Biogeochemical Application in Nuclear Decommissioning and Waste Disposal BANDD
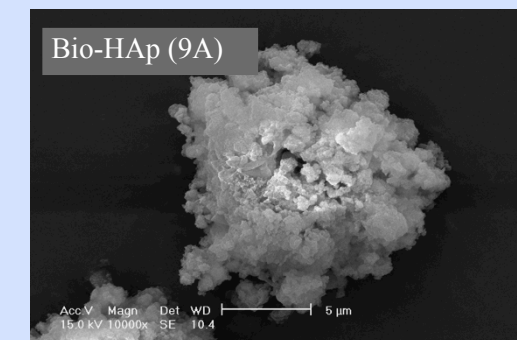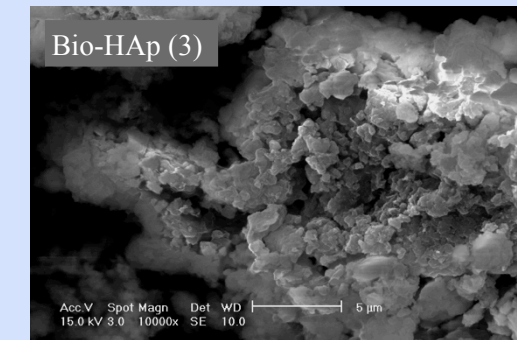