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Thermo-Hydro-Mechanical-Chemical (THMC) Modelling of the Bentonite Barrier in Final Disposal of High Level Nuclear Waste

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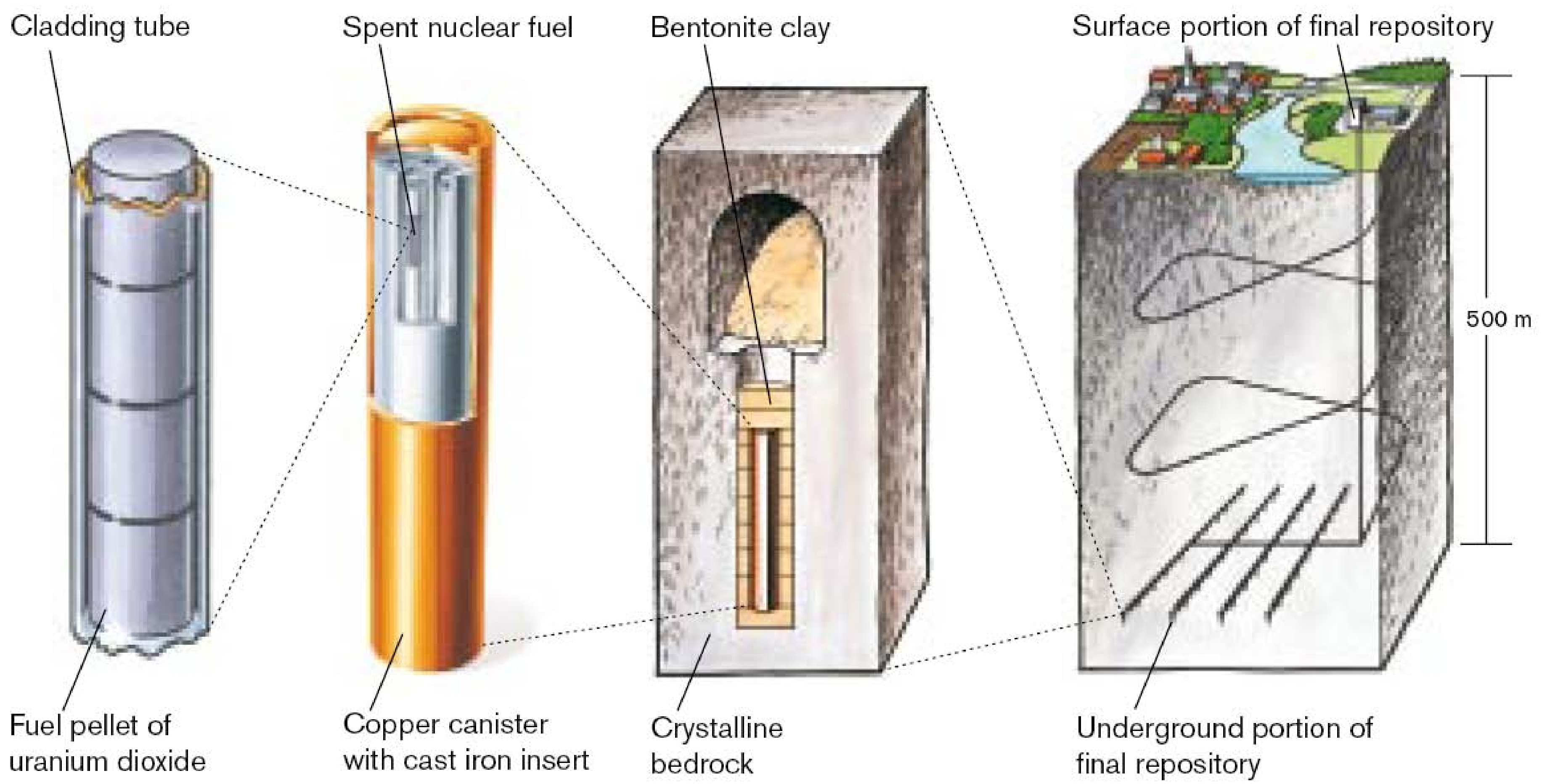
KBS-3V concept for spent fuel disposal



