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Supplement of

Deep borehole disposal of intermediate-level waste

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Demonstrating Deep Borehole Disposal of Intermediate-Level Waste: Progress from Australia's RD&D Project

SafeND – 10-12 November, 2021

Dirk Mallants and Team |

Australia's National Science Agency

safe ND
Interdisciplinary research symposium
on the safety of nuclear disposal practices


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  - ✓ Borehole mechanical stability modelling
  - ✓ Temperature evolution in borehole & host rock

Deep borehole disposal demonstration project

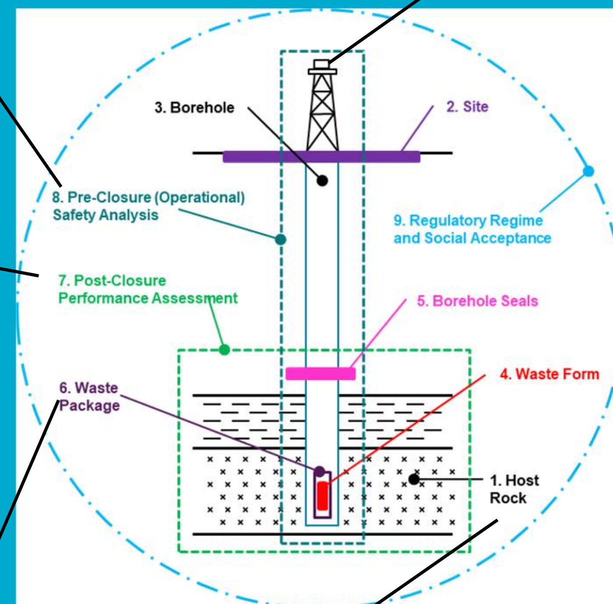
Full-scale demonstration tests:

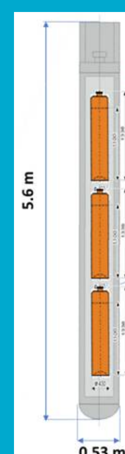
- ✓Characterisation borehole (~2000 m)
- ✓Drilling deep, large-diameter hole (0.7-m diameter, ~2000 m deep)
- ✓Waste emplacement testing of dummy canister & seal emplacement
- ✓Proto-type waste package

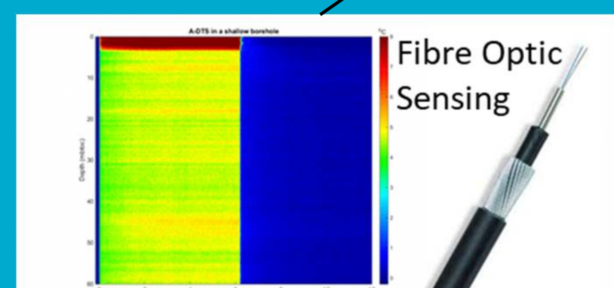
Pre-/post-closure assessments:

- ✓Intermediate-level waste (glass, synroc)
- ✓Various other waste types/forms
- ✓Various scenarios
- ✓Safety case

Australian Government
ANSTO







Bracke et al. 2017

Multiple-barrier system in a deep borehole

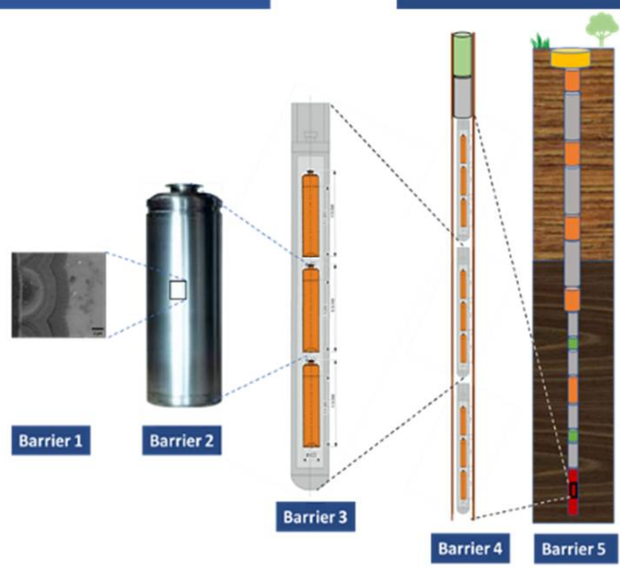
Multiple Barrier System in a Deep Borehole Disposal Concept

#1 Glass matrix
- ❑ Isolation phase

#2 Stainless steel primary package
- ❑ Isolation phase

#3 Disposal container
- ❑ Mild steel structural component
- ❑ Corrosion-resistant coating (Cu, Ti, …)
- ❑ Thermal phase