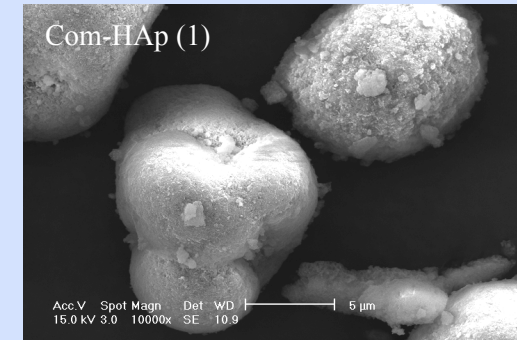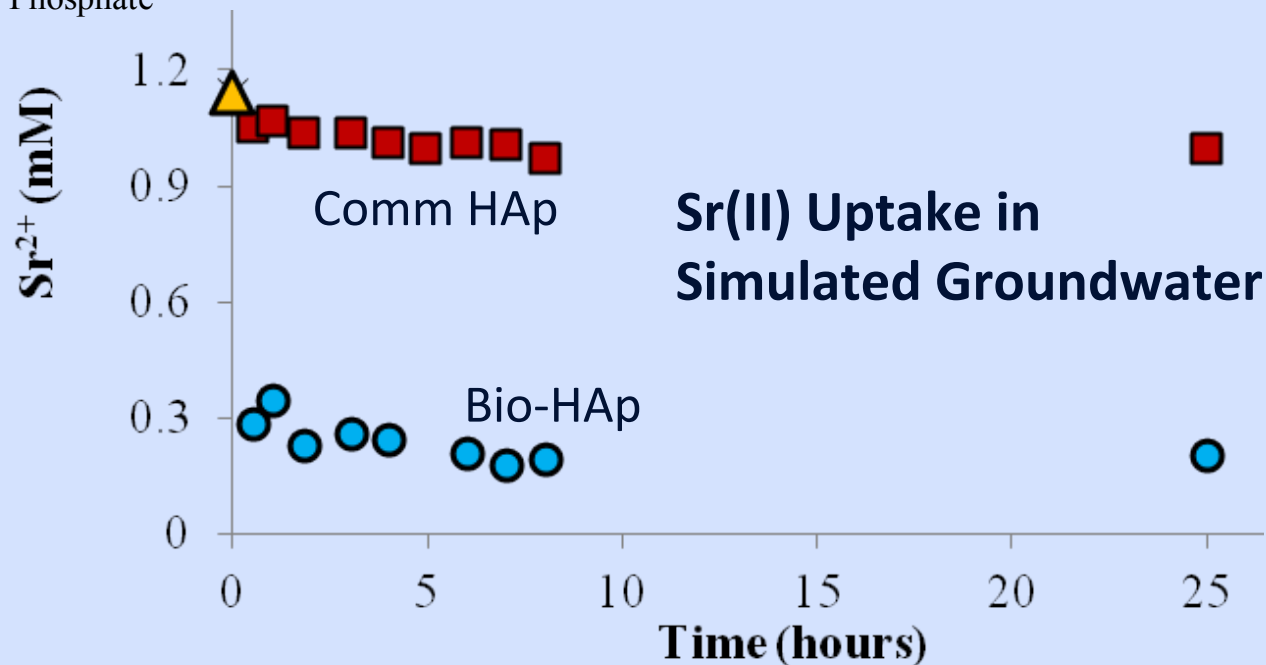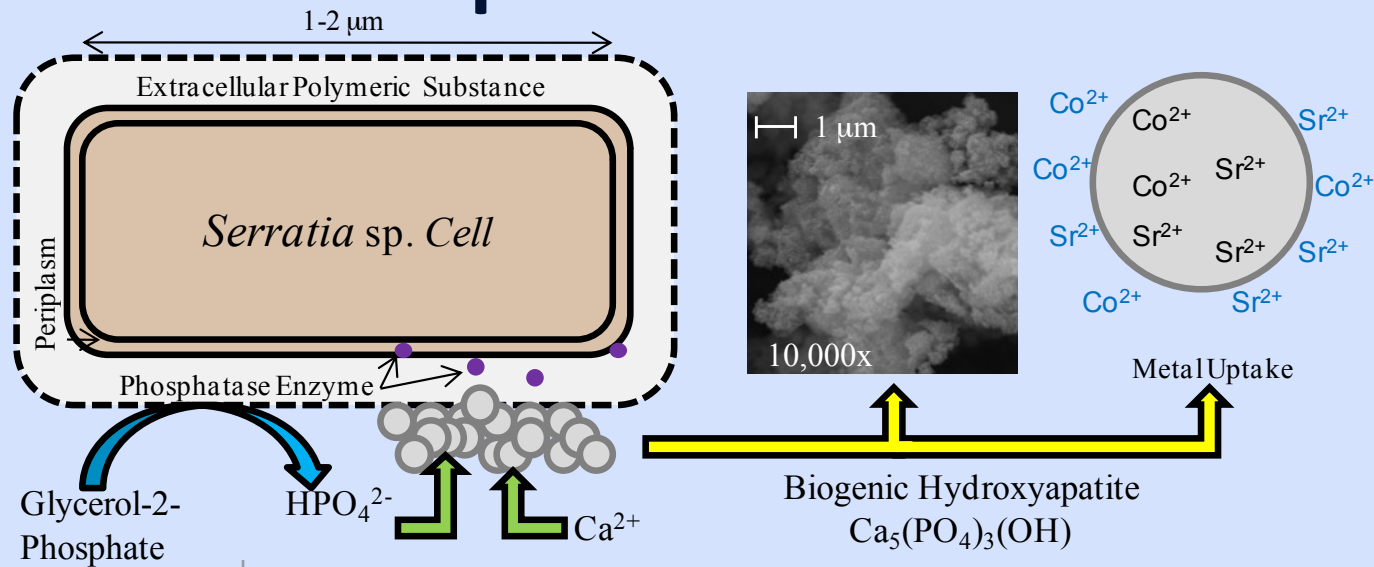
