KYT2022

# SURFACE
## Near Surface Disposal in Finland

Maaperäloppusijoitus Suomessa

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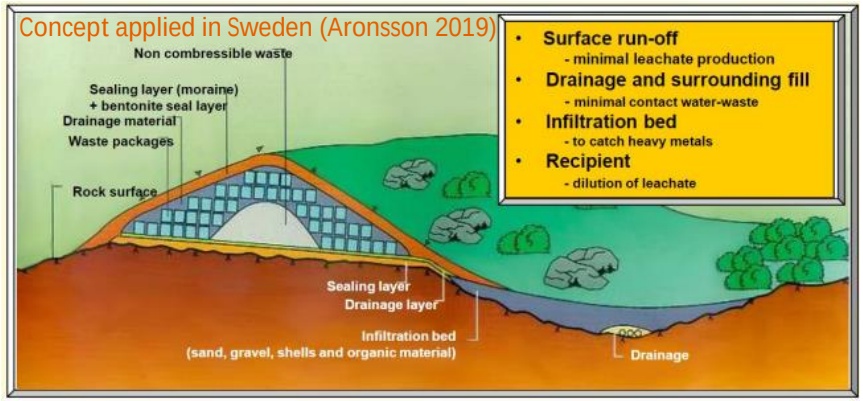
# Background

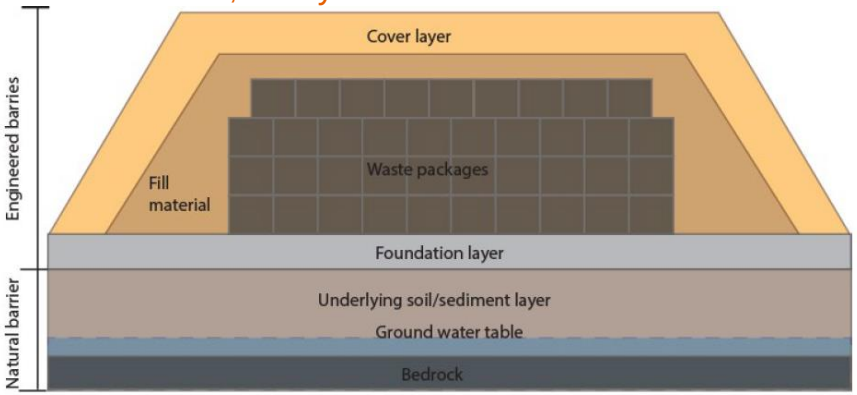
- Majority of the LLW produced in Finland is disposed in intermediate depth repositories (60-100 m). Some VLLW waste have been disposed in normal landfills, but renewal of the licences is no longer a valid option due to limitations in EU-directive (organic waste).
- Nuclear Energy Act (1987/900) permits disposal of VLLW in near surface disposal facilities.
- TVO has a plan to licence the first VLLW near surface waste disposal facility in Finland:
  - Environmental impact assessment in 2020-2021 and preliminary safety case in 2021.
  - Preparations for licencing and design of the facility ongoing, field-test planned for 2023 and construction in 2024.
  - Design follows the Swedish example with similar geological conditions and waste.
- VLLW streams are an universal nuclear industry problem that need to be solved. This will also be true for SMRs. Use of the concept for decommissioning waste should be also investigated. Results could be also applied to NORM.

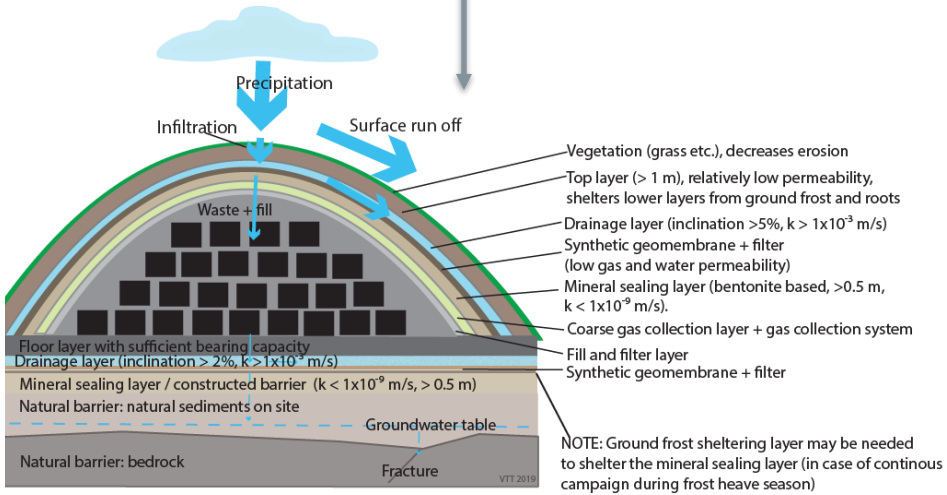
# Concept (landfill-type)




Example on hazardous waste landfill design in Finland, guidelines given by SYKE applicable to certain extent. Differences in requirements concerning service life (up to ~300 years for near surface disposal facility) and post closure monitoring.