#4 Borehole seals
- ❑ Cements
- ❑ Clays
- ❑ Crushed rock
- ❑ Isolation phase



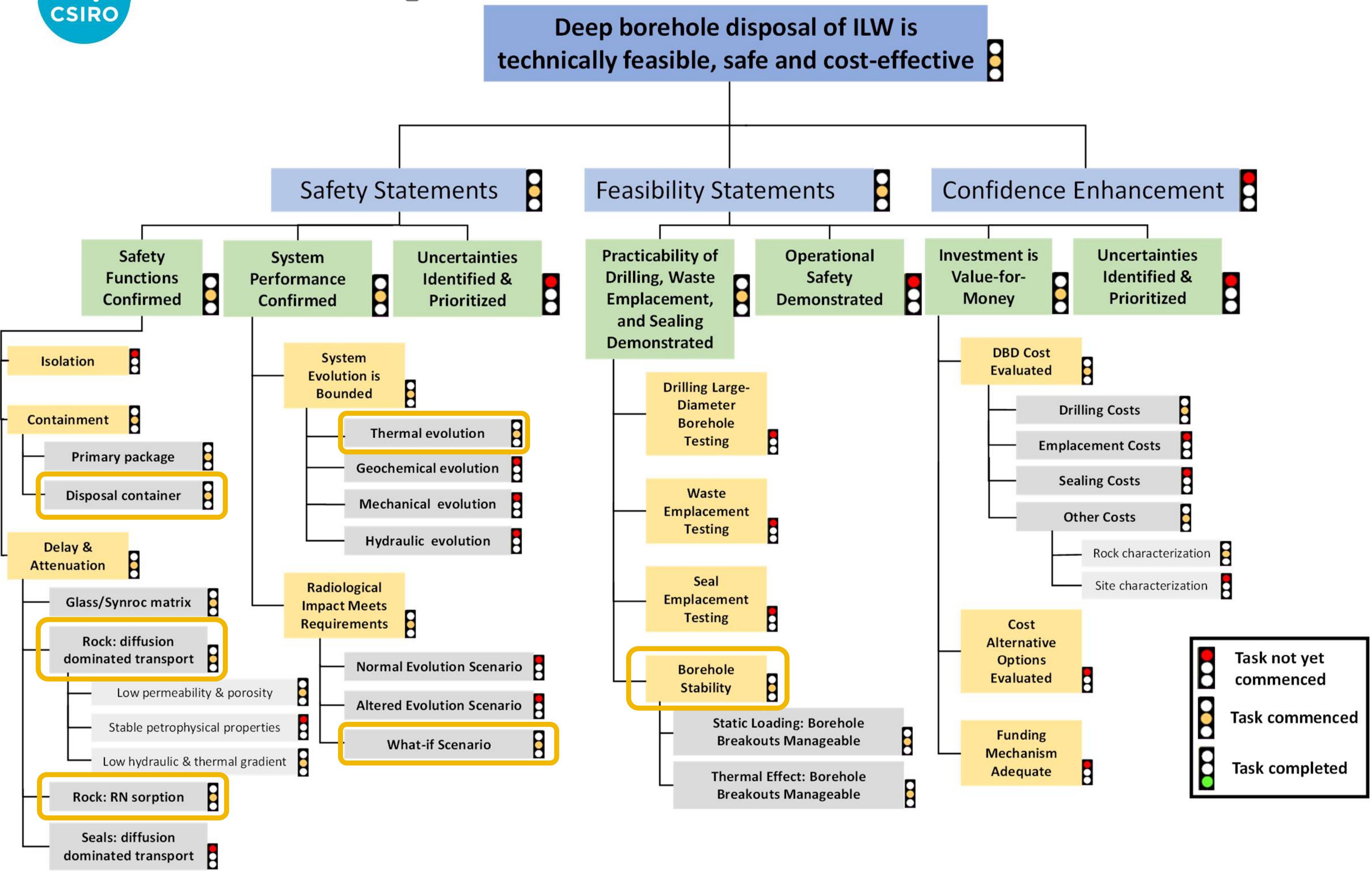
#5 Geological environment
- ❑ Deep host rock
- ❑ Geological coverage
- ❑ Geological isolation phase

Multiple safety functions: I-C-R

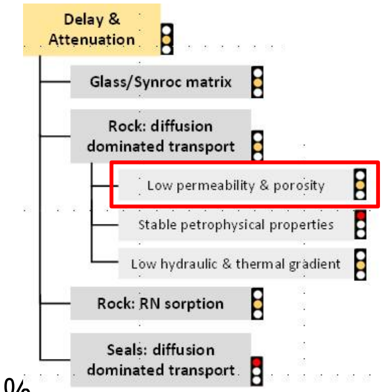
Component	Isolation (geology)	Containment (water tightness)	Delay and attenuation of releases		
			Retardation-1 (resistance to leaching)	Retardation-2 (limiting water ingress)	Retardation-3 (diffusion, retention)
Glass matrix			✓		
SS primary package		✓		✓	
Disposal container		✓		✓	
Borehole seals	✓✓			✓✓	✓✓
Geological environment	✓✓✓			✓✓✓	✓✓✓

✓✓, ✓✓✓: scalable with depth

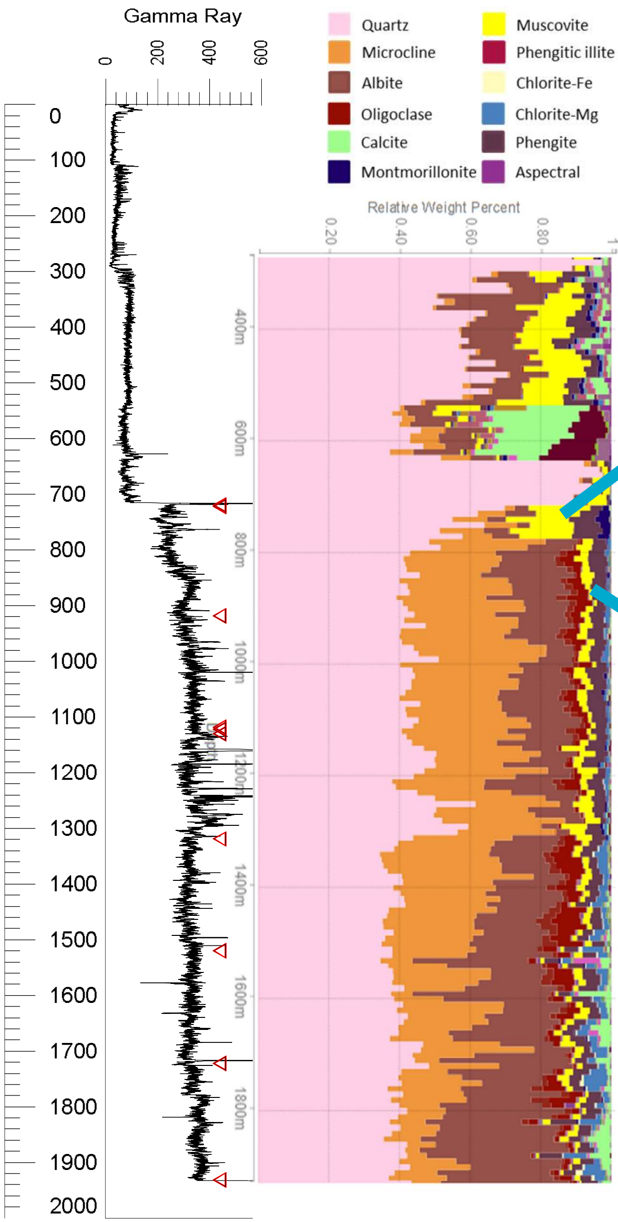
Streamlining RD&D



Confirming diffusion dominated transport - 2



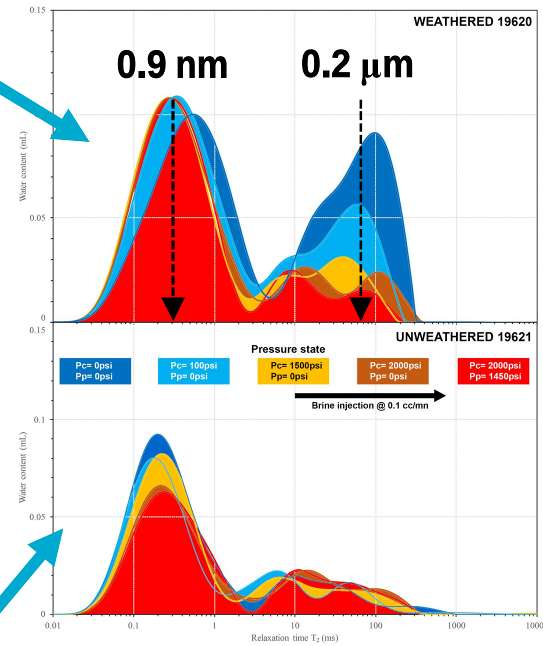
Petrophysical properties



Weathered granite

Porosity (ø) = 1.2 - 2.2 %
Permeability (k) = 1.1 - 70 μD
Hydr. Cond. (K) = $1.1\times10^{-11} - 7\times10^{-10}$ m/s

