KYT2022

SURFACE

Near Surface Disposal in Finland, Final Seminar

Maaperäloppusijoitus Suomessa

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17.11.2022

Programme

- **13:00-13:10** **Welcoming words and introduction**, Paula Keto (VTT)
- **13:10-13:40** **Radionuclide transport in barrier materials**, Gianni Vettese(UH)
  13:40-14:10 **Biodegradation of waste and steel corrosion**, Minna Vikman and Vilma Ratia-Handby (VTT)
- **14:10-14:30** **EBS and repository performance – recommendations for the design based on input from results of the SURFACE project**, Paula Keto (VTT)
- **14:30-14:40** **Introduction to SAFER 2028 plan for continuing of the work**, Paula Keto (VTT) and Gareth Law (UH)
- **14:40-14:55** **Discussion: feedback for the SURFACE project and SAFER 2028 plan**
- **14:55-15:00** **Closure of the seminar**

Introduction

State of the art

- State of the art in Finland:
  - Majority of the LLW produced in Finland is disposed in an intermediate depth repository (60-100 m).
  - Some VLLW waste have been deposited in normal landfills, but renewal of the licences is no longer valid option due to limitations in EU-directive (organic waste).
  - Nuclear Energy Act (1987/900) permits disposal of VLLW in near surface disposal facilities. Elsewhere in Europe near surface disposal facilities also for LILW (e.g. concrete vault-type).
  - TVO has a plan to licence first VLLW near surface waste disposal facility in Finland:
    - Environmental impact assessment in 2020-2021.
    - Preliminary safety case in 2021.
    - Preparations for licencing and design of the facility ongoing, construction in 3/2023.
    - Pilot test (Olkiluoto site) planned for 2023 – 2026.
    - Design follows the Swedish example with similar geological conditions and waste.
  - VLLW streams are an universal problem and need to be solved in future also for SMRs. Use of the concept for decommissioning waste should be also investigated. Results can be also applied to NORM.

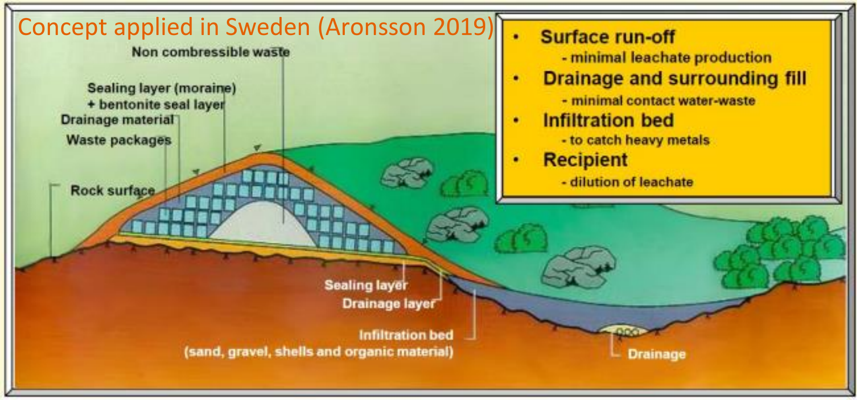
Regulations applied

- Regulations applied (in hierarchy order):
  - Nuclear Energy Act (990/1987)
  - Nuclear Energy Decree (161/1988)
  - STUK Y/4/2018 Radiation and Nuclear Safety Authority Regulation on safety of Disposal of Nuclear Waste
  - YVL D.5 Disposal of Nuclear Waste, 13.2.2018.
- IAEA Safety standards series 29, Near Surface Disposal Facilities for Radioactive Waste (good general guidelines, but not legally binding)
- Waste accepted in near surface disposal in Finland:
  - Only for VLLW (STUK Y/4/2018, 31 § 6)
  - Activity concentration < 100 kBq/kg (Nuclear Energy Act 6 § 3)
  - No significant amount of nuclides with half life > 31 years

  → Service life 300 years (~150 years are the most critical)

