MIND - Development of the Safety Case Knowledge Base about the Influence of Microbial Processes on Geological Disposal of Radioactive Wastes

Minna Vikman, Hanna Miettinen & Markus Olin (VTT)

17/11/2019 VTT – beyond the obvious

This project has received funding from the Euratom research and training programme 2014 - 2018 under grant agreement No. 661880

Microbes in final repositories

- Produce gas (methane, CO_2)
- Produce corrosive components (e.g. sulphide, acetate)
- Enhance/participate corrosion process
- Produce metabolites that form complexants with radionuclides
- Change geochemical environment in repository (e.g. pH)
- Change redox state of the radionuclides
- Can affect the performance of engineered barrier materials
- Can influence the solubility, the sorption and the mobility of radionuclides

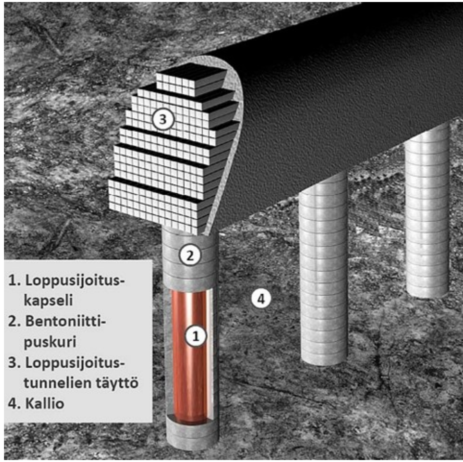

Photo: Posiva

What microbes need ?

What microbes need?

- Space to grow
- Water availability
- Major nutrients: C,H,N,O,P,S
- Minor nutrients: e.g Fe, Ca, Mg, Mn…
- Available microbial energy: results of oxidation and reduction
- Certain environmental conditions (pH, temperature etc.)

What can we do?

- Restrict space: porosity >0.2 µm
- Lower water availability
- Limit supply of major and minor nutrients (diffusion)
- Create extreme physico-chemical conditions (high pH, temperature etc.)
- Control microbial respiration to limit unbeneficial microbes

→ Information about microbial communities needed

Development of the safety case knowledge base about the influence of microbial processes on geological disposal of radioactive wastes (MIND) 2015-2019

VTT

1. Swedish Nuclear Fuel and Waste
2. Management Co, SKB
3. Microbial Analytics Sweden AB, MICANS
4. Belgian Nuclear Research Centre, SCK•CEN
5. Helmholtz-Zentrum Dresden-Rossendorf e.V., HZDR
6. National Nuclear Laboratory Limited, NNL
7. Ecole Polytechinique Federale De Lausanne, EPFL
8. Techniscka Univerzita, The Czech Rebublic
9. Centrum Vyzkumu REZ, The Czech Rebublic
10. University of Machester, UK
11. Universidad De Granada, Spain
12. TVO
13. Posiva
14. Geologian tutkimuskeskus
15. VTT

- WP1: Low and intermediate level wastes
- WP2: High level waste and spent fuel
- WP3: Integration, communication and Dissemination
- WP4: Project management

MIND
Microbiology In Nuclear waste Disposal

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Objectives of MIND

- Improve the geological safety case knowledge on:
  - microbial processes controlling radionuclide, chemical and gas release from long-lived intermediate level wastes containing organics
  - the influence of microbial processes on high level waste and spent fuel geological disposal

- Integrate, communicate and disseminate results and conclusions from the above listed objectives to the broad European community involved in radioactive waste disposal

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VTT's objectives in MIND

WP1

Gas generation from low level maintenance waste

WP2

Microbial influence on bentonite structure

Sulphide formation in deep groundwaters

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Gas Generation Experiment (GGE)

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- *In situ* large-scale experiment in Olkiluoto repository operated by TVO
- 16 waste drums (200 L) were filled with LLW maintenance waste, placed in a concrete box and closed in the gas tight tank of acid proof steel (20 m^3)
- The tank was filled with river water
- Temperature is maintained in the level of +8°C - +11°C
- The proportion of concrete to cellulose in the GGE (mass ratio 6.5) is lower than in the actual repositories

Aim: to study gas generation from cellulose-containing LLW under conditions representative of the VLJ repository

Why gas generation matters?