Core-flooding + NMR



Stress-sensitive fractures

Stress-insensitive fractures

Unweathered granite

Hiltaba suite granites ~1.575-1.6 Ga

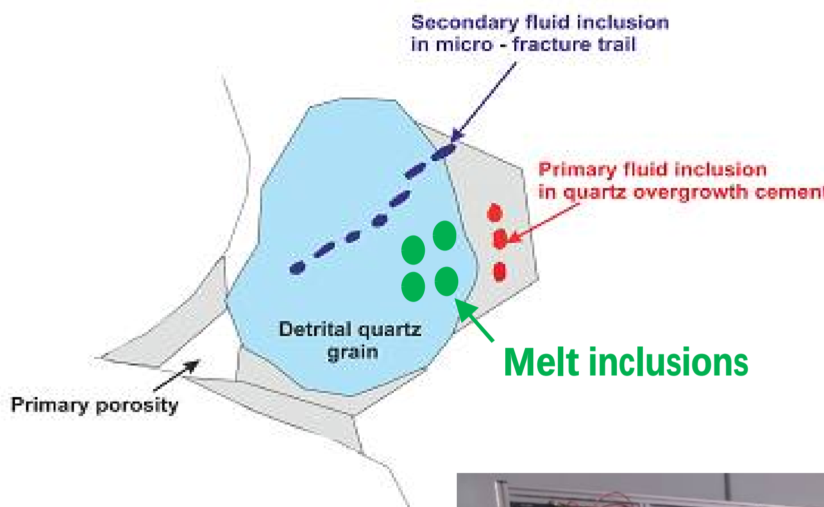
Porosity (ø) = 0.02 – 0.26 %
Permeability (k) = 0.5 - 4.5 μD
Hydr. Cond. (K) = $5\times10^{-12} - 4.5\times10^{-11}$ m/s

Confirming diffusion dominated transport - 3

- **Environmental tracers (He, Ne, Ar, Xe)**

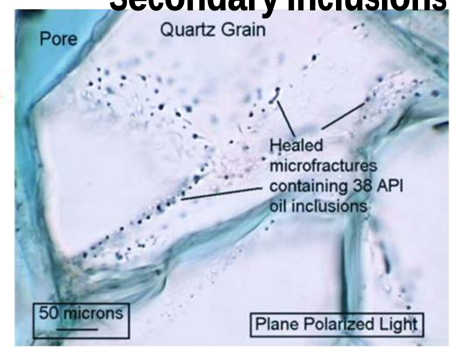
What are fluid inclusions?

- Trapped fluids inside minerals (voids in crystals)
- Heterogenous composition
- Gases, liquids and solids



Primary inclusions

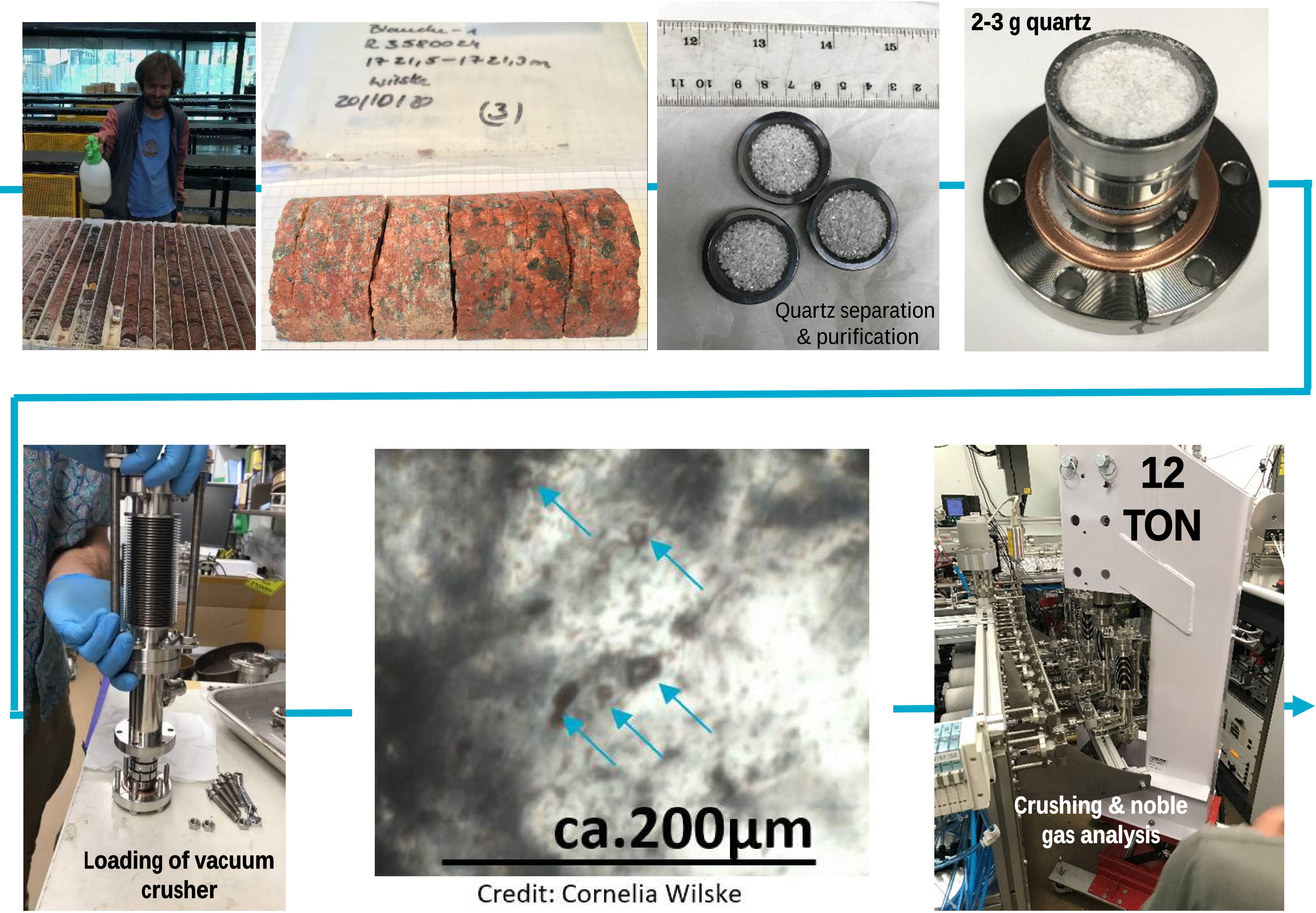
Secondary inclusions



What can fluid inclusions tell us about host rock?