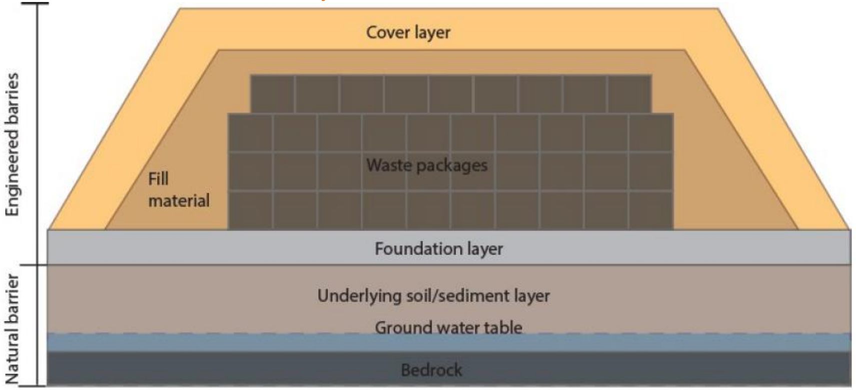
Concept (landfill-type)

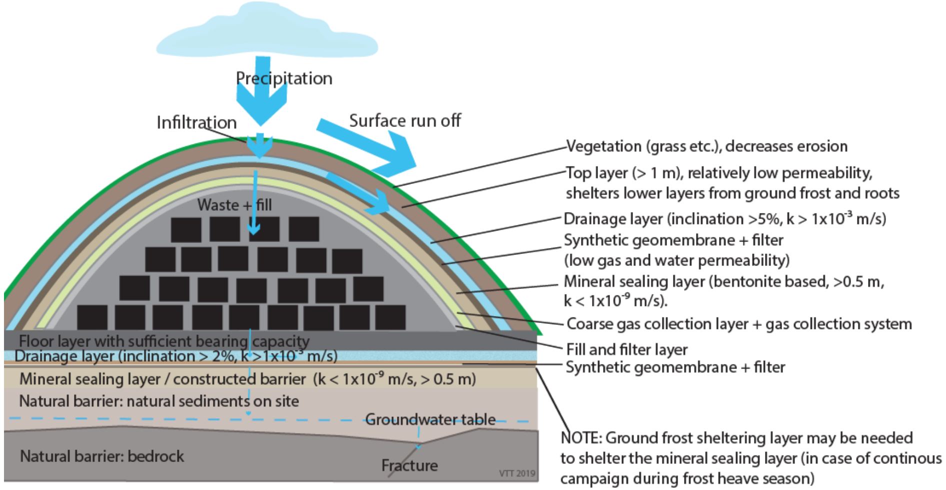
Concept applied in Sweden (Aronsson 2019)



One key question concerning the design: Applicability of hazardous waste landfill design (presented below) as a near surface repository for VLLW with service life up to 300 years.

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





Site characteristics and conditions to be taken into account in the design

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- Geological and hydrogeological conditions (effect on radionuclide transport). Typically thin sediment layers over bedrock in Finland (role of EBS). Sufficient bearing capacity. Surface water flow directions and water balance.
- Meteorological conditions
  - Temperature fluctuations
  - Precipitation (~600 mm annually, can be increased to >1000 mm)
- Formation of ground frost (locally, freezing index F, depth of snow coverage, sediment type)
- Background radiation
- Population in the area and land-use restrictions
- Terrestrial and aquatic ecosystems
- Climate change linked risks: flooding, groundwater and surface water level rise, storms, forest/ground fires.

SURFACE project

- SURFACE project started in 2019 with the aim to study the applicability of a surface disposal concept in Finland.
- The work performed in the KYT2022 SURFACE project (years 2-4), was divided into three work packages (WPs), each addressing a different theme:
  - WP1: Radionuclide transport behaviour in barrier materials;
  - WP2: Biodegradation of waste and steel corrosion;
  - WP3: Performance of engineered barriers.
- Materials included in laboratory studies:
  - Rock flour (placed around waste packages as fill material)
  - Mixture of bentonite (6, 8, 10 w-%) and crushed rock (felsic) or rock flour (mafic)
  - Steel chips (simulating metallic waste and waste packages)
  - Simulated waste (organic)

EBS and repository performance – recommendations for the design based on input from results of the SURFACE project

Objectives of the task 3: performance of engineered barriers

- Geotechnical characterisation of the test materials.
- Analysis on performance of engineered barriers based on numerical modelling and laboratory testing.
- Studies on effect of near surface processes (e.g. freezing) on performance of mineral sealing materials.
- Discuss design basis and safety functions.
- Give recommendations for the design, implementation, operation and monitoring of the repository considering all tasks.

