Source: Posiva Oy

Design and Performance of Engineered Barrier Systems for the Finnish Deep Geological Repository

7. Essener Fachgespräch Endlagerbergbau

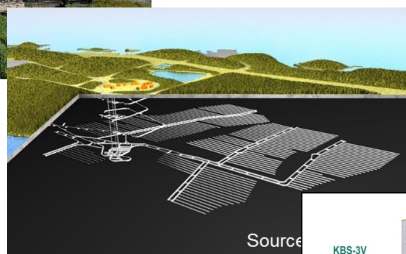
1.3.2018, DMT, Essen

Dr.-Ing. Edgar Bohner

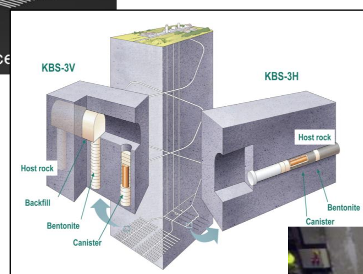
VTT Technical Research Centre of Finland Ltd

Outline

Nuclear energy in Finland



Nuclear waste management



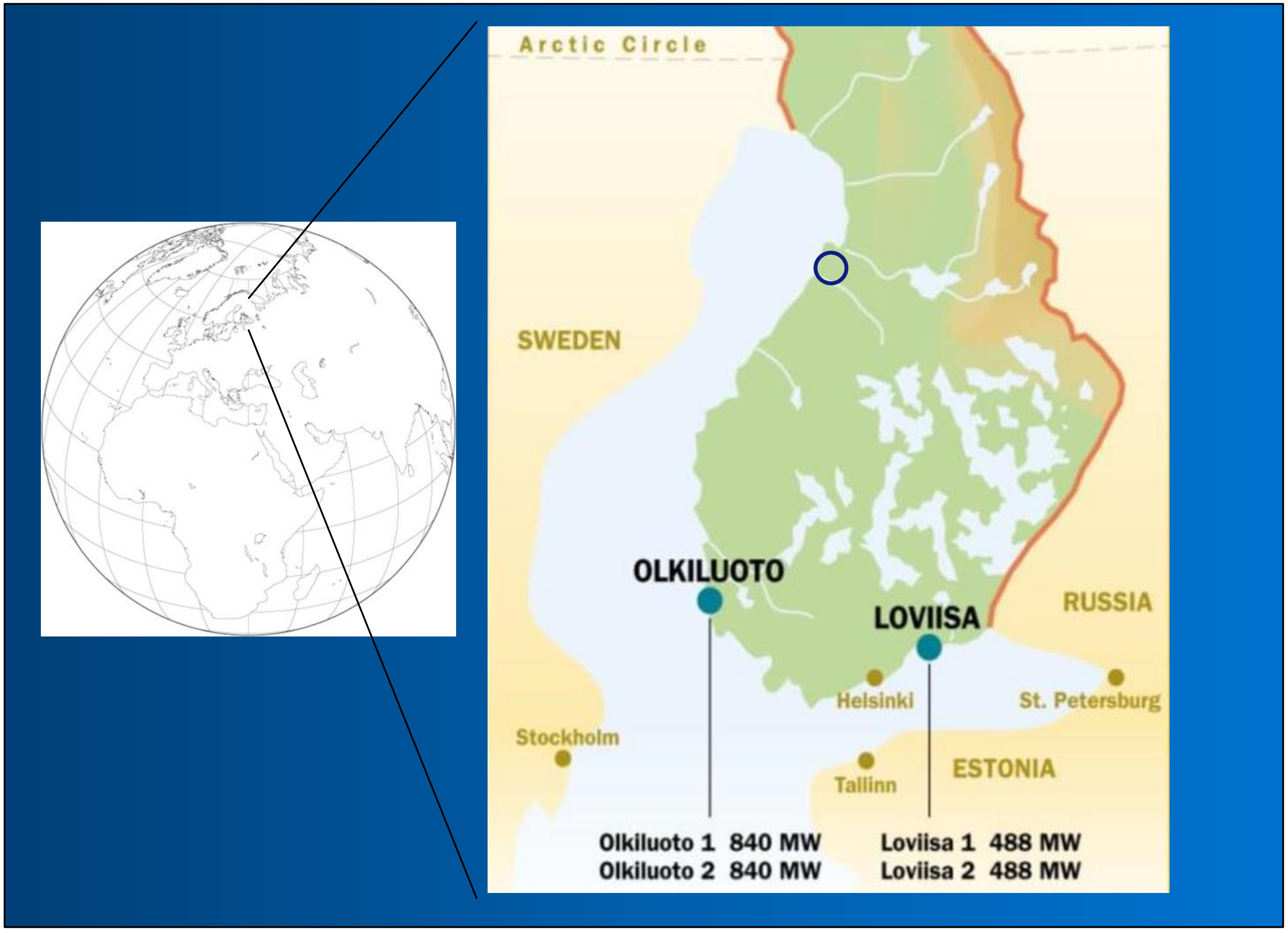
Design and manufacturing of engineered barriers

In-situ demonstrations of EBS concepts and monitoring of EBS performance

Conclusions

Nuclear Energy in Finland

Nuclear power plants in Finland



Four operational reactors (2 BWRs, 2 VVERs)

- Commissioned 1977-80
- Producing 70 TWh (2013)
- Operating at 92% energy capacity factor (world-leader efficiency)

Fifth reactor Olkiluoto 3 (1600 MW, EPR) under construction (2005-20xx)