- How old are the fluids compared to the age of the rock? Ne & Ar isotopes
- Any more recent processes involving fresh groundwater? Ne & Ar isotopes
- Provenance and residence time of groundwater (isolated system)

Fully automated, high throughput multi-Collector noble gas mass spectrometer

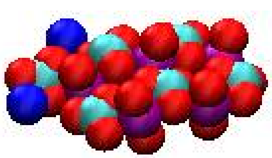

2-3 g quartz
Quartz separation
& purification
Loading of vacuum
crusher
ca.200µm
Credit: Cornelia Wilske
12
TON
Crushing & noble
gas analysis

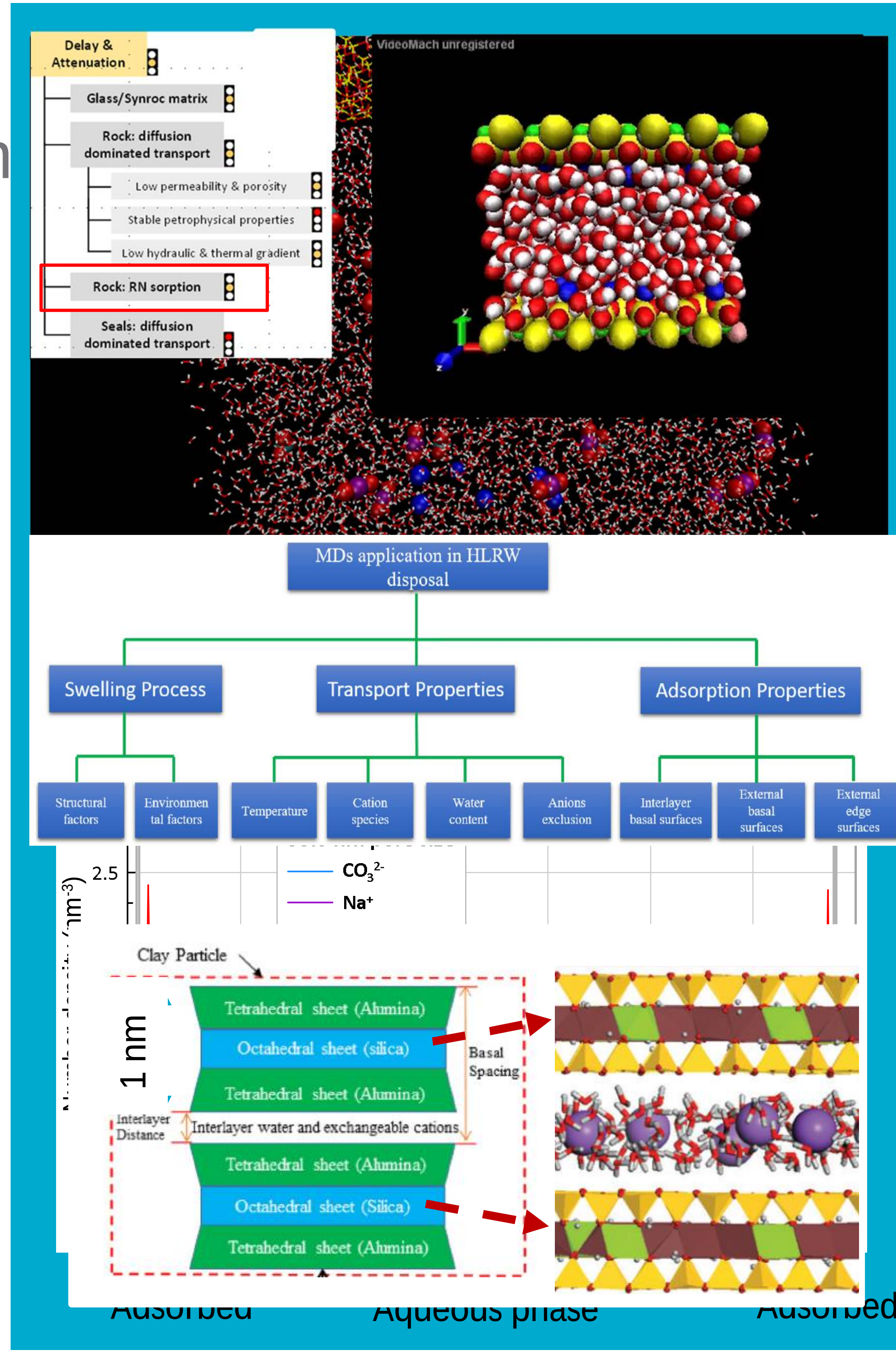
Molecular Dynamics Simulation of RN sorption

- Na-montmorillonite clay (Smectite)
- Aqueous solution: Na^{+}, CO_3^{2-}, UO_2^{2+}
- 0.162 M uranyl carbonate
- K_D calculated from atomic density profile

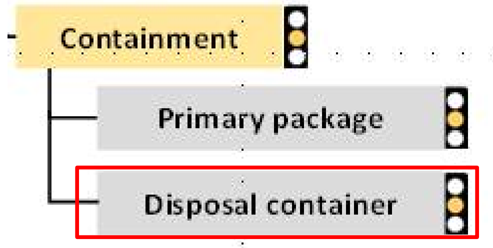
$$K_D = \left(\frac{C_{\text{adsorbed}}}{C_{\text{diffuse}}}\right)\left(\frac{V_l}{m_s}\right)$$