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- Gaseous radionuclides (e.g. ^{14}C) can be transported to the biosphere in the form of methane gas ($^{14}CH_4$)
- Development of overpressure in the repository
  - Disruption of the engineered barrier system (EBS)
  - Increase groundwater flow rates
- Produced gas in the geosphere can enhance the activity of microbial communities

→ Enhanced migration of radionuclides in groundwater to the biosphere

Gas generation rates are higher in ILW and LLW repositories compared to HLW/spent fuel repositories because of

- Larger volumes of metals
- Larges volumes of organic materials.

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Gas generation in repository conditions

1. Biodegradation of organic materials:

   $C \text{ - - -> } CO_2, CH_4, (H_2)$

2. Corrosion of metals in the waste and packaging (drums)

   $Fe + 2 H_2O \rightarrow Fe(OH)_2 + H_2$

3. Radiolysis of water and some organic molecules in the waste packages, generating mainly hydrogen

LLW maintenance in Finland

40% Cellulose/hemicellulose-based
- e.g. cotton cloth and gloves, paper, cardboard

60% Non-cellulose/hemicellulose based
- PE, PVC items, latex gloves, fire protection cloth (glass fiber), electric components, metal components, polycarbonate cloth

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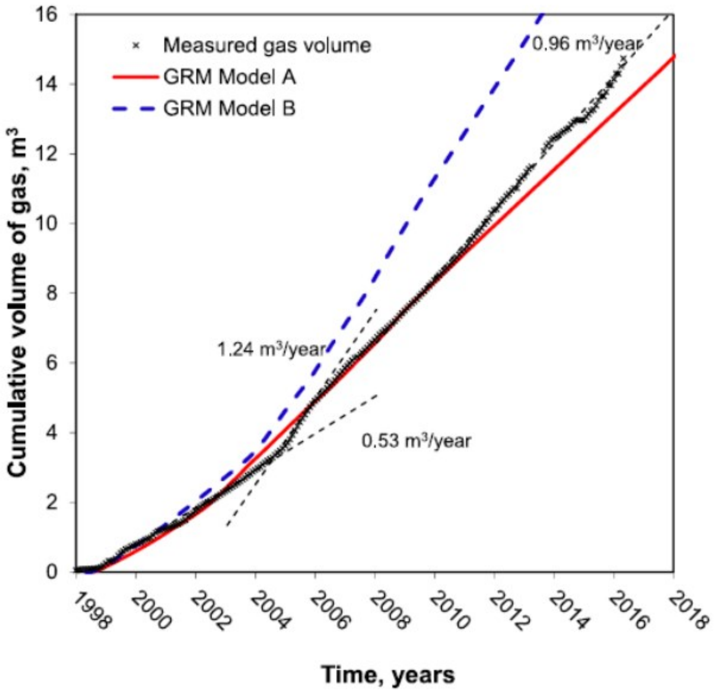
Main observations from GGE

- Cellulosic and hemicellulosic components in LLW were converted to methane and carbon dioxide as a successive action of a complex microbial consortium
- Heteregenous chemical conditions (pH, dissolved organic carbon)
  →optimal niches for microbial activity
  →gas generation started sooner than expected
- Alkaline conditions (concrete) neutralized sooner than expected
  - Production of CO_2 and microbial metabolites
    → pH decreased close neutral
- Hydrogen was formed as a results of steel corrosion (and during biodegradation of maintenance waste) but was rapidly consumed by microbes



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Bentonite characteristics after TWO years storage with indigenous bentonite and water microbes

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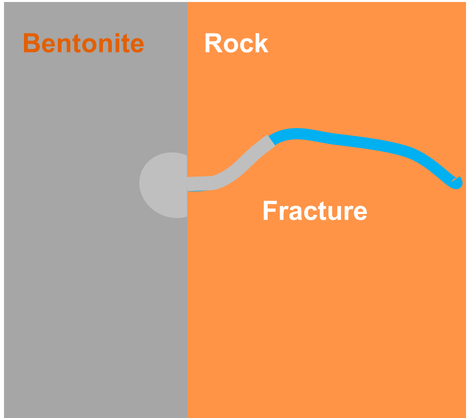
LONG-TERM MICROBIAL STORAGE EXPERIMENT OF WYOMING TYPE BENTONITE