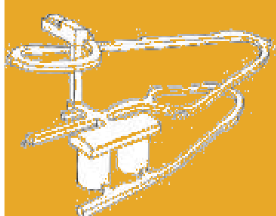
Sixth reactor Hanhikivi 1 entering construction stage (CLA submitted June 2015)

Finnish nuclear power and waste organisation

Teollisuuden Voima Oy

Olkiluoto power plant 2 reactors (one plant under construction)

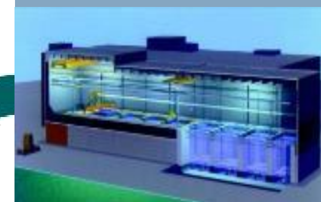
Interim storage of spent nuclear fuel



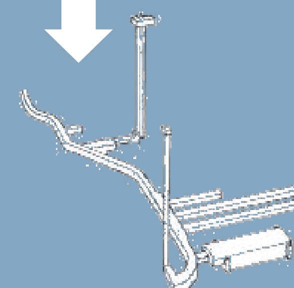
Operating waste repository

Fortum Power and Heat Oy

Loviisa power plant 2 reactors



Interim storage of spent nuclear fuel

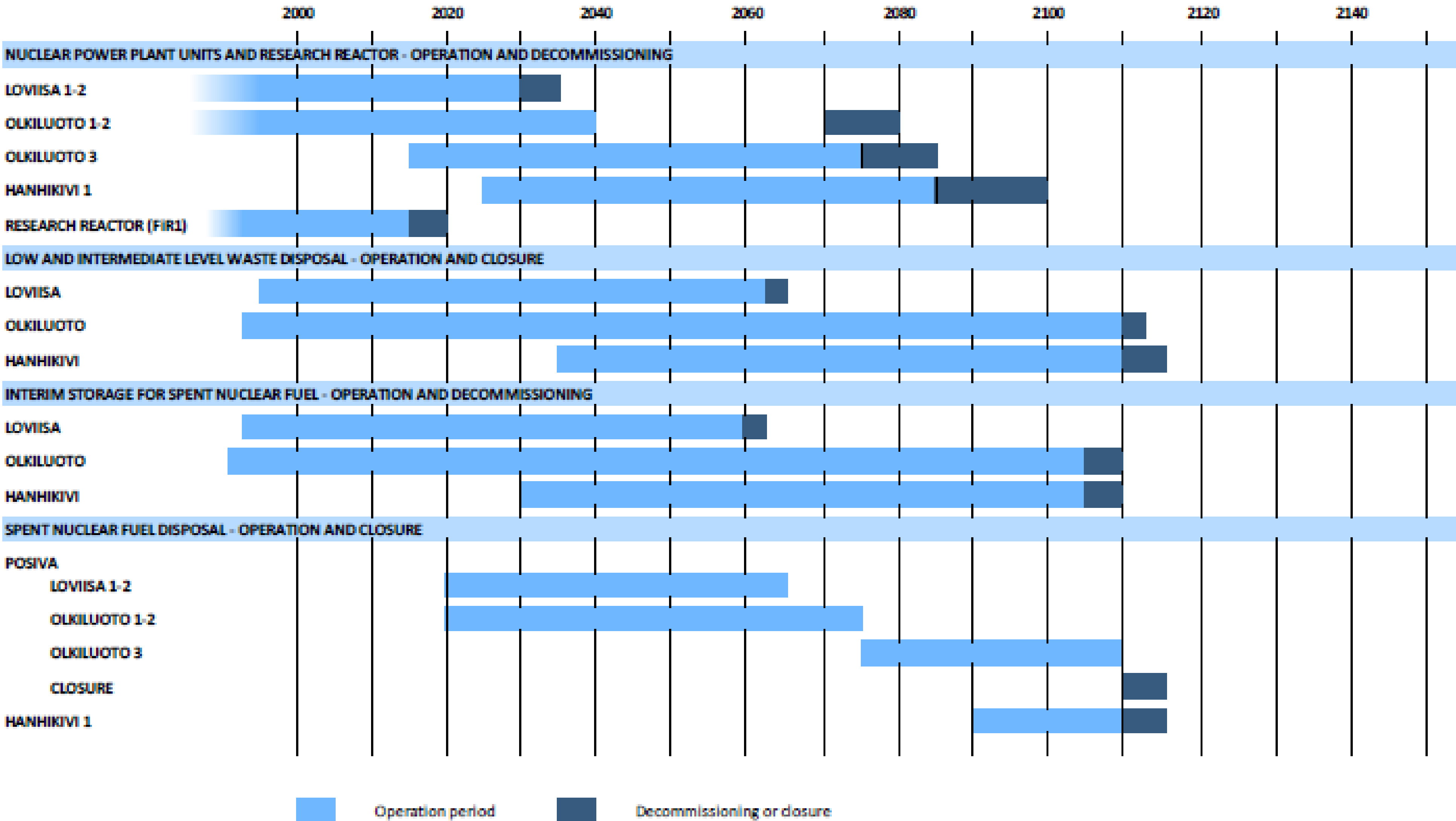


Operating waste repository

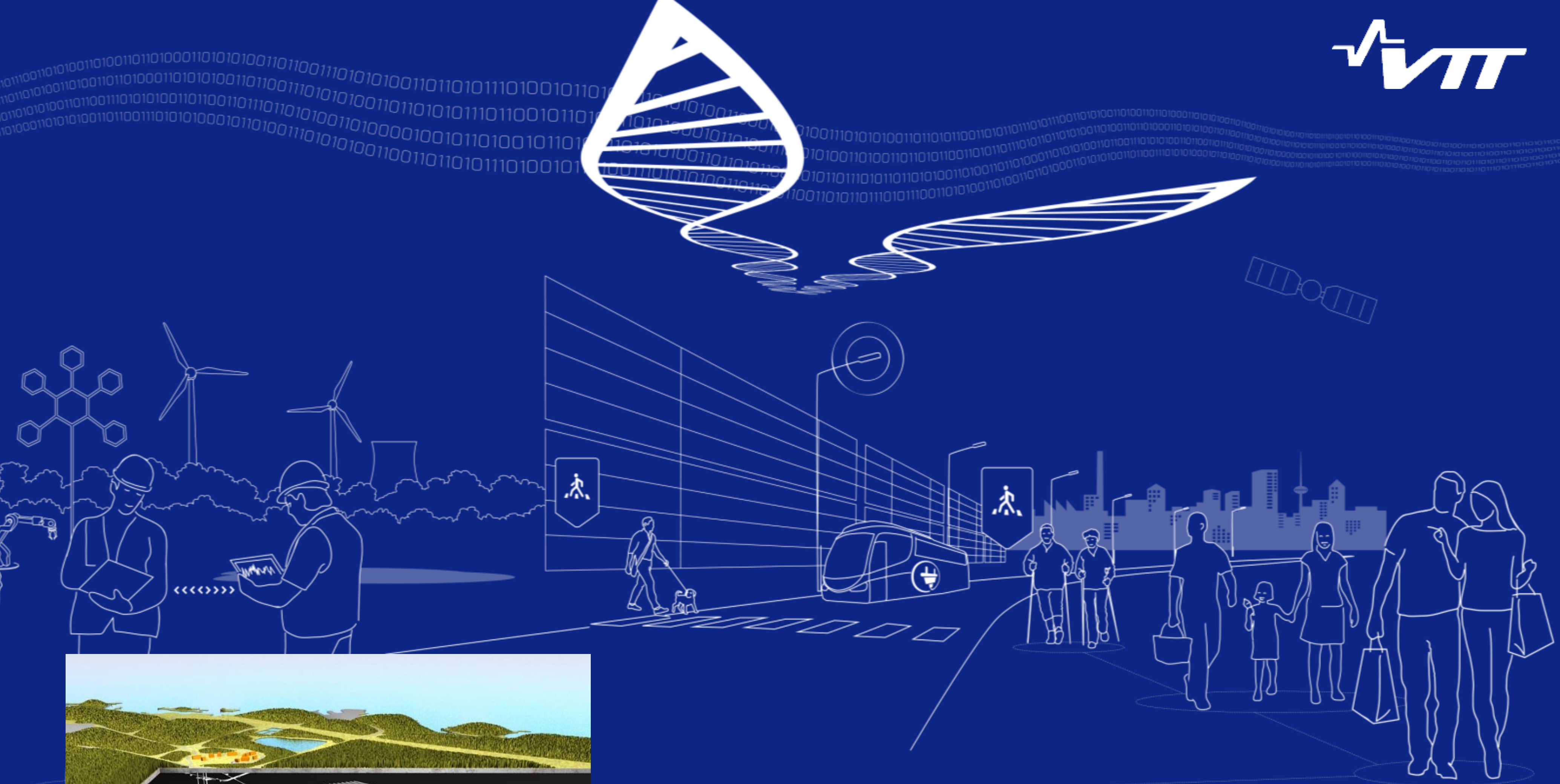
Posiva Oy

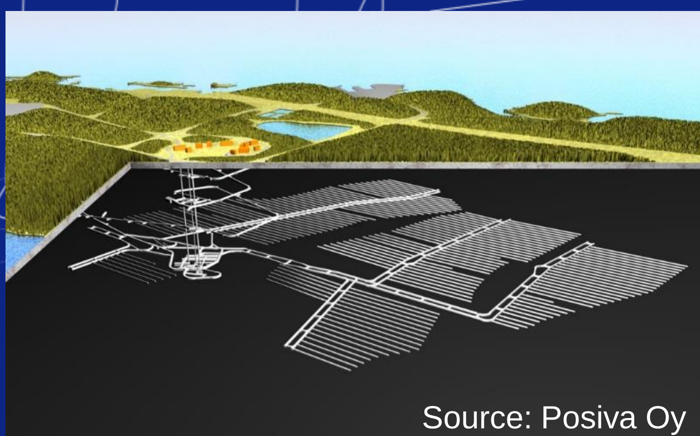
Final disposal of spent nuclear fuel

Finland's nuclear timeline



Source: STUK – Radiation and Nuclear Safety Authority in Finland





Source: Posiva Oy