Main barriers, safety also relies on WAC + waste form.



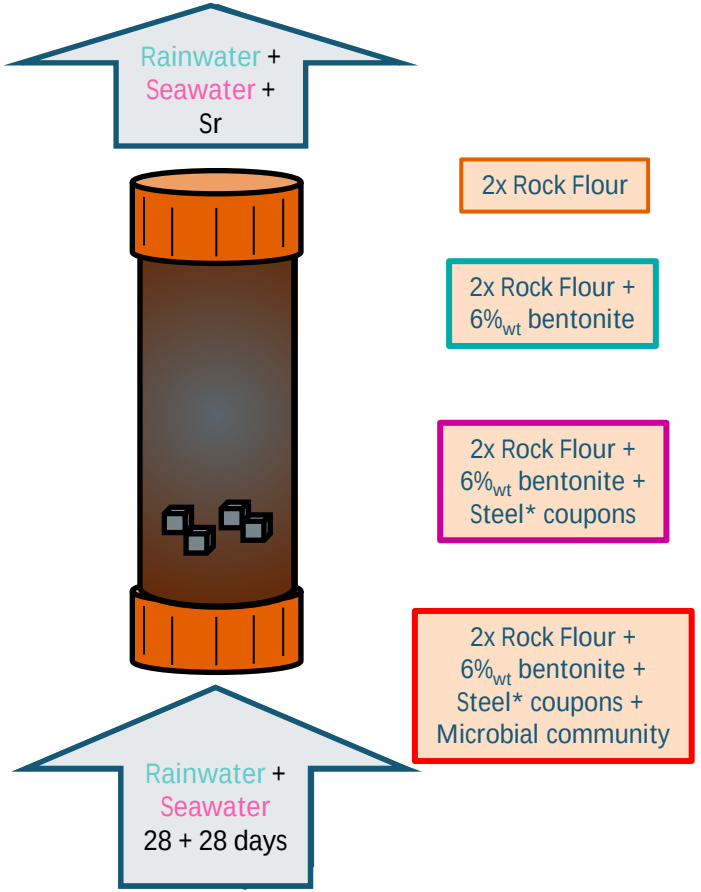
# SURFACE project

- The SURFACE project started in 2019 with the aim of studying the applicability of a VLLW surface disposal concept in Finland.
- The work performed in the KYT2022 SURFACE project (years 2-4), was then divided into three tasks with following objectives:
  - Task 1: Develop a robust, repeatable experimental system that enables studies of the radionuclide transport and /or potential retention mechanisms, and speciation.
  - Task 2: Study the evolution of the engineered barriers including corrosion, microbial activity, organic matter degradation and biogas production.
  - Task 3: Study the design basis and performance of the near-surface disposal facility design and engineered barriers and provide input to the safety case and optimization of the design.
  - All tasks considered site conditions in Finland and selected EBS materials:
    - Fill material around the waste packages (rock flour).
    - Mineral sealing material limiting ingress of water in/out of the disposal facility (mixture of crushed rock or rock flour and 6 w-% of bentonite).