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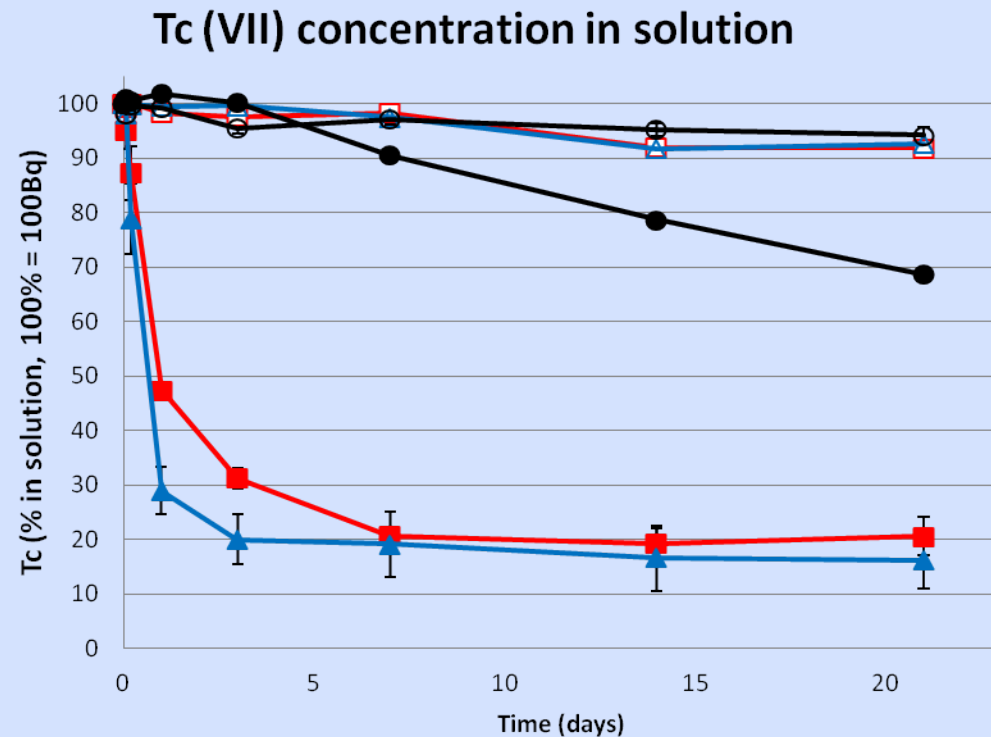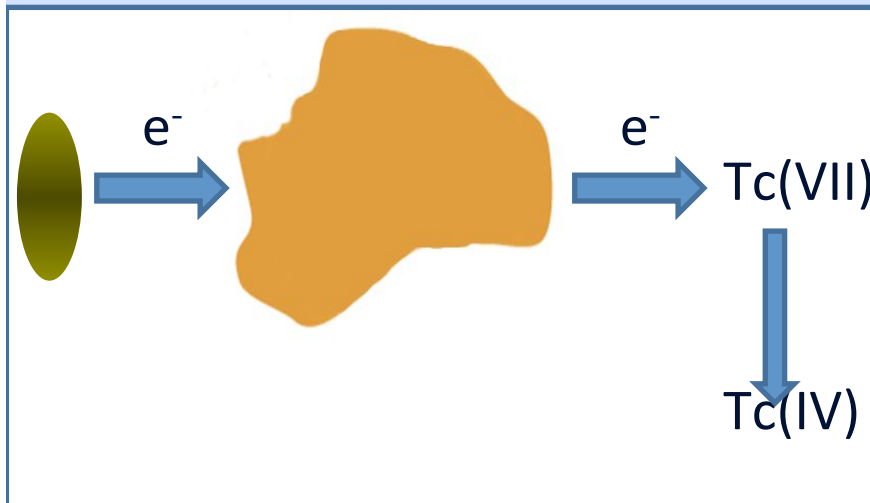
BANDD: Overview