Nuclear Waste Management

Finnish Deep Geological Repository for High Level Waste

Finland: 40 years' effort towards operation

1978
Studies into geologic disposal started

1983
Site selection research

Government's decision on timetable

1997
Selection of Olkiluoto

2001
Decision in principle by the Government and the Parliament

2004
Construction of ONKALO and site confirmation studies in Olkiluoto

2012
Application for the construction license

2015
Construction of disposal facilities

Construction license granted by The Finnish Government 12.11.2015

Test operation, commissioning

Application for the operation license

Start of disposal in the early 2020's

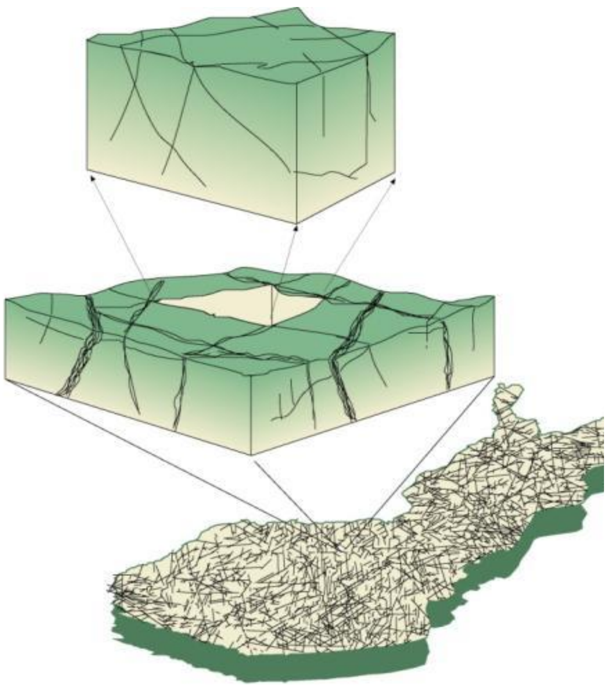
Source: Tiina Jalonen, Posiva Oy

POSIVA

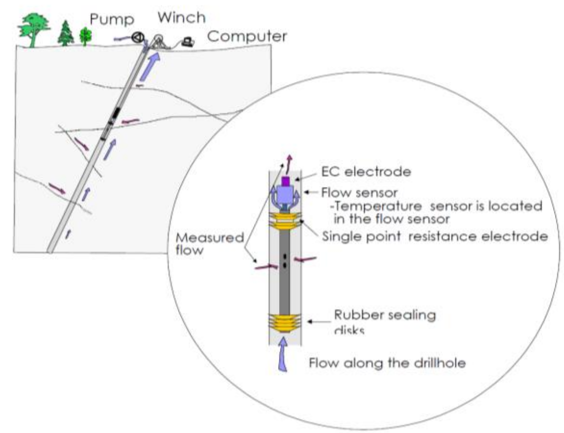
Finland: Site selection research programme 1983 - 2000