Desired (safety) functions for the EBS

- Cover structures:
  - Limit infiltration of water into the repository (inclinations, drainage system, synthetic and mineral sealing layer).
  - If slow gas generation / little gas emissions from the waste (e.g. methane) → controlled passing of gases through the cover layer OR if a lot of gas/fast gas generation rate → gas collection system.
  - Prevent intrusion of tree roots, animals and unintended human intrusion
  - Prevent formation of frost in the water drainage layer and below
  - Shelter from surface processes such as heavy rainfall and forest/ground fires.
  - Minimise risk of formation of uneven settlements that can lead to breakage of some structures and formation of “bath tubs”.
  - Act as a radiation shield (in addition to waste packages).

- Fill material around the waste packages:
  - Fill the voids between waste packages.
  - Provide drainage function to limit corrosion of waste packages.
  - Provide suitable chemical and physical properties to limit radionuclide release and transport.
  - Minimise uneven settlements to the overlying cover structure.
- Foundation layer:
  - Sufficient mechanical bearing capacity and stability.
  - Control and collect leachate water and enable monitoring of radiation levels.
  - Limit infiltration of leachate/radionuclides into groundwater. If there is very thin natural (sediment) barrier layer foundation layer should compensate the lack of this layer.
- Waste packages – keep the waste dry (plastic, metallic) and provide containment of the waste.
- Waste package layout:
  - Layout shall be designed taking into account the load bearing capacity of the waste packages (packages placed on top of each other), degradation in time (soft waste packages) and risk of formation of uneven settlements.

Comparison to requirements for hazardous waste landfills

- In comparison to hazardous waste landfills, the design basis differ in legislation applied (Nuclear Energy Act), waste acceptance criteria, defence in depth/graded approach, mutually complementary barriers, service life up to ~300 years, prevention of human intrusion and in general safety of the system shall not rely on active post-closure monitoring or maintenance.

