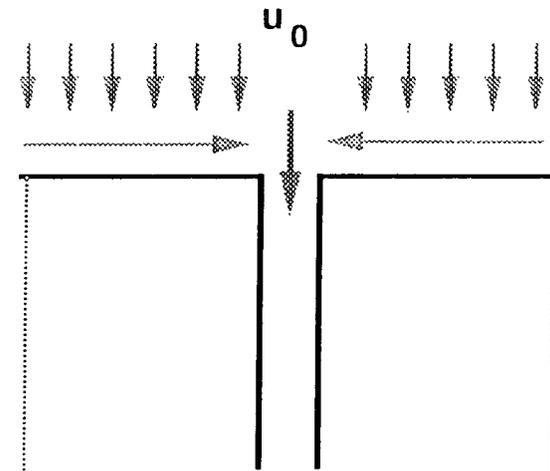
# Inlet Boundary Condition

constant head



*ponding at borehole, surface, drift floor*

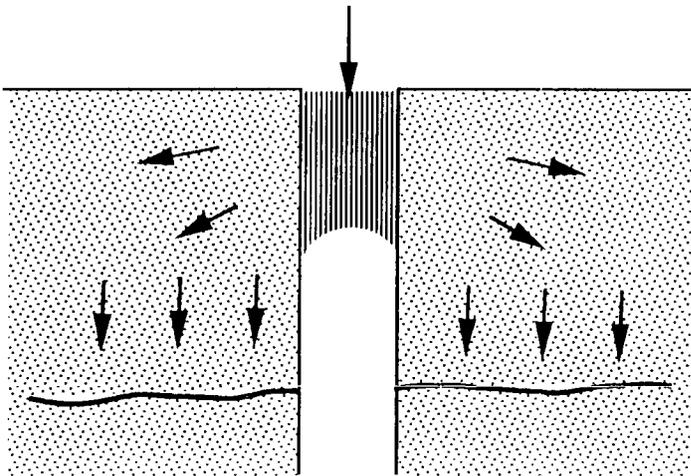
constant flux



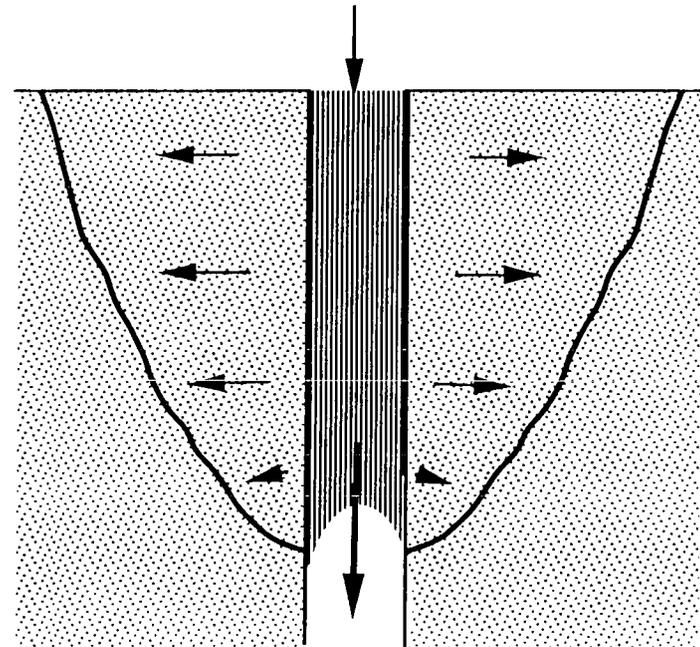
*condensation, seepage, surface infiltration*