Site Identification

1983 - 1985



More than 100 candidate sites were identified

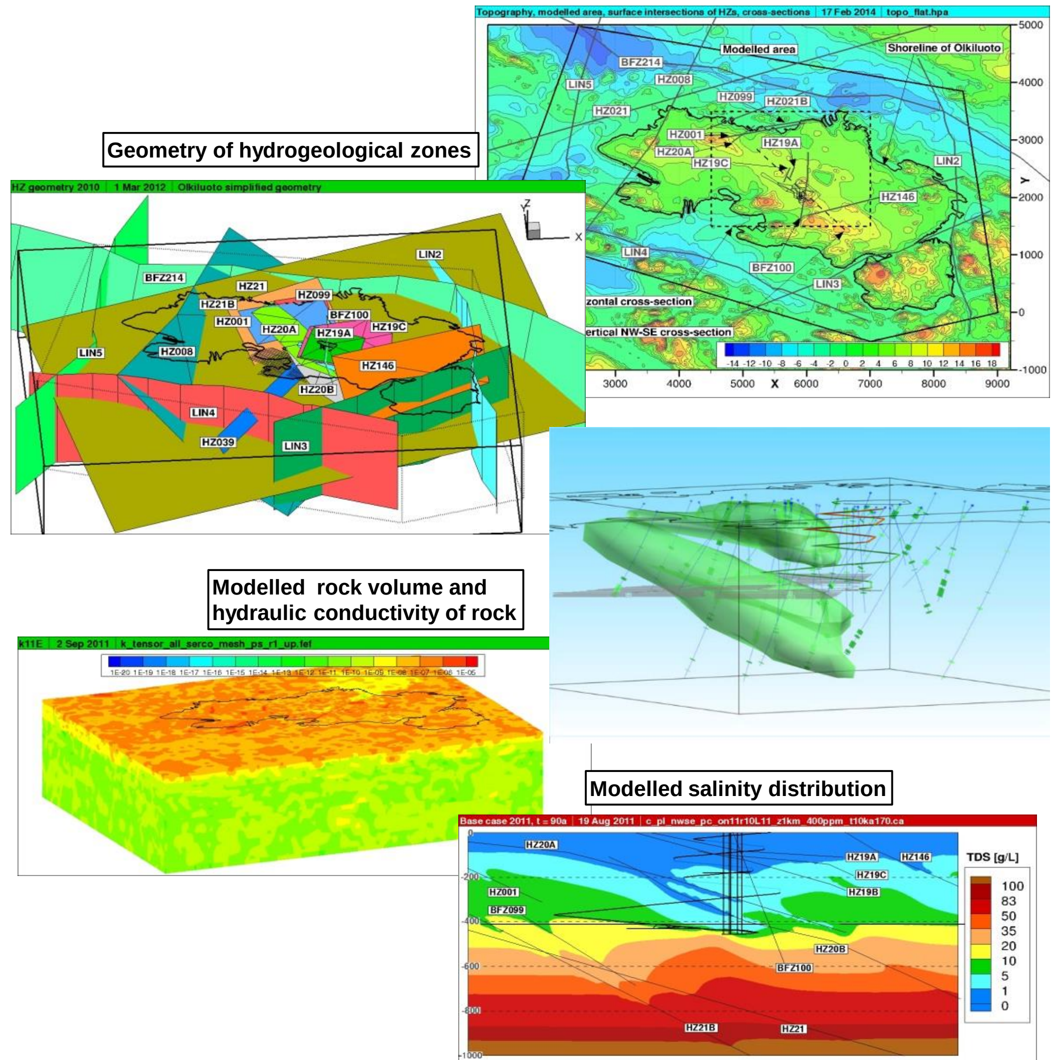


Posiva's Flow Logger PFL

Source: Tiina Jalonen, Posiva Oy

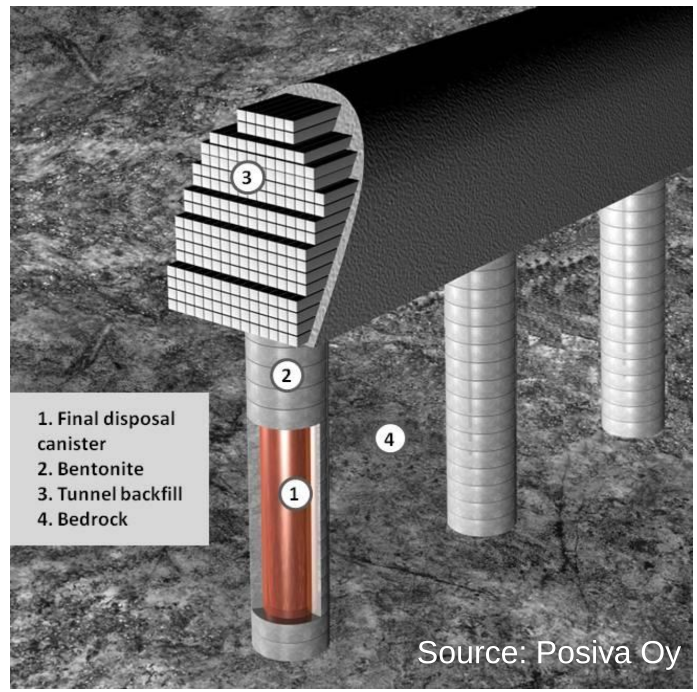
Site characterization for high level waste repository

- Olkiluoto Site Description works in form of geological and hydrogeochemical 3D models
- Geological modelling describes the long-lasted evolution of the crystalline bedrock
- Hydrogeochemistry monitoring revealed any changes caused by the construction of the ONKALO tunnels
- Simulation of coupled fluid flow, heat transfer, solute transport in fractured, heterogeneous media supports prediction of future behaviour

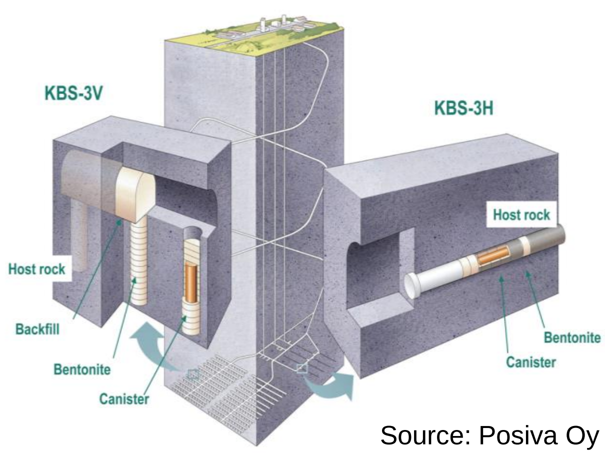


Long term disposal of highlevel radioactive waste

- International consensus that deep geological disposal on land is most appropriate way for isolating high level waste from entering the biosphere
- Barriers against movement of radionuclides are required
- Barriers include
  - waste form itself
  - corrosion resistant containers for encapsulation of waste (1)
  - special radionuclide- and groundwater-retarding materials around containers, i.e. buffer, backfill, plugs and seals (2),(3)
  - geological formation itself (4)

