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*

No Source Remediation

With Source Remediation

Modified from Parker et al., 2010
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
**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?
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:

\[ J_m = -\phi D e \frac{\partial C}{\partial x} \]

\( J_m \) - Diffusive Flux
\( \phi \) - Porosity
\( D \) - Diffusion Coefficient
\( e \) - Concentration Gradient
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
Characterize processes at the appropriate scales

- Chem, bio, thermal, mechanical, hydraulic

- Coupling of processes and conditions that can lead to coupling

Adapted from Winberg, et al., 2003
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
  vs upscaling for geomechanics

• 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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