# Summary of results, Task 1: Radionuclide Transport Behaviour in Barrier Materials

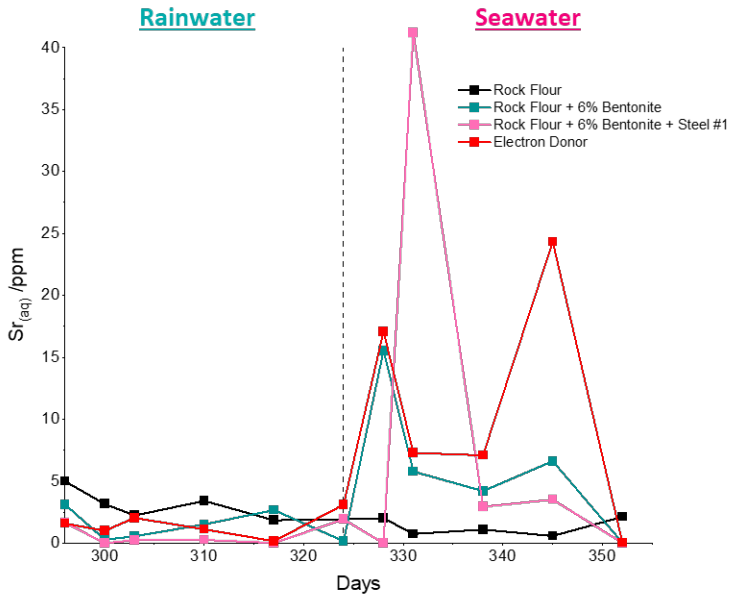
# Methodology

- UH experimental flow through column system developed in year 2 of SURFACE in collaboration with a SNRSI research project.
- 4 progressive experimental systems representative of barrier materials established and run in years 2–4.
- Sr sorption, speciation, distribution and remobilisation was studied in successive > 1 year experiments, and then in subsequent (shorter) remobilisation studies.
- Another experimental setup was tested by VTT, but the system did not produce reliable results.



# Results

- **Sr retained in all systems.**
- **Bentonite** addition **increased Sr sorption capacity** ~20%, but **microbial activity** had **little effect** on **Sr** retention.
- **pH** equilibrated to **~6.5** in **abiotic experiments**. **Microbial** activity causes increase to **~7.5**.
- **No** evidence for **colloid** formation in any experiment.
- Sequential extractions and XAS suggest Sr mobility is governed by **weak outer-sphere sorption mechanisms** at pH 6.5-7.5.
- Low IS **rainwater** remobilises Sr **slowly**.
- High IS **seawater** remobilises Sr bound to bentonite **strongly**. Rock flour systems retain most Sr over time.



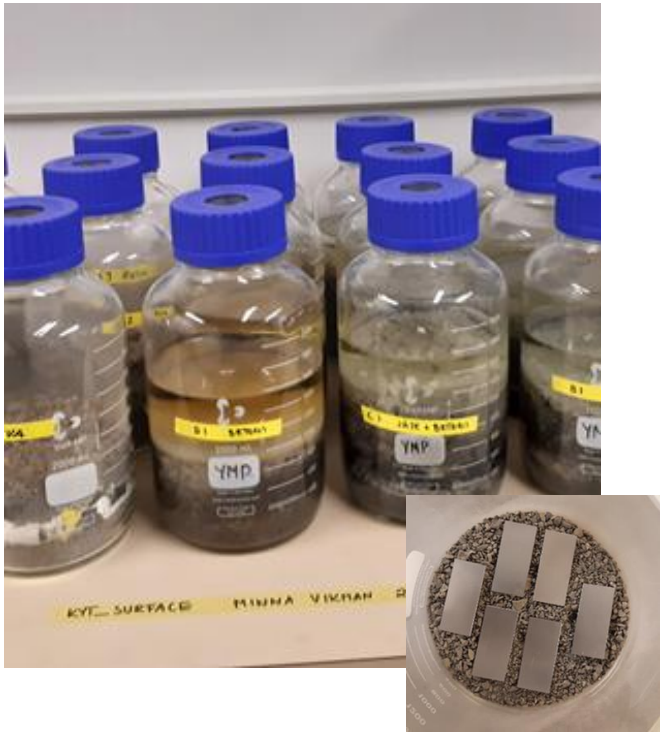
# Conclusions

- Flowing column system successfully **developed** to **mimic VLLW disposal** relevant to Finland providing **technical legacy**.
- **Experimental methodology is robust and adaptable suitable for a range of other experiments in future.**
- **Sr retained** with just rock flour but **addition of bentonite improves sorptive capacity**.
- **Microbial activity** may increase pH but ultimately **does not have significant effect on Sr mobility**.
- Colloid formation not expected under experiment conditions.
- Sequential extractions and XAS suggest Sr mobility is predominantly governed by **weak outer-sphere sorption mechanisms** at pH 6.5-7.5.
- **Remobilisation was greater when materials contacted with seawater.**
- **Suggests that barrier + backfill materials proposed for VLLW disposal are suitable for Sr retention.**
- Sr binding dominated by weak interactions, **susceptible to remobilisation by high IS water.**
- **Dissemination: Publications:** Ho et al., (2022), Sci. Total Env.; Vettese et al., (in review), Minerals; Ho et al., in draft**; Talks:** MH, GV, and GL presented multiple talks in Europe and Asia. **PhD thesis (Mallory Ho)** successfully defended in September 2022.