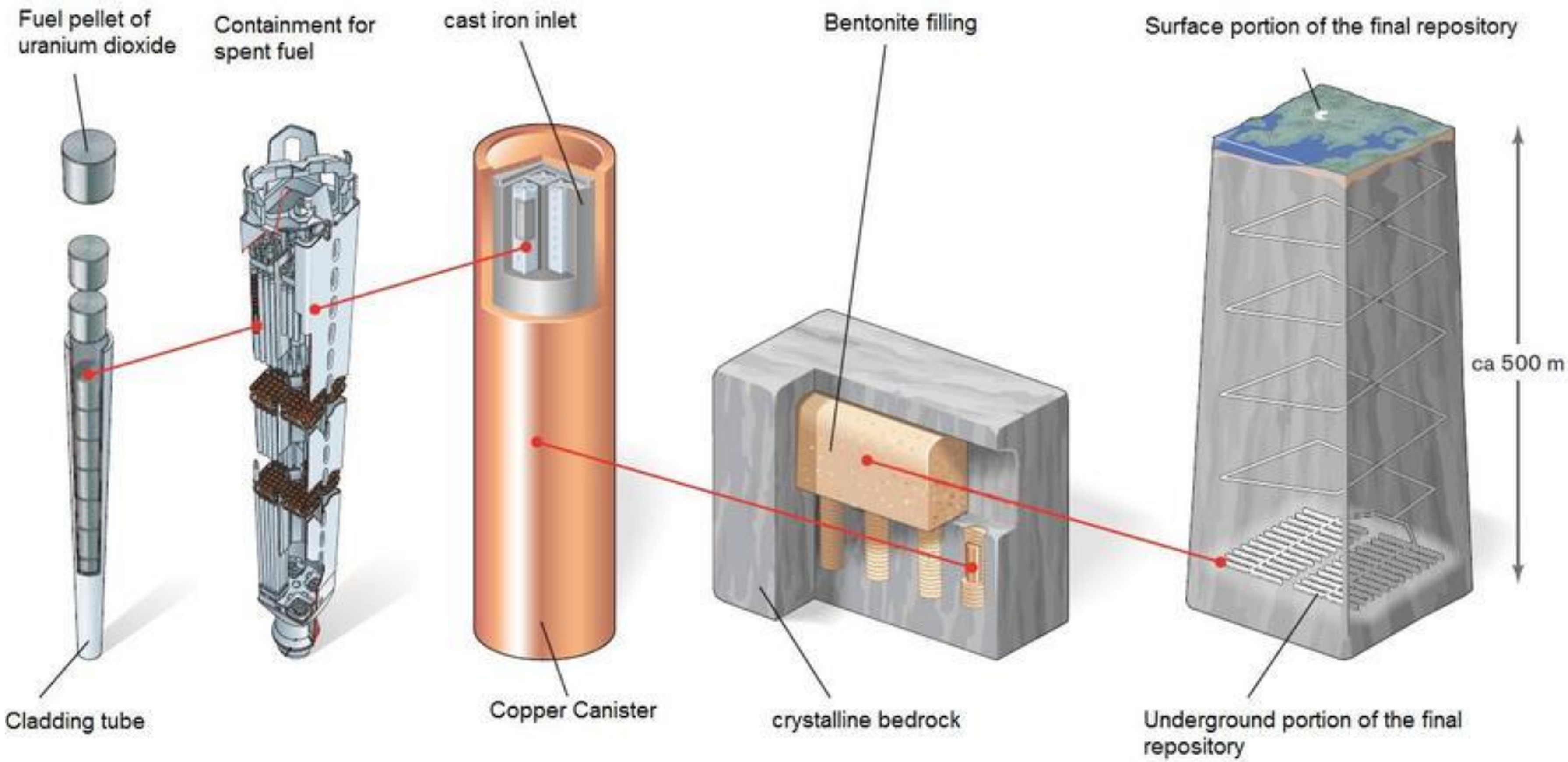


Design and Manufacturing of Engineered Barriers