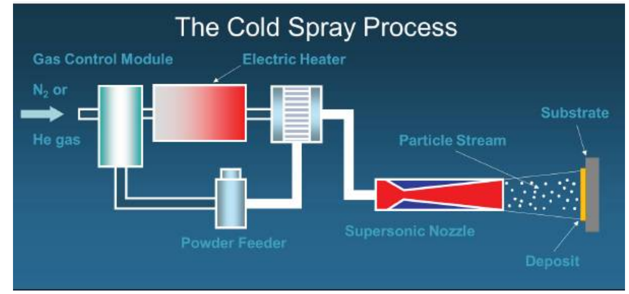
- K_D = 58 - 151 mL/g : similar to independent results from SANDIA (15 – 200 mL/g)
- Poly-nuclear U-species:
  - ✓Adsorbed: $[(UO_2)_5(CO_3)_5]^0$
  - ✓Aqueous: $[Na_2(UO_2)_5(CO_3)_6]^0$



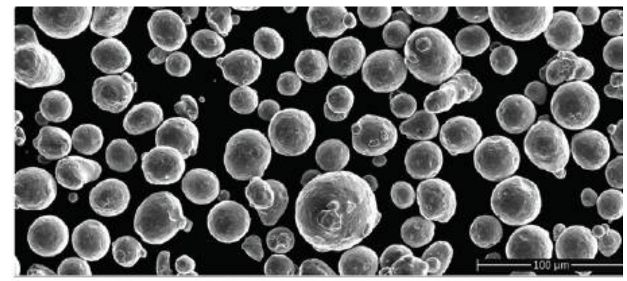


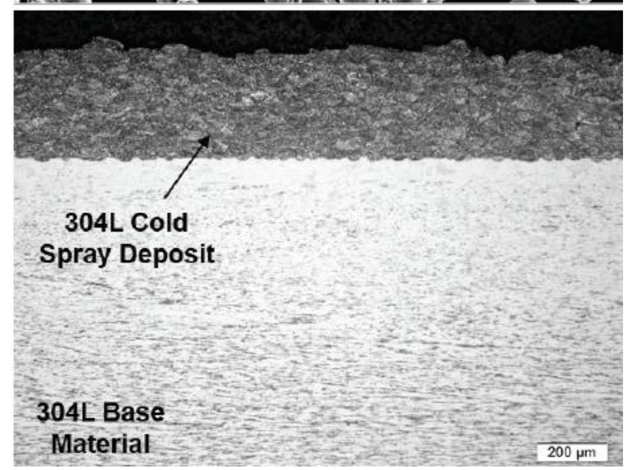
Durable coatings for disposal containers

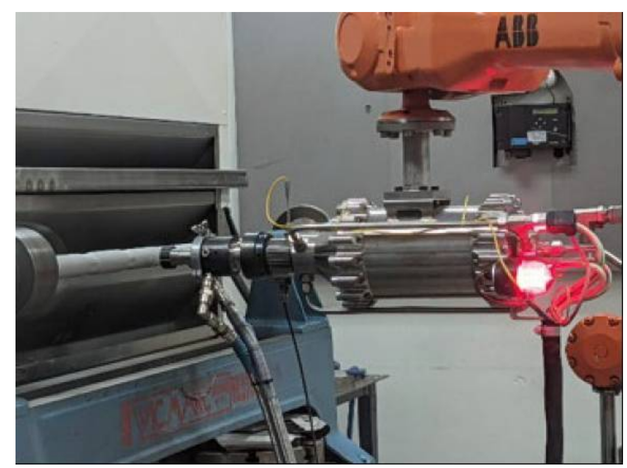




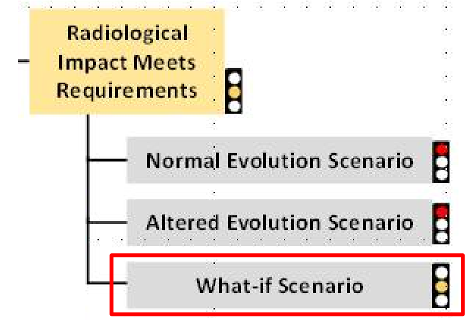
- Overpack/disposal container: mild structural steel + metal coating
- Literature review on coatings identified cold spray as most promising technology (minimal porosity, no high T effects)
- Cold spray uses supersonic particle velocities to deposit a dense layer of metallic powder on the surface of components
- Coating materials:
  - ✓ Titanium, Copper, Nickel, Chromium, Ni-Cr alloys, Tantalum
  - ✓ Composites (metal + ceramic)
- Benefits: surface property modification (corrosion and/or wear resistance)
- Corrosion & Abrasion testing underway

