Characterization, Modeling, Monitoring, and Remediation of Fractured Rock: A New Academies Report

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Statement of Task
Address issues related to flow and transport in fractured rock for lifecycle of infrastructure
- Fracture/matrix characterization, conceptual modeling
- Detection of pathways/travel times
- Thermal, hydrological, chemical, mechanical, and coupled processes
- Remediation and monitoring
- Decision making

RECOMMENDATIONS
(two types)
- Ways to improve engineering practice given today’s tools and knowledge
- Suggestions for R&D to improve future practice
Develop and communicate realistic expectations related to remediation effectiveness

Effective characterization and parameterization, and explicit understanding of matrix diffusion → realistic and achievable remediation goals

Honesty is the only policy...
The technical community needs to document failures as well as successes

Existing resources (e.g., Clu-in) provide access to vast amounts of data and studies, however there are significant gaps in communication of remediation

Monitoring programs need to be comprehensive from spatial, analyte, process, and temporal standpoints to help us believe

Take an interdisciplinary approach to engineering in fractured rock

use site geologic, geophysical, geomechanical, hydrologic, and biogeochemical information

conceptualize

• transport pathways
• storage porosities
• Fate/transport mechanisms
• coupled processes that control rock fracture-matrix interactions.

Use observational methods and adaptive approaches to inform engineering decisions

Estimate the potential for contaminant transport into and back out of rock matrix over time.

• Interactions between fracture and matrix are rapid and powerful!

• Fick’s First Law:

\[ D = \frac{\partial C}{\partial x} \]

Diffusion Flux

Diffusion Coefficient

Concentration Gradient

Conceptualization is Key

• What types of transport pathways may exist?
• What boundary conditions may exist?
• What storage porosities need to be considered?
• What fate/transport mechanisms need to be considered?
• Which coupled processes need to be estimated or considered explicitly?
**Quantify contaminant in mobile and immobile zones**

Monitoring wells provide limited information about where contaminant is, but can tell you where it is going.

Core section analysis needs to be a fundamental component of any site investigation.

**Develop appropriate hydrostructural conceptual models for fracture and rock matrix geometries and properties**

Perform preliminary calculations (e.g., analytic or simple numerical) to better inform and allocate resources for site characterization, modeling, and remediation.

**Recognize processes and their scales**

Scale 3

Scale 2

Scale 1

**Characterize processes at the appropriate scales**

Chem, bio, thermal, mechanical, hydraulic

Coupling of processes and conditions that can lead to coupling.

**Base numerical models on an appropriate hydrostructural model**

- Number/connectivity of mobile (advective) and immobile (diffusion, sorption) porosities
- Geometry/reactive surface area of transport pathways (e.g., streamline vs branching)
- Matrix/fracture interaction (Sigma factor, flow wetted surface)
- Infilling, coatings, matrix
- Geochemical and geobiologic processes (solution/precipitation, filtering, colloid transport)
Error, bias, and uncertainty introduced by simplification and upscaling

- Equivalent continuum models
  - Are they equivalent?
- Upscaling for flow
  - vs upscaling for transport
- Discrete models
  - Are they over or underconnected?

Incorporate long-term behavior into monitoring system design.

- Planning for change means less changes in plan
- Understand most of the action starts in the fractures but not all fractures are active and the action shifts from where it started
- Base design on understood discrete pathways, matrix contaminant storage, and issues of geologic heterogeneity and anisotropy when using point source concentration measurements

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