Source of the picture: SKB, Sweden

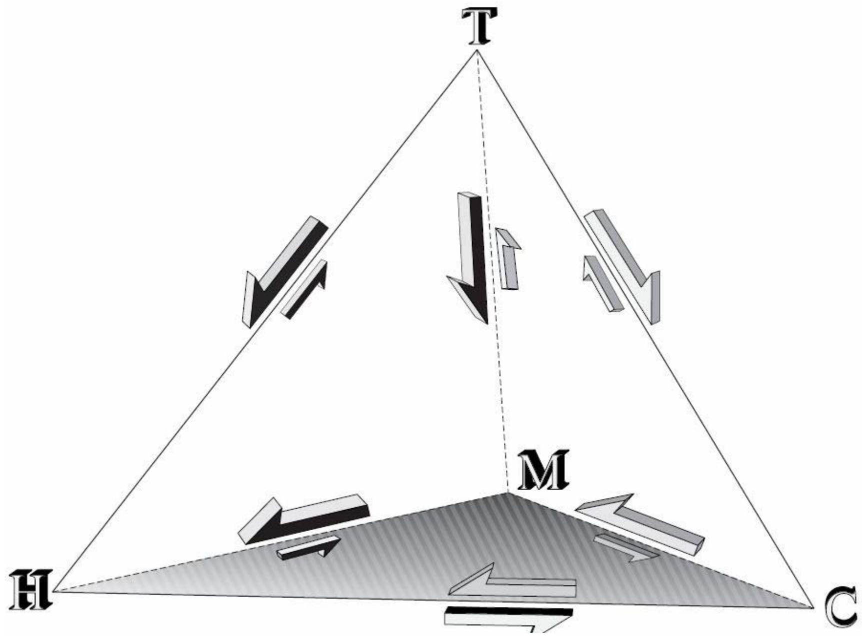
The planned site for spent fuel disposal in Finland, Olkiluoto

Source of the picture: Posiva, Finland

Relevant phenomena and processes

Main functions of bentonite buffer:

- to minimize hydraulic conductivity near waste canisters (hydraulic processes (H))
- to maintain beneficial chemical environment (chemical (C) and thermal (T) processes)
- to delay or limit release of radionuclides (CH) and
- to limit stresses acting on the canister (mechanical processes (M))



Schematic view of couplings between the THMC processes.

Equations used

- Darcy's law - fluid flow, fully saturated porous media
- Richard's equation - fluid flow, partially saturated porous media
- Heat equation
- Fick's law - Solute transport
- Theory of elasticity

$$\alpha_i \frac{\partial c_i}{\partial t} = \nabla \cdot \left(D_a \nabla c_i \right) - \nabla \cdot \left(-\mathbf{u} c_i \right) + R_i$$

Time, Diffusion, Advection, Reactions

- Chemical reactions
  - Equilibrium
  - Kinetics
  - Surface reactions

Modelling tools applied

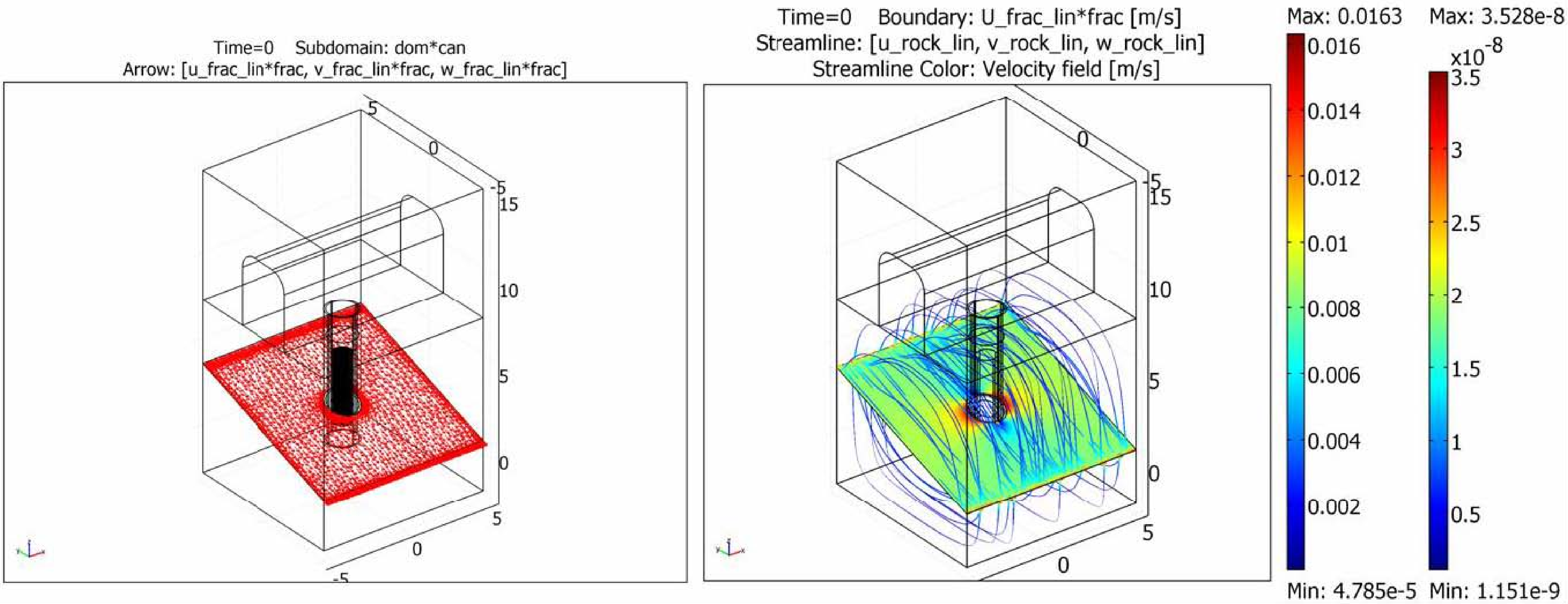
- COMSOL (main tool)
  - General tool for solving partial differential equations
  - Limited chemistry
- EQ3/6
  - Chemical reactions
  - Limited transport
- PetraSim
  - Coupled THC modelling
  - Limited chemistry support
- GoldSim
  - Radionuclide transport modelling