Source: Posiva Oy

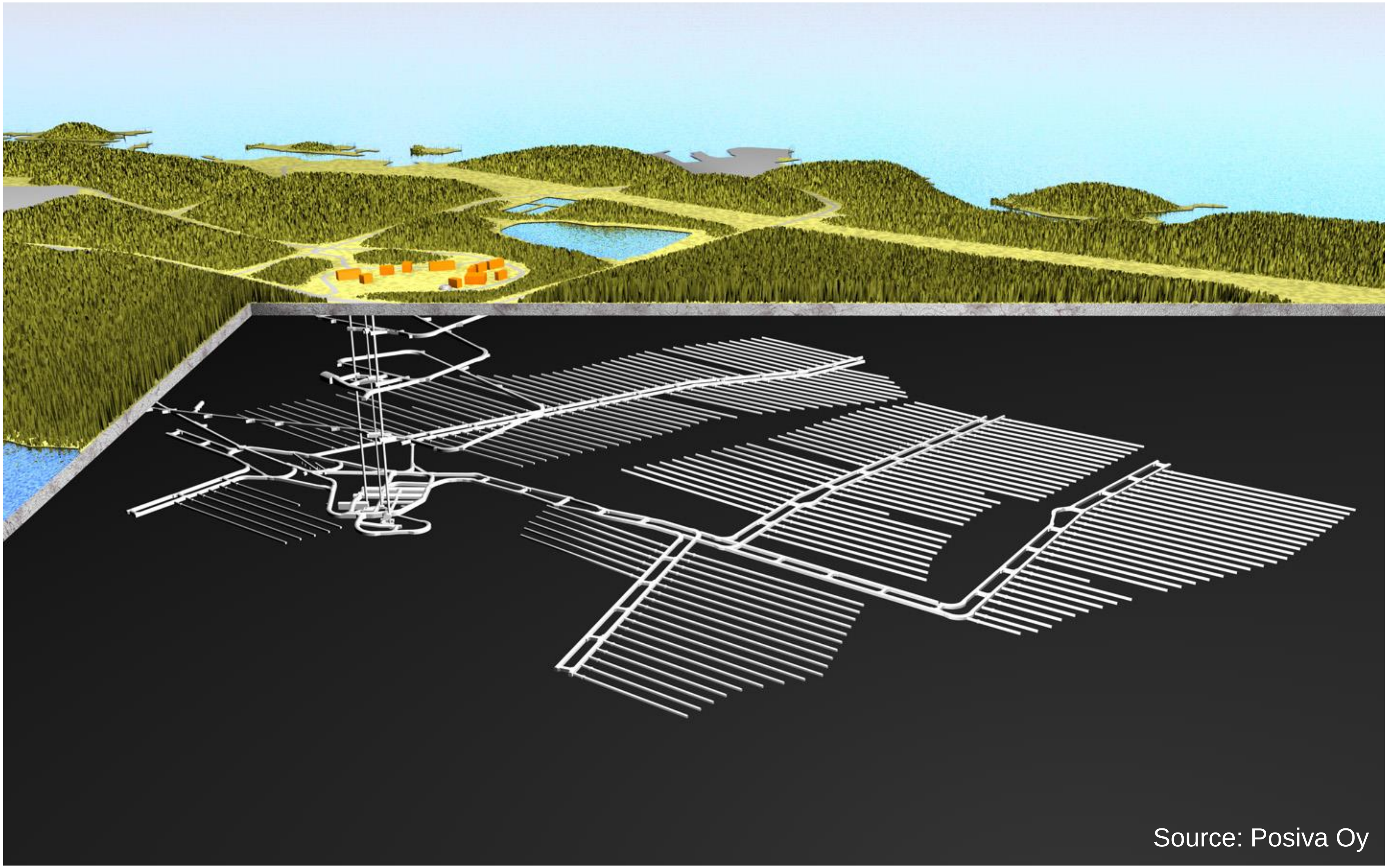
Engineered barrier system (EBS) – KBS-3 concept