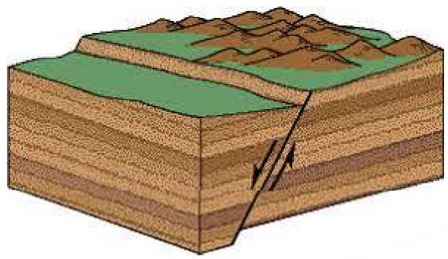


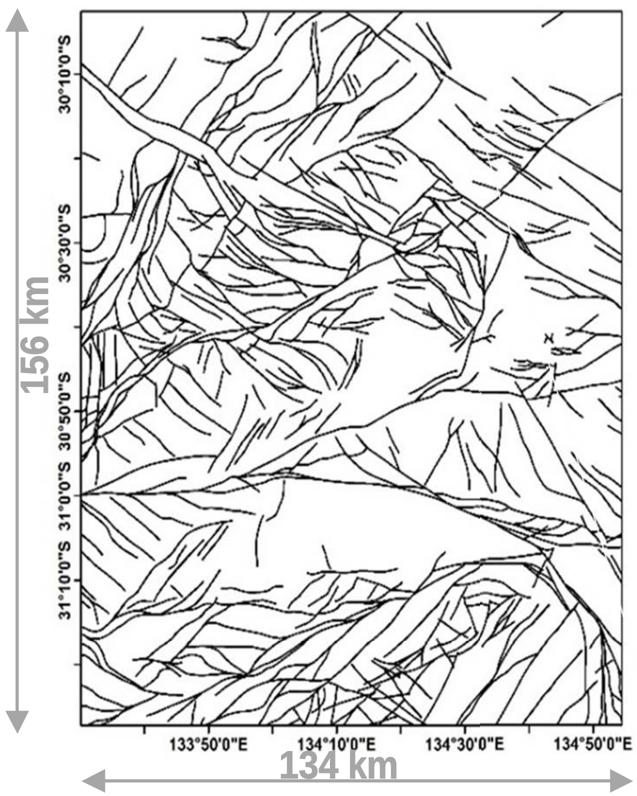




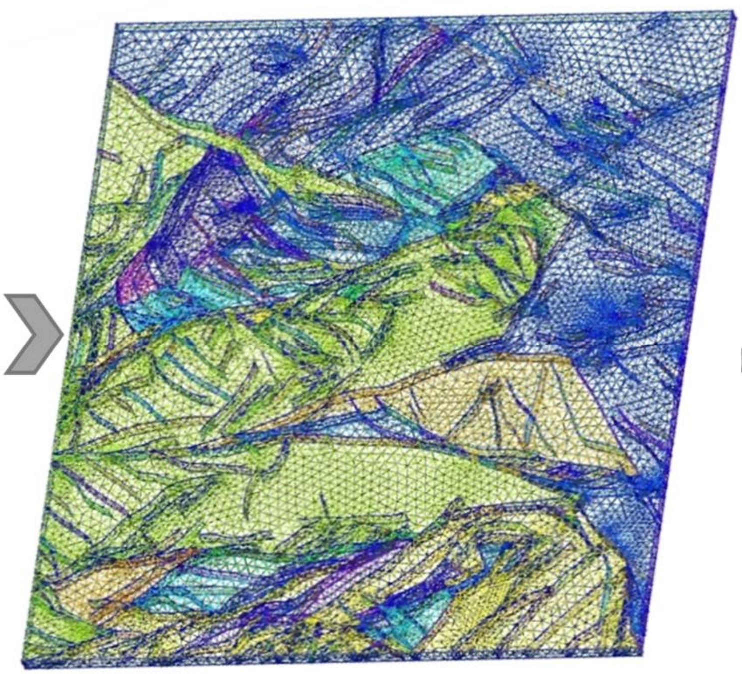
Geological fault network analysis/ FE mesh generator



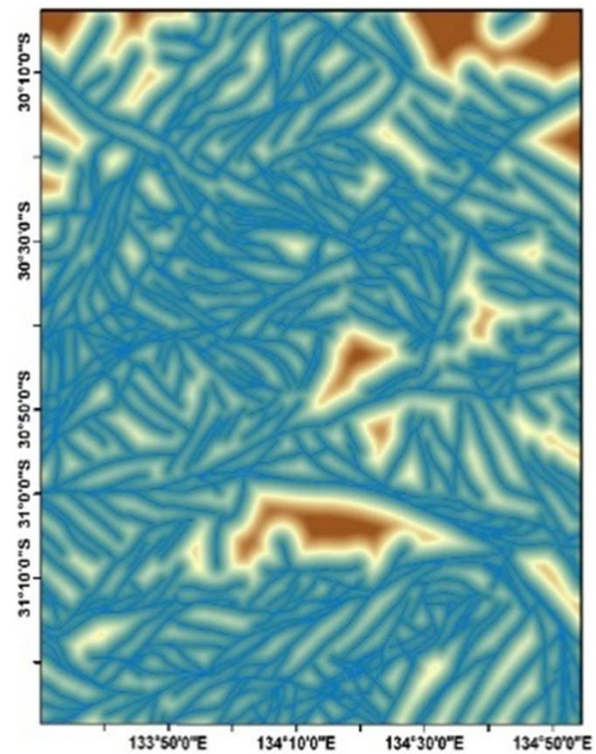




Fault trace map

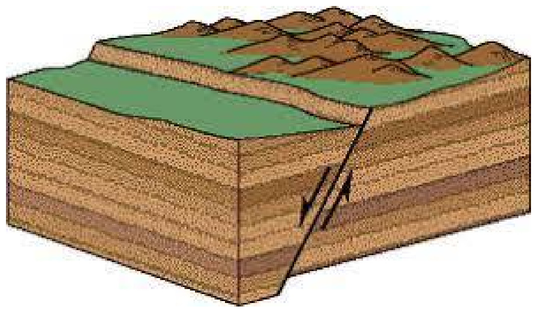


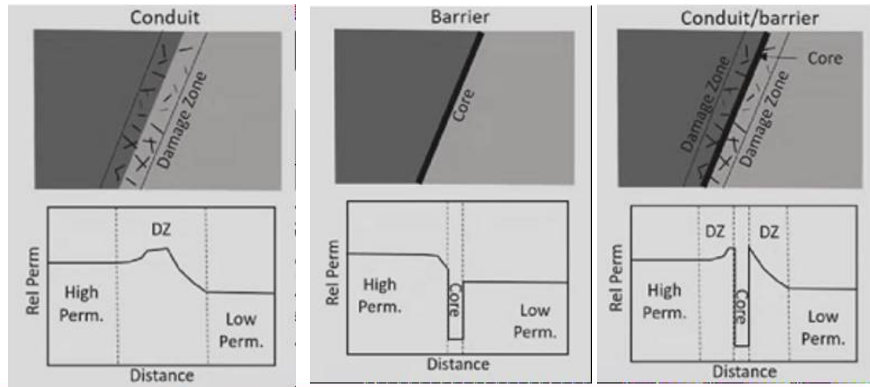
Automatic conversion in 2D finite element grid

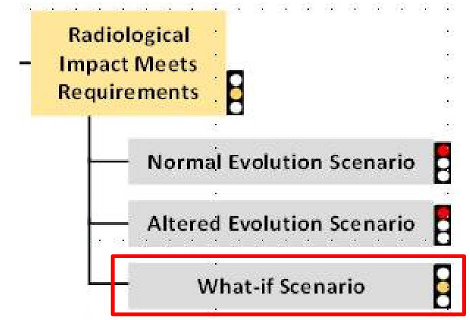


Calculated distance from faults + -

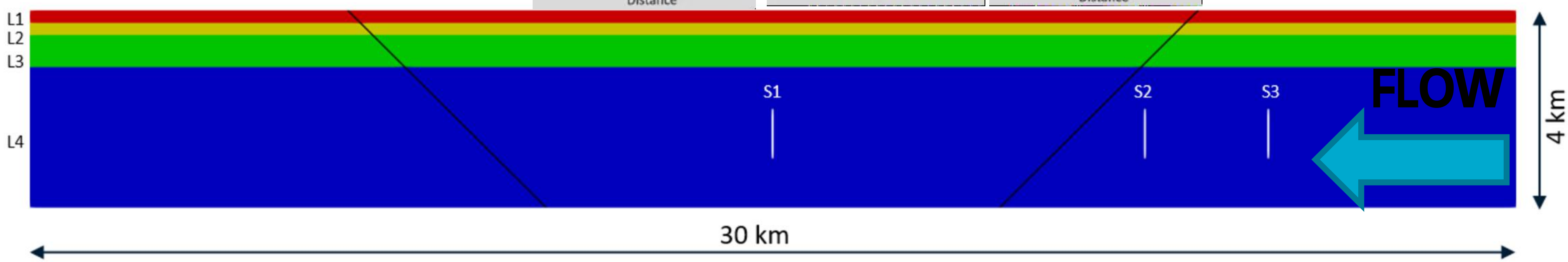
Geological fault modelling: chemical transport