# Critical Flux for Matrix vs. Fracture Dominated Flow

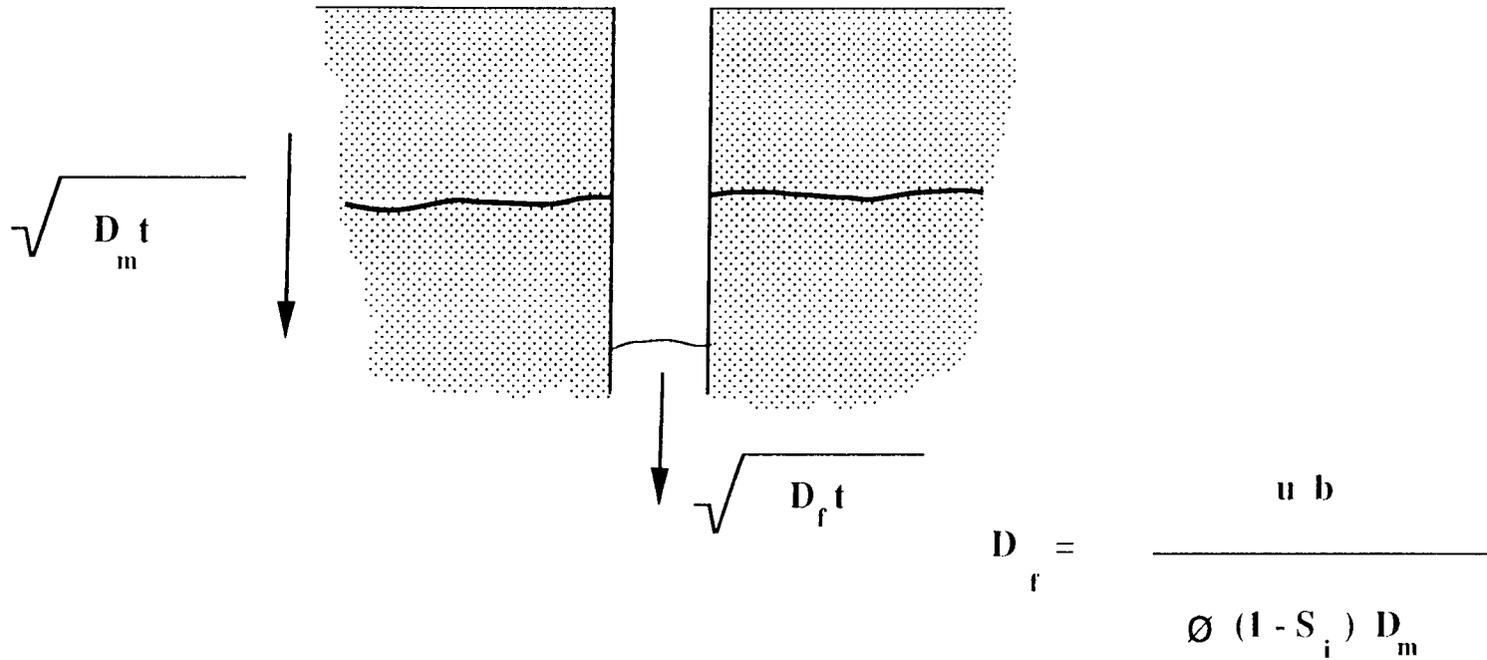
$$u \ll u^*$$



$$u \gg u^*$$

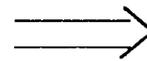


# Comparison of Matrix and Fracture Diffusivities



$$D_f \gg D_m$$

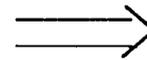
fracture dominated



$$u \gg u^*$$

$$D_f \ll D_m$$

matrix dominated



$$u \ll u^*$$

$$u^* = \frac{\phi (1 - S_i) D_m}{b}$$

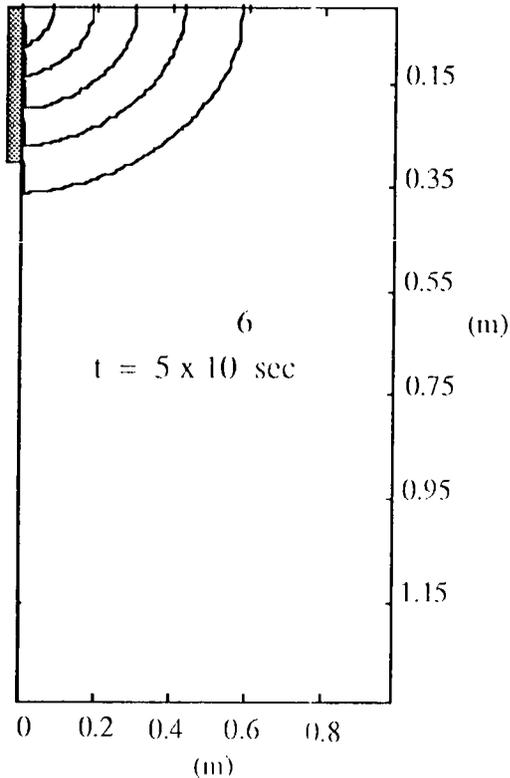
# Liquid Saturation Contours

(no interference with neighboring fractures)