Source: SKB

- Primary safety function: complete containment
- Secondary safety function: retardation
- Multi-barrier requirements: thermal-hydraulic-mechanical-(bio)chemical

Repository for spent nuclear fuel in Olkiluoto



Safety functions assigned to EBS in Posiva's repository

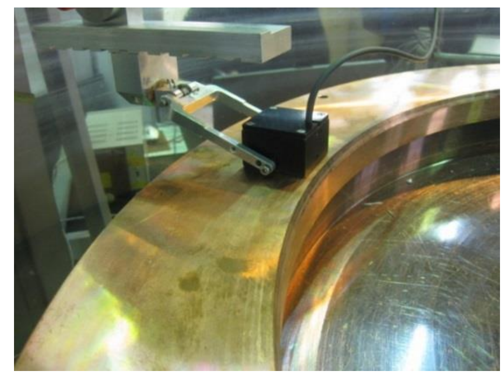
Barrier	Safety functions
Canister	Ensure a prolonged period of containment of the spent fuel. This safety function rests first and foremost on the mechanical strength of the canister's cast iron insert and the corrosion resistance of the copper surrounding it.
Buffer	Contribute to mechanical, geochemical and hydrogeological conditions that are predictable and favorable to the canister. Protect canisters from external processes that could compromise the safety function of complete containment of the spent nuclear fuel and associated radionuclides. Limit and retard radionuclide releases in the event of canister failure.
Deposition tunnel backfill	Contribute to favorable and predictable mechanical, geochemical and hydrogeological conditions for the buffer and canisters. Limit and retard radionuclide releases in the possible event of canister failure. Contribute to the mechanical stability of the rock adjacent to the deposition tunnels.

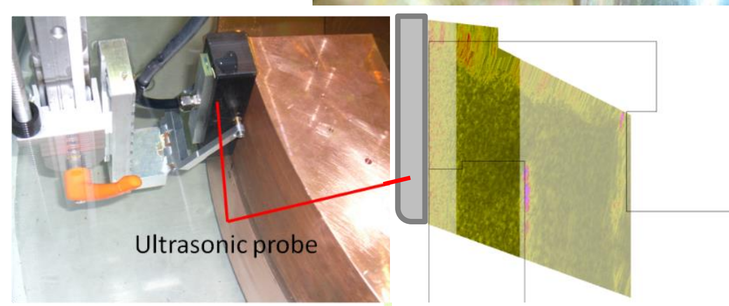
EBS – basic requirements

- Metal canister/container
  - complete waste isolation
  - high corrosion resistance
- Clay/bentonite buffer, backfill
  - low permeability and hydraulic conductivity
  - self-sealing ability
  - maintaining thickness
  - physical and chemical longterm stability
  - minimise microbial activity
  - colloid filter
- Concrete plugs and seals
  - low permeability and diffusivity
  - chemical conditioning (low pH)

Disposal canister

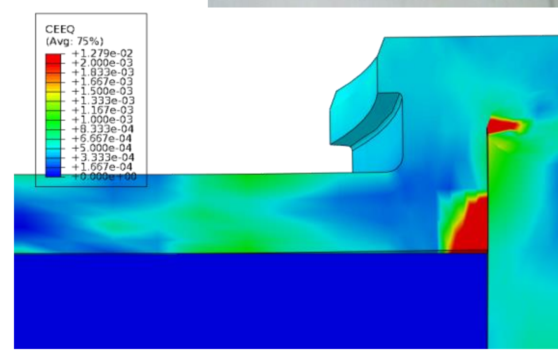
- Oxygen free copper overpack for corrosion resistance
    - Thickness 50 mm
    - Welding with Friction Stir Welding (FSW)
- Nodular cast iron insert for mechanical strenght
    - Three types
- Design criteria to be set to ensure the integrity of the canister with NDE
    - all the components, including copper overpack, lid and welds
    - NDE testing based on visual, Eddy current, ultrasonic, radiographic methods