Hydraulic properties of the mineral sealing layer

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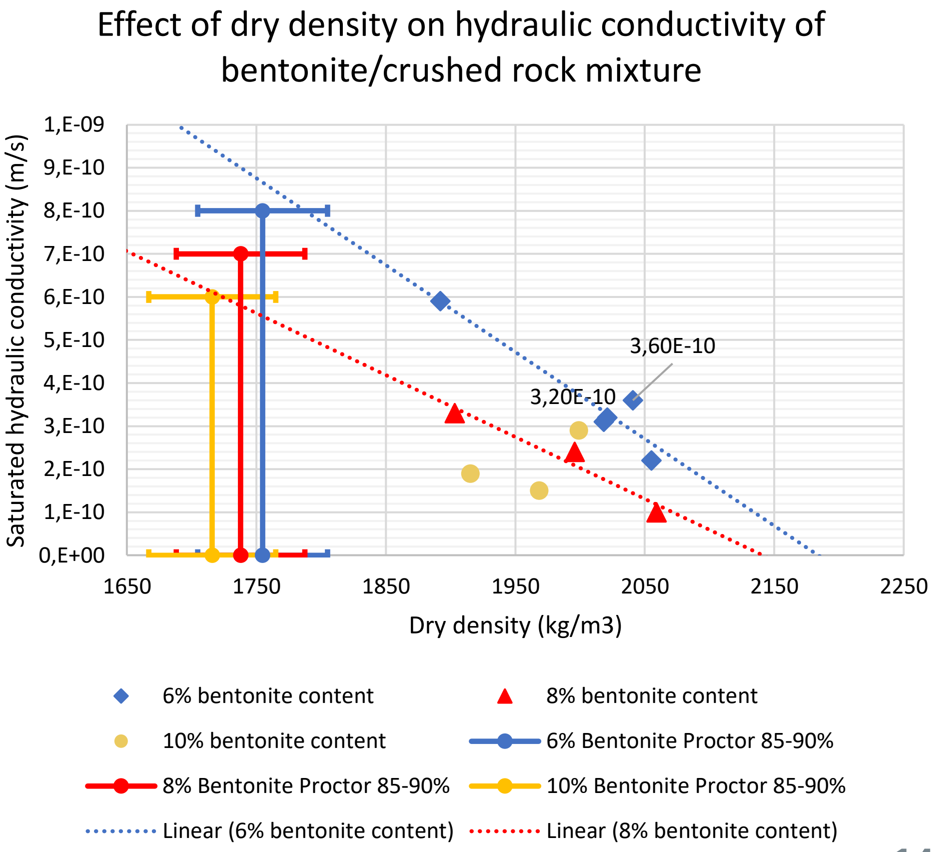
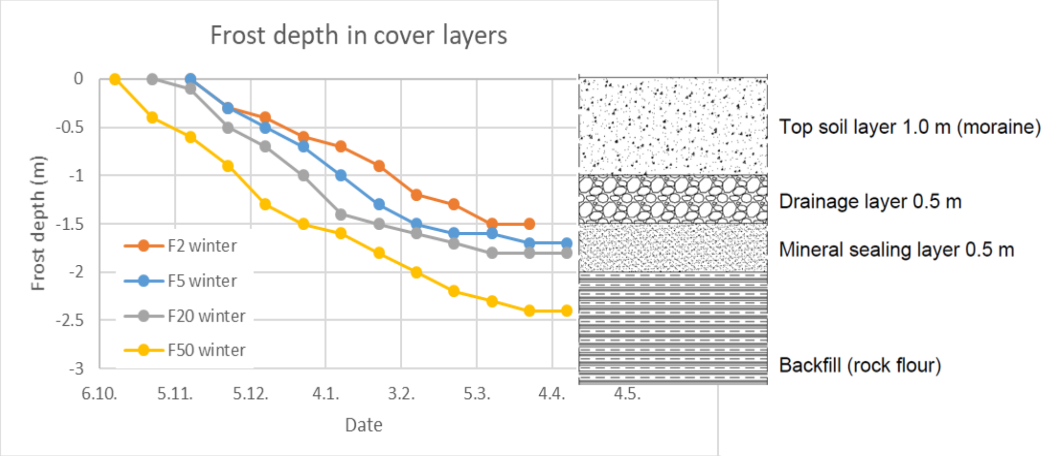
- Mineral sealing layer with thickness ≥ 0,5 m recommended to provide long-term sealing function even in case of degradation of synthetic sealing layers in time.
- After installation realistic k-value ~$1x10^{-9}$ m/s → combination with synthetic sealing layer recommended to gain lower initial combined k-value (≤ $1x10^{-10}$ m/s).
- Selection of the synthetic sealing layer so that it allows controlled escape of gases (slow gas generation rate scenario).
- If gas generation is fast, the synthetic liner should have low gas permeability and should be combined with a gas collection pipes.
- Exposure of samples during entire winter 2021-2022 did not increase hydraulic conductivity.