matrix dominated

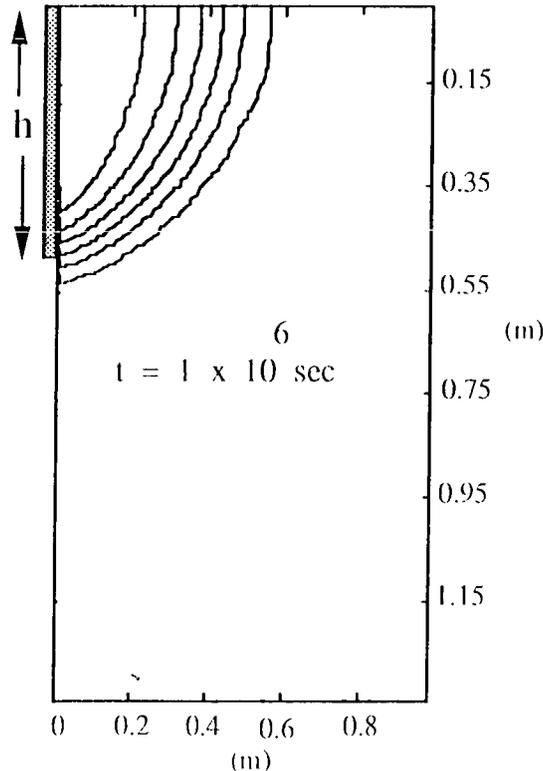
$$u = 0.1 \times u^*$$

$$h \approx \sqrt{\frac{4 u b t}{\pi \phi (1 - S_i)}}$$



intermediate

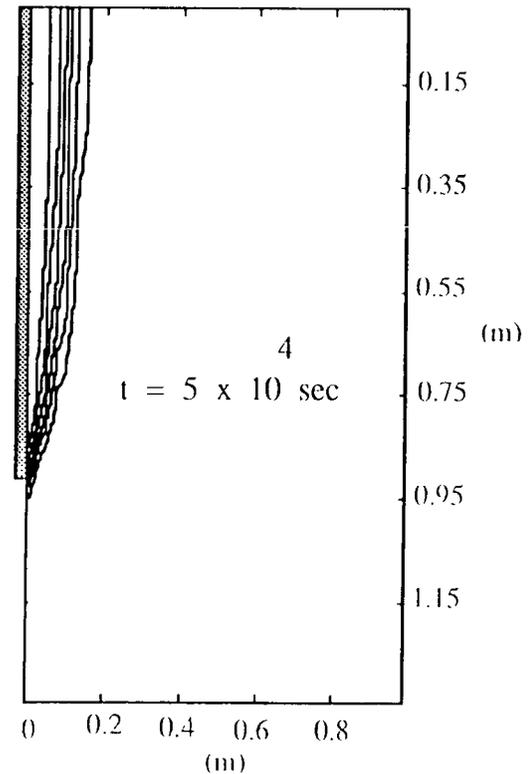
$$u = u^*$$



fracture dominated

$$u = 10 \times u^*$$

$$h \approx \frac{u b}{\phi (1 - S_i)} \sqrt{\frac{\pi t}{D_m}}$$

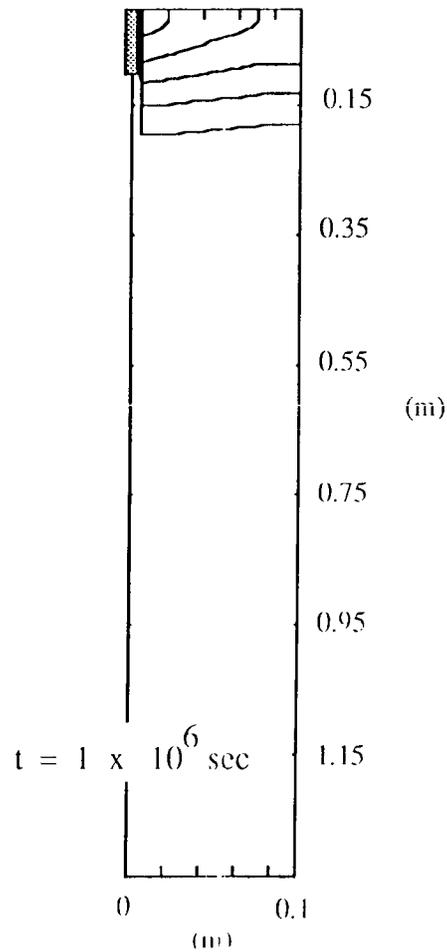


# Liquid Saturation Contours

(0.2 m fracture spacing)