Cases to be studied

- 3D model
  - whole buffer volume and surrounding rock, including various fractures cutting the deposition whole; scale 10x10x8 m^3
  - bentonite buffer and fracture cutting it, either cylindrical or bit simpler rectangular; scale 2x1x0.5 m^3
- 2D model for diffusion or heat transport calculations between fracture and buffer, combined possibly with chemical reactions; scale 0.5x0.5 m^2
- 1D model for transport between the fracture and buffer in very complicated chemical reaction combined with variably saturated bentonite buffer

Preliminary results - 3D model of the disposal site.

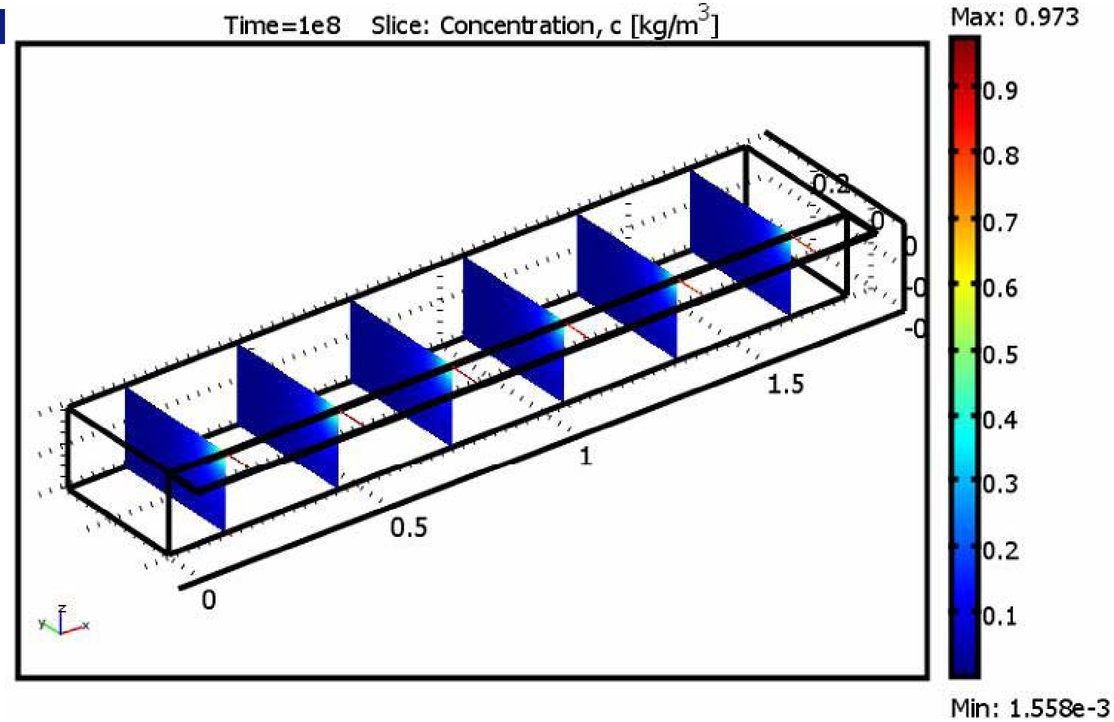
- Velocities by Darcy's law. The velocity field is shown by arrows in the left figure and by streamlines in the right figure.
- Dimensions:
  - copper canister: radius = 0.53 m, height 4.8 m
  - bentonite: thickness = 0.35 m, height = 1+4.8+1 m
  - rock block: 10m x 10m x 8m.
  - The tunnel section is not yet in use, but gives a rough idea of the scale.