- £1.9M EPSRC Energy Programme
- Two main applications for biomineralisation processes:
  - The use of biomineralisation to reduce subsurface permeability
  - The use of microbial biomineralisation processes for solid-phase capture of radionuclides
- 4 PDRAs: Glasgow, Strathclyde, Birmingham
- 3 PhDs: Manchester, Cambridge, Strathclyde

Uptake of Radionuclides by Phosphate Minerals

1-2 μm

Extracellular Polymeric Substance

Periplasm

Serratia sp. *Cell*

Phosphatase Enzyme

Glycerol-2-Phosphate

HPO_4^{2-}

Ca^{2+}

1 μm

10,000x

Co^{2+} Co^{2+} Sr^{2+}
Co^{2+} Co^{2+} Sr^{2+} Co^{2+}
Sr^{2+} Sr^{2+} Sr^{2+} Sr^{2+}
Co^{2+} Sr^{2+}

Metal Uptake

Biogenic Hydroxyapatite
$Ca_5(PO_4)_3(OH)$

Com-HAp (1)

Acc.V Spot Magn Det WD
15.0 kV 3.0 10000x SE 10.9   5 μm

Bio-HAp (3)

Acc.V Spot Magn Det WD
15.0 kV 3.0 10000x SE 10.0   5 μm

Bio-HAp (9A)

Acc.V Magn Det WD
15.0 kV 10000x SE 10.4   5 μm

Sr(II) Uptake in Simulated Groundwater

Comm HAp

Bio-HAp

Sr^{2+} (mM) vs Time (hours)

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Interactions between Microbes, Minerals & Radionuclides

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- Microbially-mediated reduction of minerals alters their reactivity towards redox-sensitive radionuclides.

e⁻ → (mineral) → e⁻ → Tc(VII)

Tc(VII) → Tc(IV)

Tc (VII) concentration in solution

Y-axis: Tc (% in solution, 100% = 100Bq), 0 to 100
X-axis: Time (days), 0 to 20

Legend:
- Fresh biotite
- Bioreduced biotite
- Fresh Chlorite
- Bioreduced chlorite
- No mineral control
- Cell only control

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Biomineral barriers to flow

- Fractures may provide pathways for radionuclide migration
- Unloading fractures in the Excavated Damage Zone may cross-cut existing fracture networks
- Traditional cementitious grouts not suitable for fine aperture fractures
- Safety case is likely to require rock mass hydraulic conductivities in the range of 10^{-9} to 10^{-10} m/s
- The challenge is to develop grouts that
  - can seal very fine fractures
 - provide good penetration into the rock
  - are strong
  - are durable

Microbial Induced Calcite Precipitation

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- Stimulate bacterial calcite formation to clog fractures in rock → limit fluid flow through the fracture.