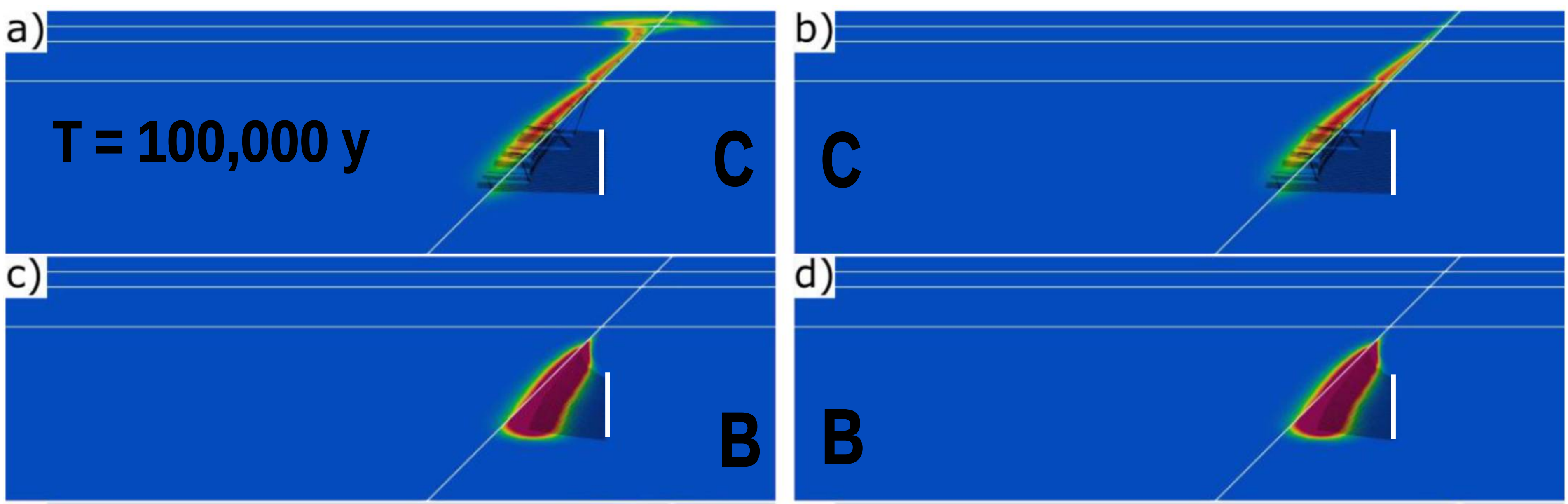




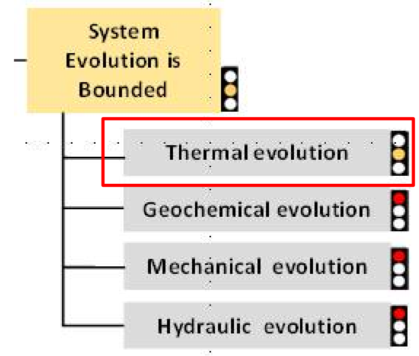


McCallum et al. 2018

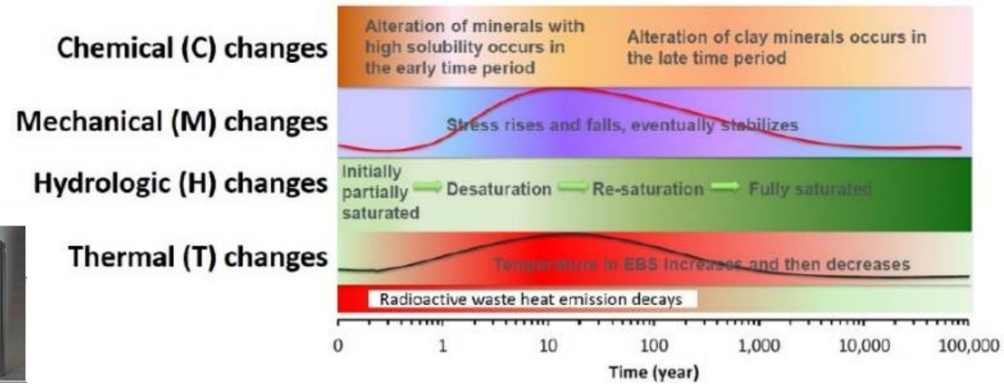


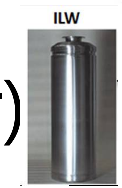


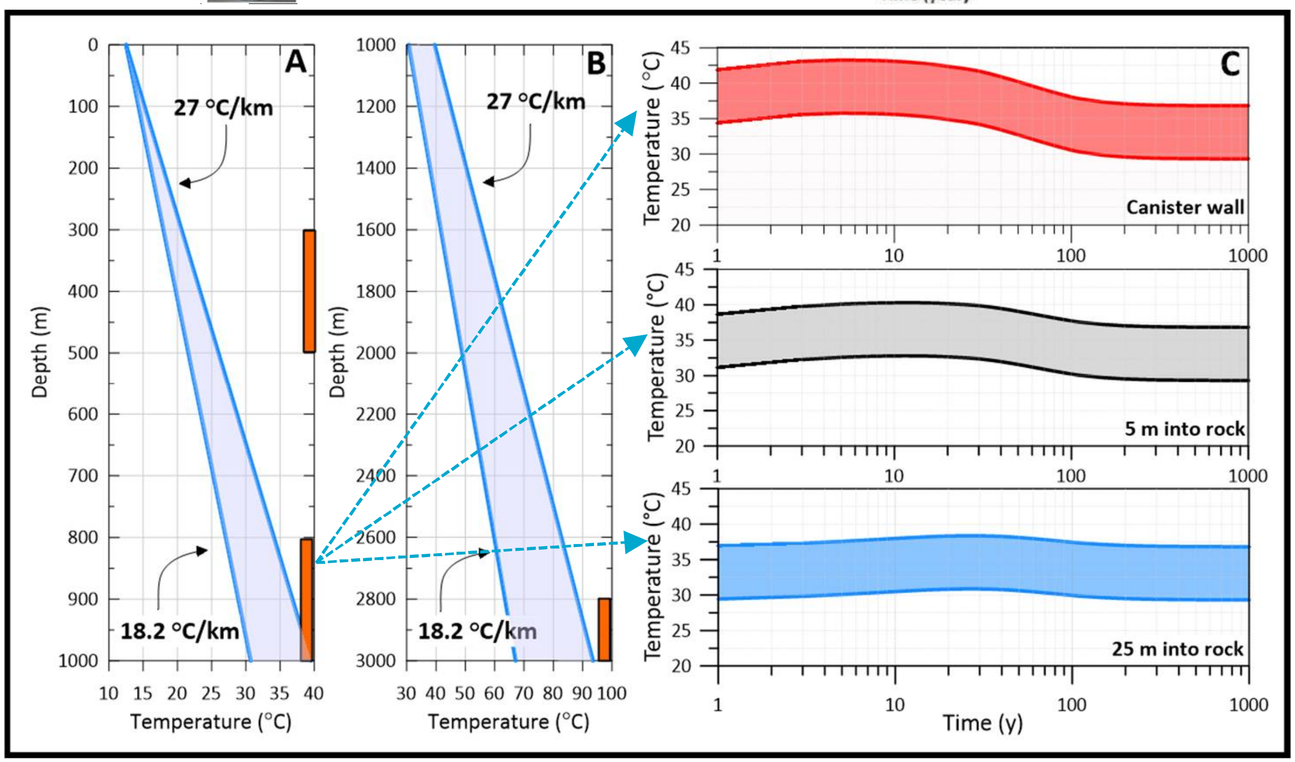
Temperature evolution in borehole & host rock



- NF & HR subject to perturbing processes:
  - ✓THMC
- **Thermal evolution from ILW**
  - ✓ low heat load (50 W/canister)
  - ✓ sensitivity analysis
    - ➢ disposal depth
    - ➢ heat load
    - ➢ geothermal gradient
    - ➢ thermal properties
- **TH** evolution
  - ✓ Negligible convection