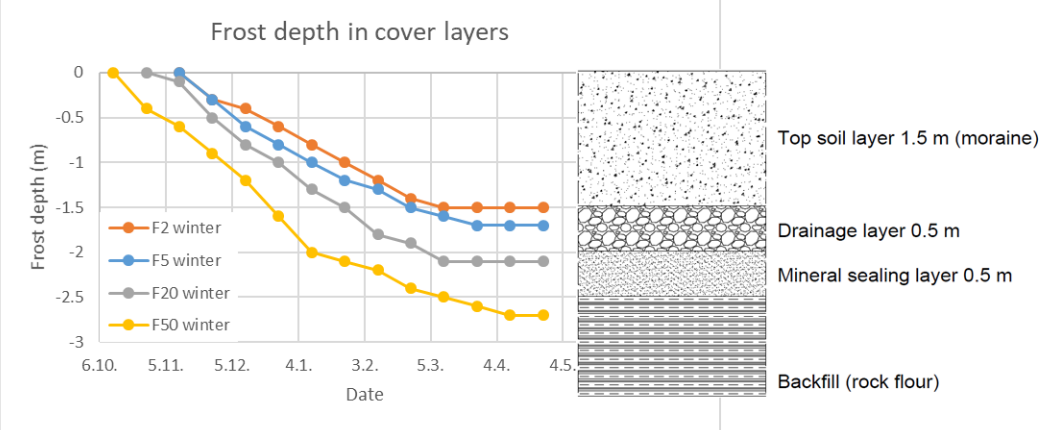


Hydraulic transport through barriers

- Water transport within the repository was modelled with the HELP model
  - Quasi-two-dimensional hydrological model
  - Barrier properties and weather data as input parameters
- Change of water storage within the repository was tested with different scenarios (varying ambient conditions and material properties)
  - The conceptual landfill-type of repository functions well in collecting leachate waters
  - Hydraulic conductivity (k) of the mineral sealing layer in the order of $1x10^{-10}$ m/s ensured better sealing of the system in comparison to $1x10^{-9}$ m/s, assuming imperfections in the synthetic liner. However, in practice the k-value for the mineral sealing layer with low bentonite content (e.g. 6%) remains closer to $1x10^{-9}$ m/s.
  - Mutually complementary barriers, combination of synthetic and mineral sealing layer, is required to reach low hydraulic conductivity for the system in long-term.
  - Properly installed and undamaged geomembranes are important
- Recommended: modelling of the transport through a pilot test in Olkiluoto and transport model verification through the results.

Ground frost





- Frost depth should not reach the drainage layer or layers below that.
- Thermal modelling was performed using TEMP/W finite element software by GeoStudio.
  - Effect of top soil layer thickness.
  - Effect of snow coverage.
  - Effect of future climate scenarios.
  - Average winter period (F2),
  - Winter periods occurring once in:
    - 5 years (F5)
    - 20 years (F20), and
    - 50 years (F50).
- Recommendation: Site specific numerical modelling and verification of the model with the Olkiluoto pilot test.

Top layer (in cover structure)

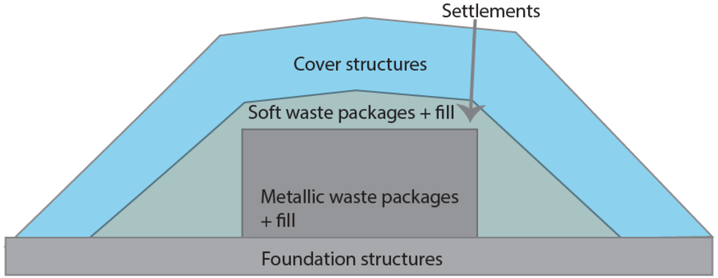
- Thickness/composition should be defined based on:
  - Local conditions, site specific numerical modelling and measurements (model verification)
  - Risks linked to climate change.
  - Risk of human unintended human intrusion.
  - Risk of animal and tree root intrusion:
    - Compaction while installation to sufficient density state (1.8 t/m^3) and penetration resistance of 2.5 MPa,
    - Typically tree roots cannot intrude synthetic liners.
    - High density also decreases oxygen content in the material (<2%) also preventing root penetration.
    - Use of nutrient poor materials.
- Vegetation at the surface optimised for erosion resistance and increasing evaporation (grass, alternative “kuntta”).
- Some safety margin suggested, e.g. up to 2 m.

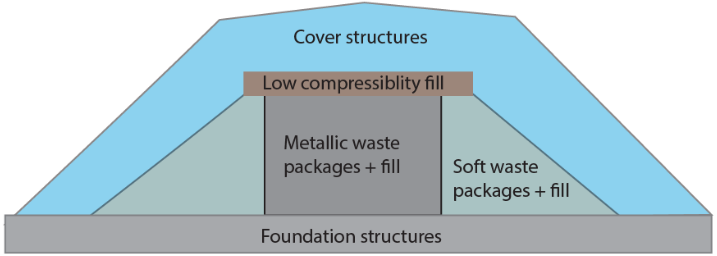
Fill material around waste packages

- Rock flour:
  - Sorption capacity up to a certain limit.
  - Sufficient, but not optimal for drainage function from corrosion point of view (tends to stay wet longer than coarser materials).
  - Effect on uneven settlements?
- Crushed rock as an alternative:
  - Due to coarser grain size, potentially less sorption capacity than rock flour.
  - Better drainage function (if relatively coarse and poorly-graded grain size distribution), also faster route for radionuclide dispersion.
  - Less effect on uneven settlements?
- Both chemically compatible with waste packages, some effect on pH in the beginning, depending on the rock type (mafic a bit higher pH in the beginning in comparison to felsic rock).

Uneven settlements

- Experiences from Sweden, risk of uneven settlements has realised in some cases. Re-design and re-installation of the cover layer during the operational period is possible, but perhaps could be avoided.
- Possible solutions:
  - Placement of soft waste packages into metallic waste containers (also for limiting gas generation!)
  - Optimisation of the waste fill material from settlements point of view (crushed rock)
  - Waste package layout optimisation (soft packages placed so that risk of uneven settlements are minimised).
  - Other concept (e.g. concrete vault).