- In situ permeability reduction of the host rock → limit radionuclide migration

$$NH_2CONH_2 + 2H_2O \xrightarrow{\text{urease}} 2NH_4^+ + CaCO_3 + 2Cl^-$$
$$+ CaCl_2$$
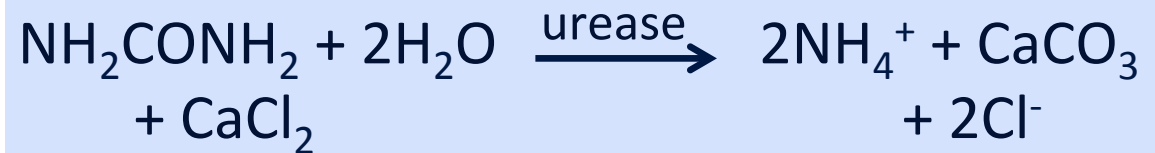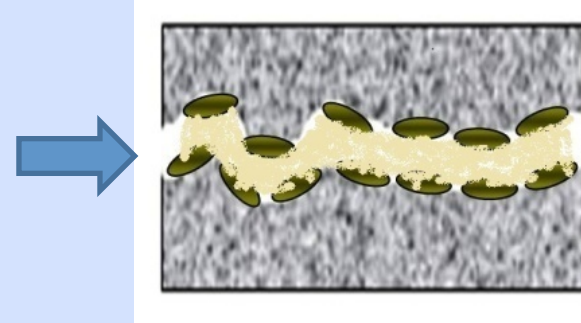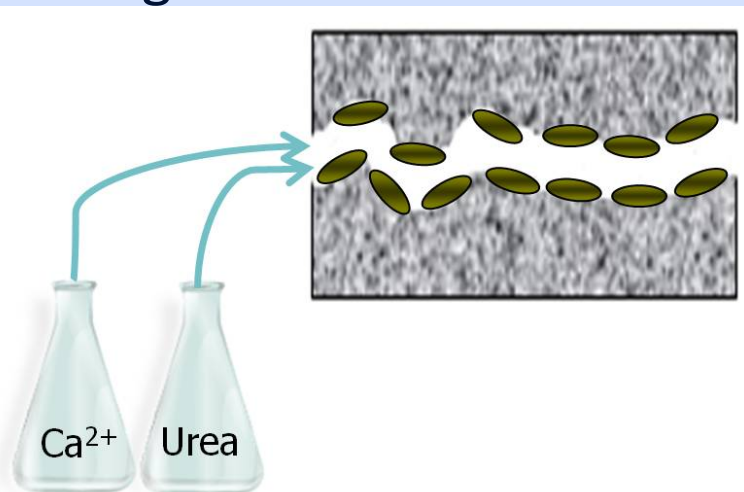
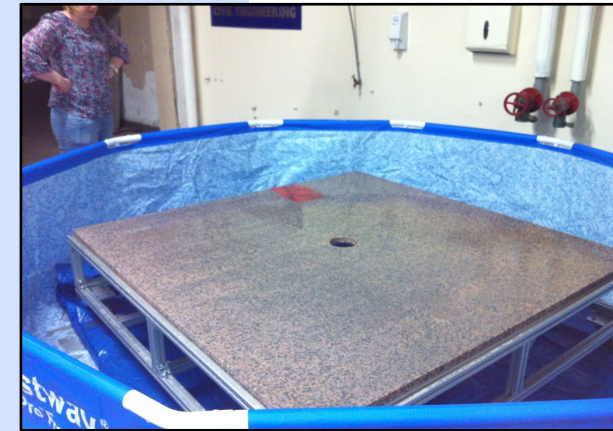- Develop novel MRI techniques to image & quantify bioprecipitation
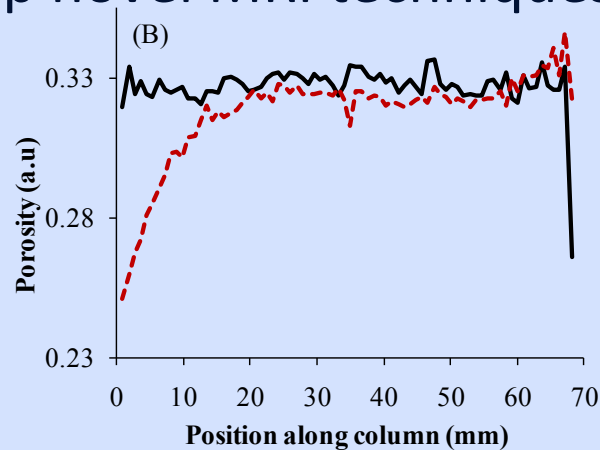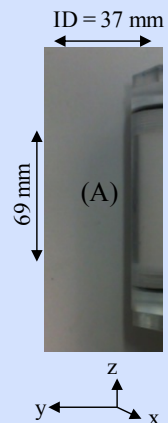
1D magnetic resonance profiles depicting the porosity along the column
t = 0 —   t = 65 h ---.