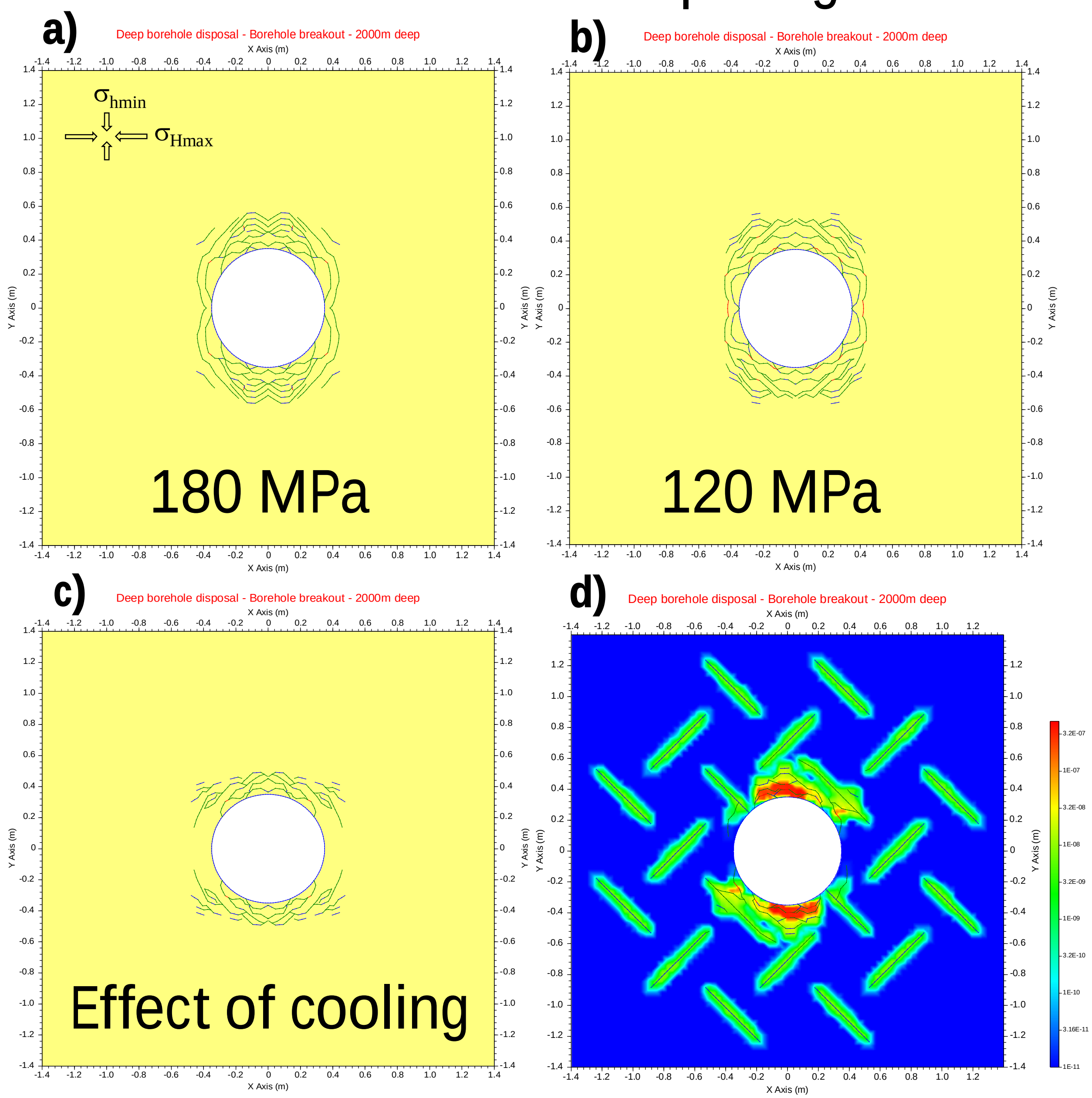




Borehole mechanical stability modelling

Breakouts at 2000 m depth - granite

- Borehole breakout simulations using FRACOD
- Field-data available
- Exploratory analyses
  - ✓ Effect of rock strength
  - ✓ Effect of heating/ cooling
  - ✓ Effect of pre-existing fracture networks + effect on permeability



Thank you

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Our Noble Gases on Record
[explanatory video of CSIRO's noble gas capability in the groundwater sciences]

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