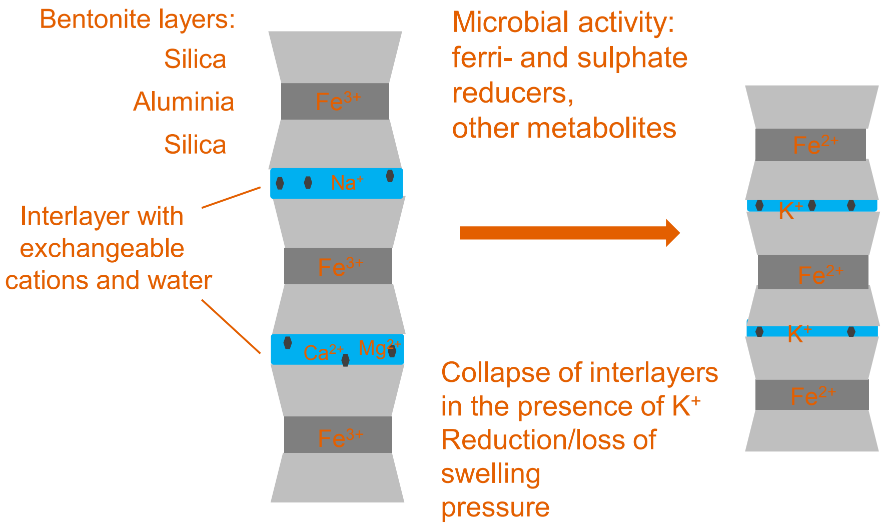
AIM:

To study if and how microbes and their metabolites influence bentonite structure and performance in bentonite-water-bedrock interfaces where bentonite density and pressure is lower than planned for the disposal facility



Background

- Will the bentonite swelling pressure be reduced/lost in conditions favourable for microorganisms



Anoxic and oxic bentonite (Wyoming type) storage experiment started 2016

30°C

Bottle volume 110 ml
Water 80 ml,
Rock crush 5 g,
Bentonite 5 g
Nutrients

37°C

ANOXIC:
Water mixture: 3 anaerobic ground-waters + Olkiluoto surface water (anoxic) 25:25:25:5 (mL)
Gas mixture: N_2:CO_2:H_2 80:10:10 + CH_4 15 ml added after closure

OXIC:
Water mixture: Olkiluoto surface water and anaerobic groundwater mixture 65:5:5:5 (mL)
Gas mixture: Air

Nutrients: Na-acetate and -formate 0.1 mM, methanol 0.05 mM

Controls:
1) Abiotic: heat treated bentonite (180°C, 16h), sterile filtered water, autoclaved rock
2) Bentonite microbes, sterile filtered water, No nutrients

Some results and future plans

- Hydrogen used within two weeks in anoxic bottle
- Oxygen used in half a year in oxic bottles
- Microbial activity low/decreased after one year
- Microbial sulphate reduction ongoing in anoxic microbial bottles by ^{35}SO-label method, not in abiotic nor in oxic samples

Anoxic microbial microcosms Abiotic

- No significant changes in bentonite structure in 2 years, microbes are slow in nutrient poor environment
  - After 3 years: acceleration of microbes with nutrient addition and next follow up after 4 years in KYT-2022 (Finnish Researach Programme on Nuclear Waste Management)

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- Mohamed Merroun, University of Granada

K YOU FOR YOUR ATTENTION

Publications and presentations

VTT

- Vikman, M., Marjamaa, K., Itävaara, M., Nykyri, M., Small, J., Paaso, N., Microbial degradation of low-level radioactive waste in repository conditions, Presentation, Goldschmidt 2017, 13 - 18 August 2017, Paris, France 2017. European Association of Geochemistry.
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- Miettinen, H., Bomberg, M., Vikman, M. 2018. Acetate activates deep subsurface fracture fluid microbial communities in Olkiluoto, Finland. Geosciences 8, 399. doi:10.3390/geosciences8110399

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