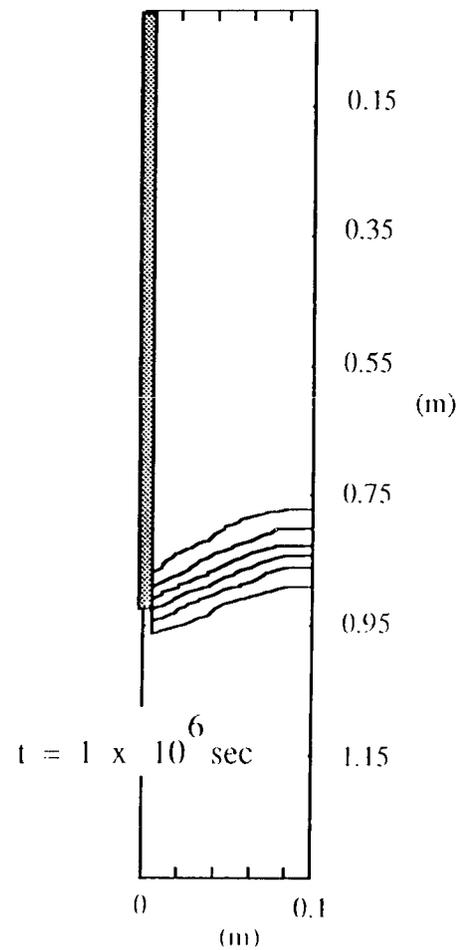
matrix dominated

$$u = 0.1 \times u^*$$



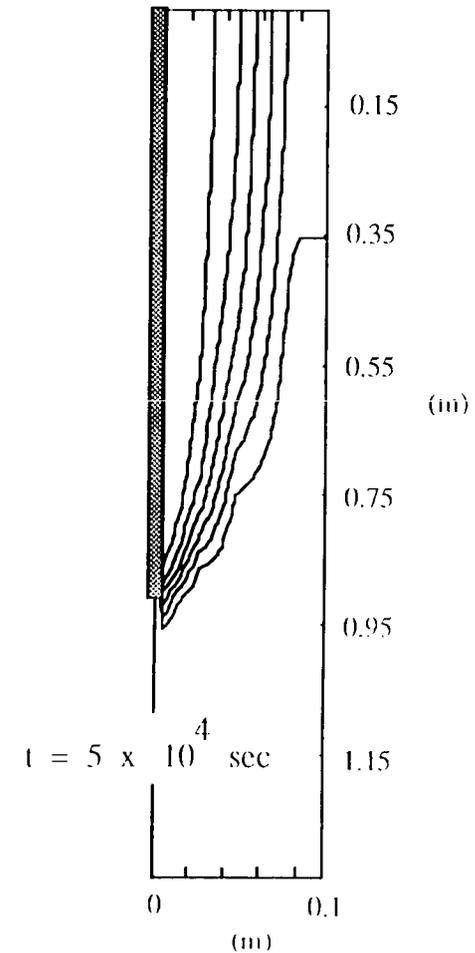
intermediate

$$u = u^*$$

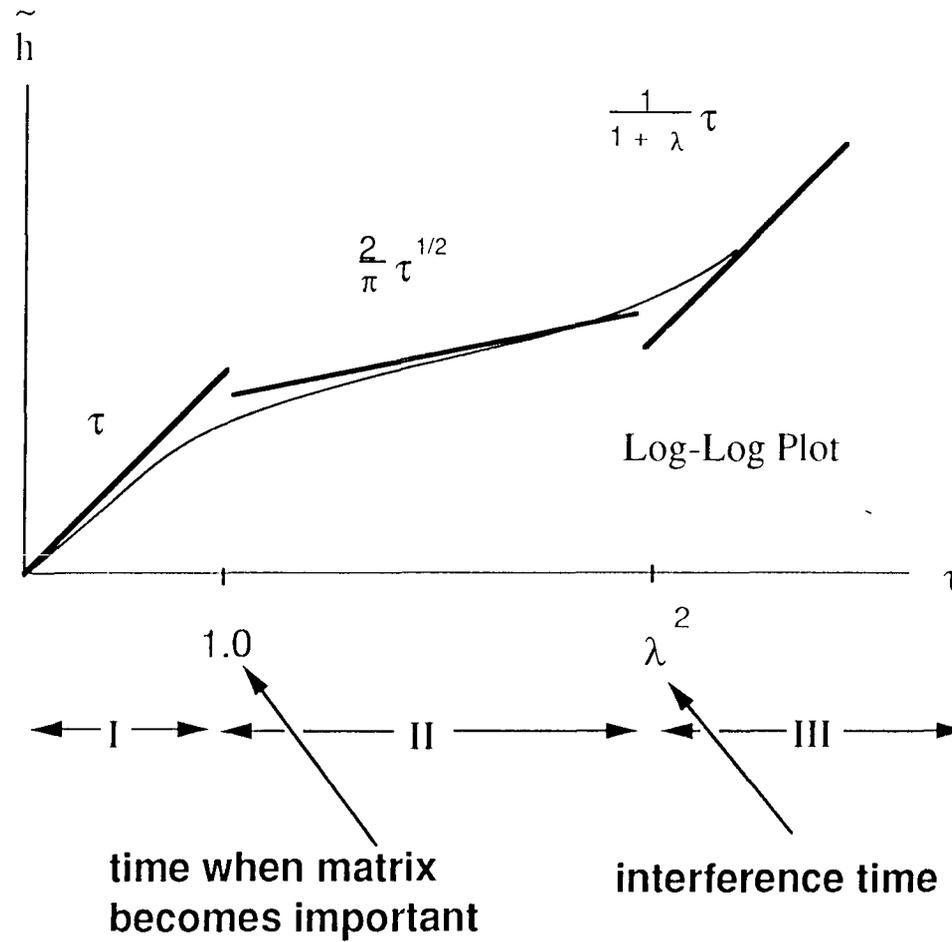


fracture dominated

$$u = 10 \times u^*$$



# Asymptotic Behavior of Fracture Penetration for Fracture Dominated Flow

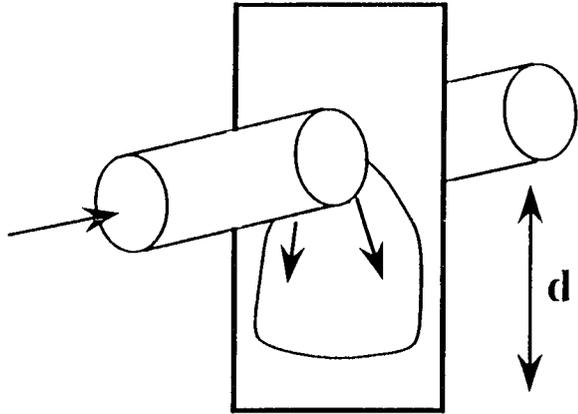


$\lambda$  = initial unsaturated matrix to fracture pore volume

# Fracture Flow Time Periods

- |                                |   |
|--------------------------------|---|
| <b><u>Flow Period I.</u></b>   | <b>dominated by boundary conditions and gravity</b>                             |
| <b><u>Flow Period II.</u></b>  | <b>dominated by matrix imbibition and gravity</b>                               |
| <b><u>Flow Period III.</u></b> | <b>matrix imbibition reduced due to interference with neighboring fractures</b> |