Risk analysis

- A bowtie risk analysis was created to identify risks associated with the presented barrier designs
  - Risks and risk controls associated with individual barriers were addressed
  - Risks and risk controls associated with the cover structures, fill material and encapsulated waste, and foundation structures were also addressed
  - Risks were rated before and after mitigative actions
- Risk analysis identified similar barrier specific challenges as was discussed on the previous slides
  - Water accumulation and flow within the fill material and waste layer is one of the main causes for contaminant release
    - Multiple barriers aim to both preventatively and mitigatively control this
  - Cover layer: Erosion, Tree roots and animals, Uneven settlements, and human intrusion
  - Fill material and waste packages: Degradation of waste packages through corrosion, compression of soft waste packages
  - Foundation layers: Weight of overlying layers, freezing temperatures during construction

Summary of recommendations

- Performance of the cover layer is important for limiting corrosion and formation of leachate water and gas. Recommendations:
  - Combination sealing structures (synthetic and mineral sealing layers) needed for ensuring sufficiently low permeability (target for the combination structure $\leq 1x10^{-10}$ m/s). Same recommendation for the foundation layer, especially important in case of thin natural barrier (sediment) layer at the site.
  - Slow generation rate of gases → gas permeable cover structure materials sufficient for handling the gas. In case of fast/significant generation of gas → build up of gas collection system needed.
  - Optimisation thickness of the top layer (frost, animal and unintended human intrusion, post-closure forestation, forest fires etc.). Compaction to density of at least 1.8 t/m^3 (tree roots, animals). Synthetic layers (tree roots).
  - Controlling risks linked to uneven settlements (material selection, installation, waste packages, waste package layout).

SAFER 2028

SURERAD
Safety and Evolution of Near Surface Disposal in Finland

SAFER2028 programme

- **Research topics identified in SAFER2028 programme concerning near surface disposal:**
  - **Design:** For example optimisation of engineered barriers systems.
  - **Performance:**
    - Waste evolution;
    - Transport through engineered barriers into geosphere (biochemical reactions, colloid formation and transport, interface reactions);
    - Possible climate induced changes (e.g. sea-level rise).
  - **Monitoring aspects:** Need and type during operation and post-closure.

SURERAD work packages and project objectives

- Work package 1: Engineered barrier performance and optimisation:
  - Task 1.1. Documentation of the initial state of the TVO pilot study.
  - Task 1.2. Formulation of climate scenarios relevant considering repository lifetime.
  - Task 1.3. Mechanical and thermal evolution of the near surface disposal facility.
  - Task 1.4. Summary of the findings and optimisation of the design.
  - Task 1.5. Project management and stakeholder engagement.

- Work package 2: Waste form evolution, radionuclide behaviour and migration, and future optimisation of surface disposal:
  - Task 2.1 Understanding waste package evolution, radionuclide behaviour, and potential for radionuclide migration.
  - Task 2.2. Understand future radionuclide migration risks related to climate change.

- Work package 3: Hydrological modelling of the near surface repository and the surrounding site
  - Task 3.1. Simulation of hydrological surface-subsurface interactions on the repository
  - Task 3.2. Simulation of water flow and radionuclide transport within the repository
  - Task 3.3. Simulation of hydrological processes and radionuclide transport at the site level

- Work package 4: Monitoring
  - Task 4.1 Monitoring of the pilot study including design and set-up monitoring systems, documentation of the monitoring systems and gathering and analysing monitoring data during 2023-2025.
  - Task 4.2 Development of monitoring strategy for the entire life-cycle of the repository.

SAFER DENSE project: SUREPhD

- Aligned to SURERAD but stand-alone project. Student: Taavi Vierinen, Chemistry / Radiochemistry Masters UH. UH, VTT, and HZDR supervisors.
- Assessing:
  - ^{14}C creation, partitioning, and speciation from VLLW waste-forms under evolving repository conditions;
  - ^{14}C release and migration potential through barriers into biosphere;
  - Applicability of surface disposal for select decommissioning wastes (concretes);
  - Possible optimisation of waste packaging for future VLLW disposal.

Thank you for your time