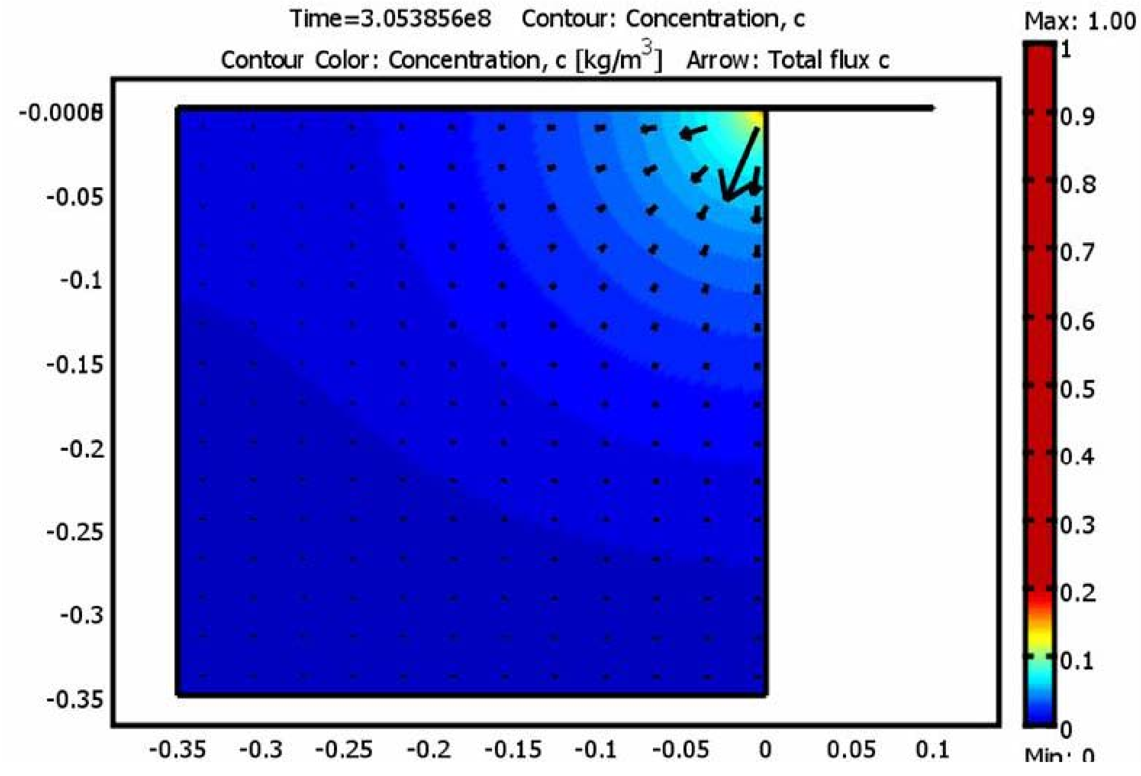


Preliminary results

- Simplest possible 3D-geometry: Bentonite around the canister is “straightened” to a rectangular slab and the fracture is in front of the bentonite. Water flows along the fracture and diffusion is in horizontal (towards canister) and vertical directions

- Simple 2D-geometry, which enables the use of very thin fracture, but lacks groundwater flow. Diffusion in two directions: horizontally, where on the left side of the figure is the canister, and vertically, where there are possibly several meters of bentonite.





Conclusions

- Some challenging issues:
  - Couplings between THMC-phenomena
  - Geometry: fracture, bentonite
  - Meshes
- COMSOL
  - appears to suite quite well for transport studies
  - BUT Modelling of chemical equilibrium seems to be clumsy

Future prospects

- Further modelling is needed to predict the evolution of nuclear waste repository
- Parellel use of our modelling toolbox
- Long-term goal is integrated THMC model

Thank you for your attention!