## Calculation for drilling water

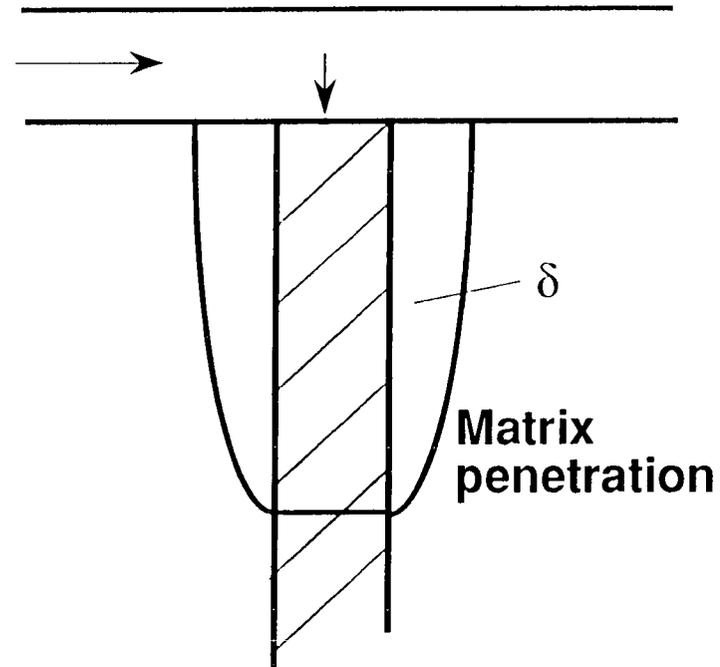


**Nominal matrix diffusivity @ 48 hrs.**

$$d = 20 \text{ m}$$

$$\delta = 6.5 \text{ cm}$$

**20% moisture perturbation**

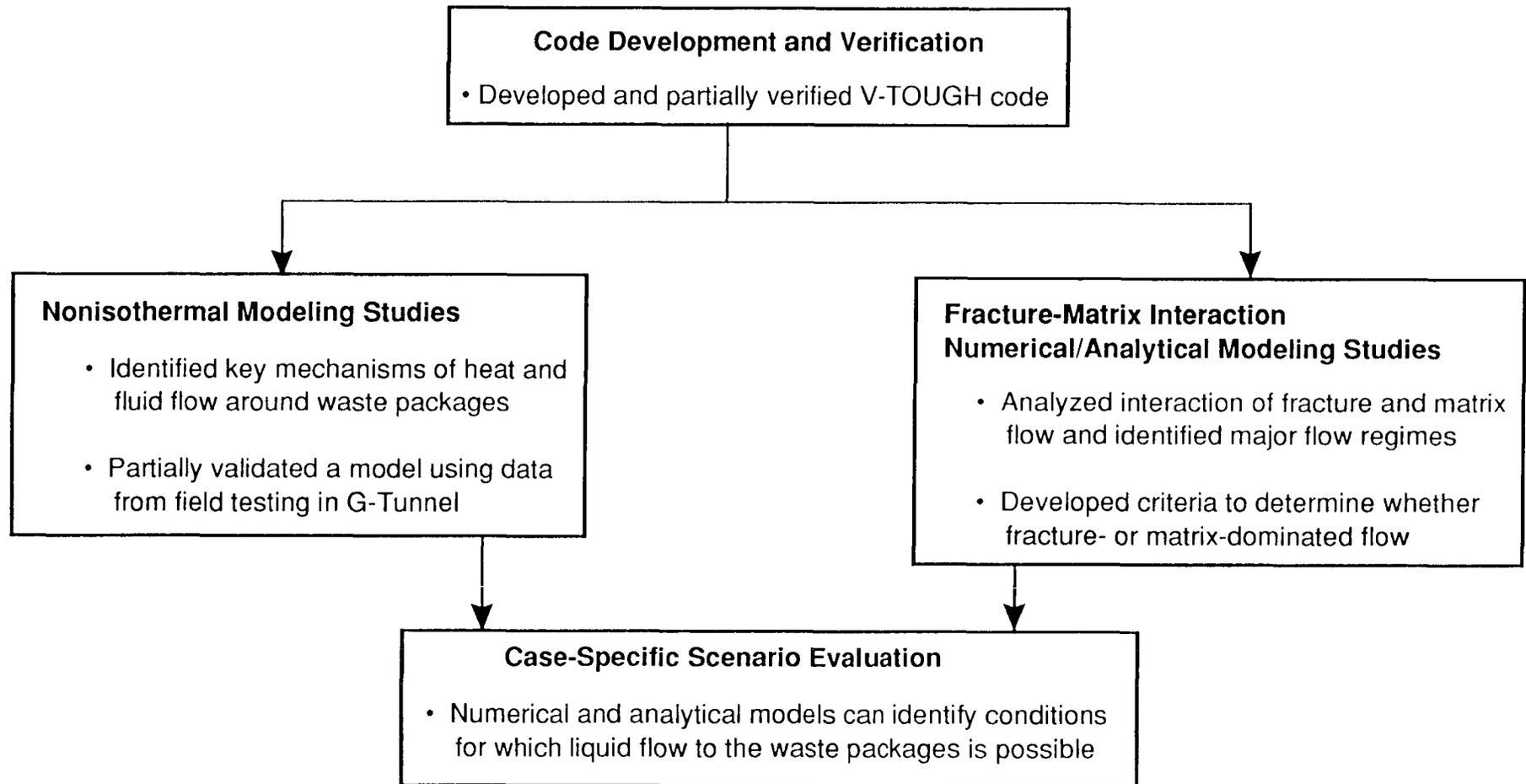


**1/40th nominal @ 48 hrs.**

$$d = 140 \text{ m}$$

$$\delta = 1.0 \text{ cm}$$

**4% moisture perturbation**



# Future Work

## Non-Isothermal Environment

- Long-term field testing
- Scaling laws for drying and condensed flux
- Integrated parameter modeling
- Dual porosity models

## **Fracture/Matrix Flow**

- **Need for experimental confirmation of theory**
- **Flow in multi-dimensional fractures and fracture systems**
- **Development of dual-porosity and fracture network models**