# Summary of results, Task 2: Biodegradation of Waste and Steel corrosion

# Methodology

- Simulation experiments in the laboratory
  - Simulated rain water
  - Waste
  - Steel specimens
  - Aged concrete
  - Bentonite-crushed rock, rock flour
- Analyses
  - Gas generation and composition
  - Steel corrosion (corrosion rate, corrosion products, type of corrosion)
  - Water chemistry
  - Microbiology focusing on methane producing microbes



# Conclusions

- No water → No gas generation nor corrosion → Prevention of water entering to the repository is essential
- Gas is mainly composed of methane and carbon dioxide
- Hydrogen formed as a result of corrosion is consumed by the microbes → not detected in gas phase
- Aged concrete
  - Did not prevent microbial activity and gas generation
  - Decreased corrosion rate of steel
- Steel corrosion was more rapid in reactors containing waste. Possible reason are:
  - More microbes and enhanced microbial activity
  - Chemical conditions more favourable

# Summary of the results, Task 3. Performance of the Near Surface Disposal Facility and Engineered Barriers

# Design basis and methodology:

- Design basis:
  - Regulated under Nuclear Energy Act (990/1987)
  - Applicable IAEA guidelines: SSR-5 and SSG-29
  - Good practices applicable considering construction of hazardous waste landfills in Finland.
  - Waste acceptance criteria: VLLW with activity concentration < 100 kBq/kg and no significant amount of nuclides with half life > 31 years

    → *Service life 300 years (~150 years are the most critical)*
  - Preliminary safety functions defined for landfill-type repository.
  - Site conditions to be taken into account in Finland: e.g. annual precipitation, ground frost, flooding and sea-water intrusion risks taking into account climate change.
  - Preventing unintended human intrusion (e.g. post-closure land-use restrictions)
- Methodology: literature review, numerical modelling, risk analysis and geotechnical laboratory testing.

# Conclusions

- Performance of the cover layer very important considering the *long-term performance* of the near surface disposal facility.
  - Shelters from surface processes, limits ingress of water to the waste, formation of leachate waters, corrosion + gas generation. → Recommended: Combination of synthetic and mineral sealing layers. Sufficient layer thickness and density for top layer below vegetation.
  - Gas generation cannot be ruled out → either gas permeable cover structures OR combination of gas impermeable synthetic layers + gas collection system.
- Other recommendations:
  - Limiting uneven settlements requires careful design, to be considered placing soft waste packages into metallic waste packages.
  - Foundation structure should be designed taking into account the natural barrier layer thickness and properties at the site.

# Dissemination of the results and further studies recommended concerning near surface disposal in Finland

# Dissemination of the results

- Doctoral dissertation by Dr Mallory Ho (HY): The Long-term Biogeochemistry of Se-79, Tc-99 and Sr-90 in Complex Environmental Systems (2022-09-16).
- Scientific articles on:
  - Radionuclide transport / retention mechanisms: **(1)** Ho et al., (2022): *Science of the Total Environment*; **(2)** Vettese et al. (in review): *Minerals;* **(3)** Ho et al., *in prep.*
  - Biodegradation and steel corrosion: **(4)** Vikman & Ratia-Handby. *in prep.*
- Technical reports on the design basis, design and EBS performance (Keto et al):
  - Design basis and different design options are discussed in the 2019 report "Near surface repositories in Finland" VTT-R-00124-20.
  - Design basis and performance of a landfill type of repository: VTT-R-00016-21 and VTT-R-00077-22.
  - Summary report, to be published in February 2023.
- Technical report on VTT radionuclide transport studies:
  - Gouëllo, M. & Myllykylä, E. 2022. KYT SURFACE: Status Report on Radionuclide Transport (VTT-R-00942-22)
  - Lamminmäki, S., 2023. Additional analysis. *In preparation.*

# Recommended further studies

- Further radionuclide transport studies:
  - Further tests with other key-driving radionuclides (DENSE)
  - Effect of climate change (sea-water intrusion)
  - Interaction with wider range of EBS materials
- Repository evolution:
  - Gas generation rate and corrosion in realistic conditions, but also in sea-water intrusion case
  - Development and validation of reactive transport models for studying transport of radionuclides through engineered barriers to the geosphere
  - Evolution and performance of the EBS considering 300 year time-scale
- Applicability of the concept for decommissioning waste:
  - Contaminated concrete (FiR1 sampling)
- Studies related to monitoring and closure:
  - Site monitoring for validation of the numerical models
  - Development of monitoring strategy