Improving realism and reducing pessimisms in the safety case for geological disposal of ILW

Microbiological FEPs important for ILW

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Safety cases for geological disposal of ILW recognise that microbial processes may occur in the waste and the barrier system

- Mostly, no explicit account is taken of the effects of microbes in performance assessment (PA)

Different treatments/cases:

- Detailed microbiological processes may be subsumed/simplified within other chemical FEPs
- Processes have been ignored (where conservative) due to uncertainties or data requirements
- Some microbiological processes have not been considered because of incorrect assumptions / lack of research
Microbial effects on speciation, solubility, sorption of redox sensitive radionuclides (e.g. Se, Tc, U)

- Microbial processes mediate processes governed by thermodynamics
- Representation by equilibrium models is considered adequate

Biogeochemical research underpins this simplified approach

- e.g. examining mechanisms of U and Tc reduction
Conservative representation of Microbiological FEPs

- Effects of alkaline cellulose degradation products (CDPs)
  - Conservative approach ignores biodegradation of CDPs
  - Recent research shows microbial activity at pH 11 (Rizoulis et al, 2012) and microbial utilisation of CDPs at pH10 (Bassil et al, 2014)

- Potential to reduce significance of CDP / radionuclide transport FEPs

- However, are there other FEPs related to alkaline cellulose biodegradation?
Gas generation experiment, VLJ Repository, Olkiluoto

~13m$^3$ of gas generated after ~16 years
Cellulose biodegradation - effect on pH and bicarbonate

- The VLJ repository design has a small pH buffering capacity
  - Small amount of concrete
  - High water content
- However, it improves understanding of microbial / cellulose degradation FEPs
Microbial cellulose degradation - further effects

- Lower pH – effects on radionuclide sorption and solubility
- Aqueous carbonate may act as a complexing ligand e.g. for U(IV)
- Carbonation of cement may
  - Affect flow properties of porous cement backfill
  - Armour/isolate backfill, further reducing pH buffering
Gas FEPs - treatment in the safety case

- Generally conservative with respect to CH₄ generation
  - Microbial processes are considered!
  - Assumptions/models vary between WMOs
  - pH limitation, wasteform/pH heterogeneity?

- H₂ utilisation as electron donor ignored
  - Conservative with respect to H₂ generation by anaerobic corrosion and radiolysis
  - Research now started

- Inconsistent consideration of H₂ in methanogenesis
  - \(4H₂ + CO₂ \rightarrow CH₄ + 2H₂O\)
TVO gas experiment - very limited H₂ production

Methanogenesis after sulphate reduction

Sulphate reduction is a key process for ILW
- Outcompetes (limits) methanogenesis
- Main sink for H₂

No H₂ after sulphate reduction established ~year 1999/2000
Mont Terri URL – $H_2$ studies
Loss of H₂ due to reaction with Fe(III) or SO₄²⁻? (Vinsot et al)
In situ microbial oxidation of H₂

Alexandre Bagnoud, Rizlan Bernier-Latmani [EPFL]
Olivier Leupin, Bernhard Schwyn [NAGRA]
Ino deBruijn, Anders Andersson [SciLifeLab, KTH]
Karuna Chourey, Robert Hettich [ORNL]
H₂ consumption chemistry

Recirculation mode

Batch mode

Results

Pressure (kPa)

Flow rate (ml/min)

Fe(II) [µM]

Sulfide (µM)

O₂ [mg/L]

O₂ reduction

Fe(III) reduction

Sulfate reduction

Time (Days)
Microbial analysis

SO$_4^{2-}$-reducing bacteria

Desulfosporosinus

Desulfotomaculum

Novispirillum

Desulfoccapsa

O$_2$-reducing bacteria
Microbial ILW FEP Summary (groundwater)

- Influence on radionuclide valency / mobility
  - No specific representation needed?
  - Justified by underpinning biogeochemical research
  - More detailed FEP representation unlikely to have significant impact on safety analysis

- Cellulose degradation
  - Scope to reduce radionuclide mobility though degradation of CDPs & other organic complexants
  - Microbial effects on pH & carbonate – complex FEP interactions - could enhance radionuclide mobility

- Other organic polymers
  - Degradation rate and products (including gases) uncertain
  - Combined effects of radiolysis and biodegradation?
Microbial ILW FEP Summary (gas)

- **Methanogenesis**
  - pH limitation / heterogeneity
  - SRB competition
  - Effects could either enhance or reduce CH$_4$ generation and speciation / mobility of $^{14}$C

- **Hydrogen utilisation**
  - Reduce gas flux and $^{14}$C gas release
  - Lower rates of gas generation, beneficial to physical FEPs; pressurisation, cracking, effects on hydrogeology etc

- **Sulphate reduction**
  - Indirect effects on the above processes involving CH$_4$ & H$_2$ gases
  - Also important for organic/groundwater FEPs

- **Microbial FEPs need to be considered under *in situ* conditions**
  - Need to consider physical constraints on microbial growth
  - Studies to date are mainly in laboratory microcosms or in water filled boreholes
  - Microbial processes within ILW packages (storage & disposal)