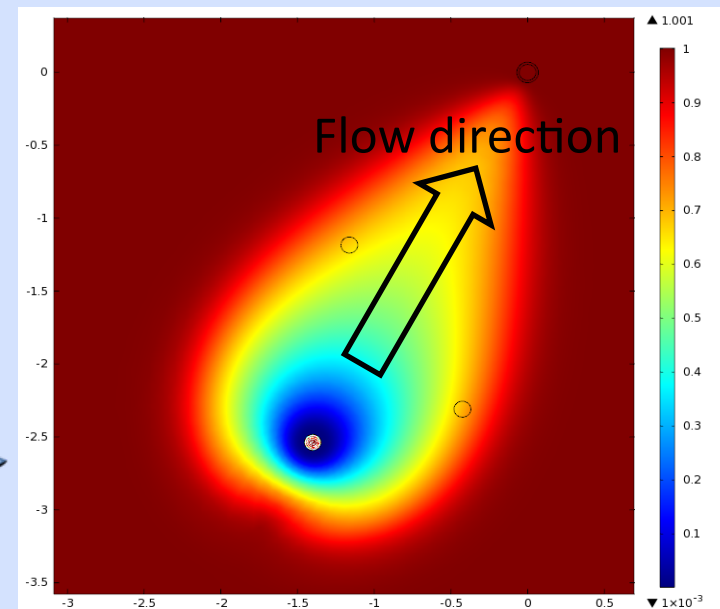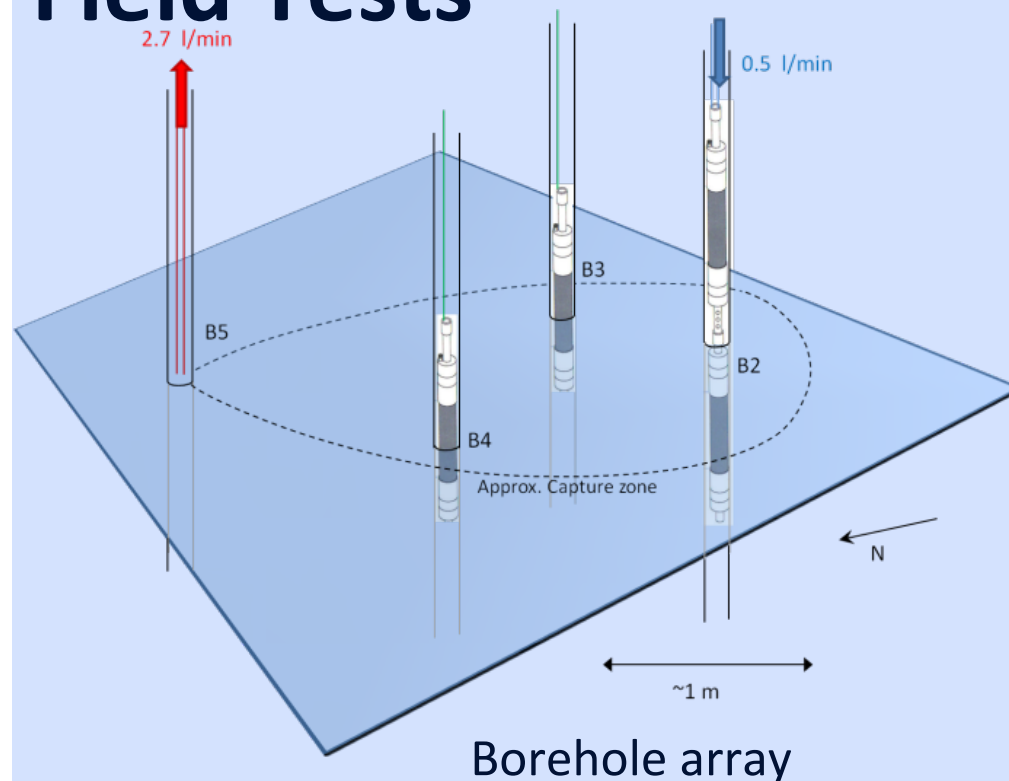University of Strathclyde Engineering

Laboratory Tests

Field Tests

Borehole array

Flow direction
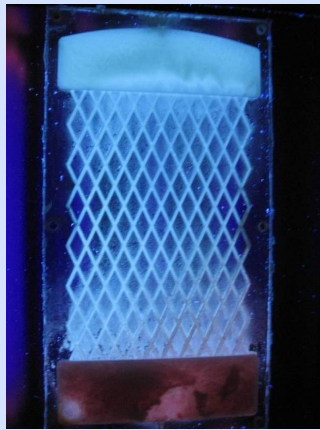
Modelled distribution of fracture transmissivity after grouting, normalised to initial value (i.e. T/T_0)

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