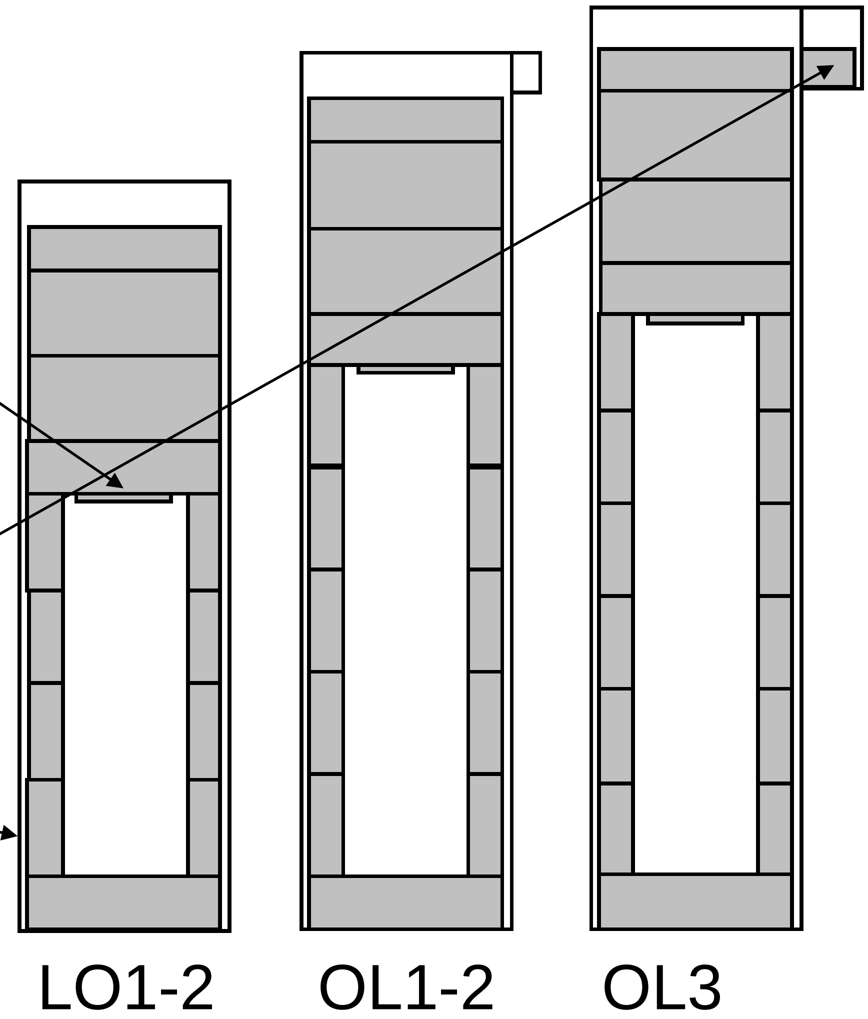
Disposal canister

- Mechanical behaviour of the copper disposal canister under complex stress state caused by
  - internal heating due to residual activity of fuel
  - external bentonite buffer
- Experimental testing of copper canister and characterization of damage modes.
- Modelling of stresses and strains during disposal
- Life time estimation of the canister and its welds



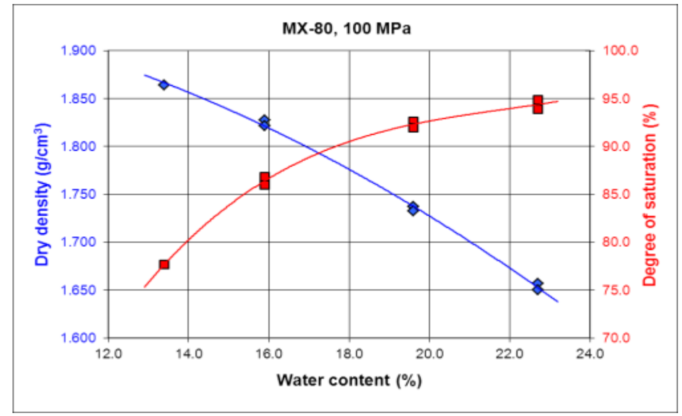
Buffer design (Posiva's design 2012)

- Buffer consits of
  - 4 disks on top of the canister
  - a block in canister's recess
  - 4 to 6 ring blocks
  - a bottom block
  - for OL3 fuel also a chamfer block
  - gap between the block and rock surface are filled with bentonite pellets

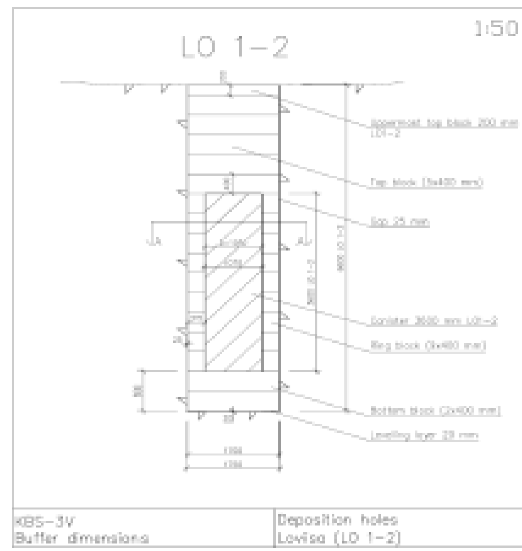


Buffer design (Posiva's design 2012)

- In the reference design
  - the target density of the saturated buffer is 2000 kg/m^3
  - the allowable tolerance is ± 50 kg/m^3



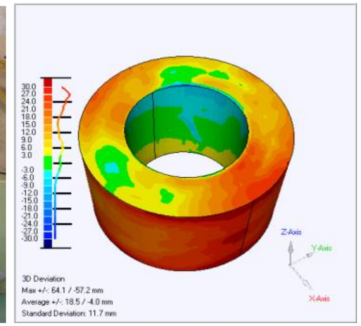
- This is achieved using (in installation phase)
  - ring shaped blocks with a nominal bulk density of 2050 kg/m^3
  - disk blocks with a nominal bulk density of 1990 kg/m^3
  - pellet filling with a loose density of 1075 kg/m^3
  - the water content of 17% for all the buffer components



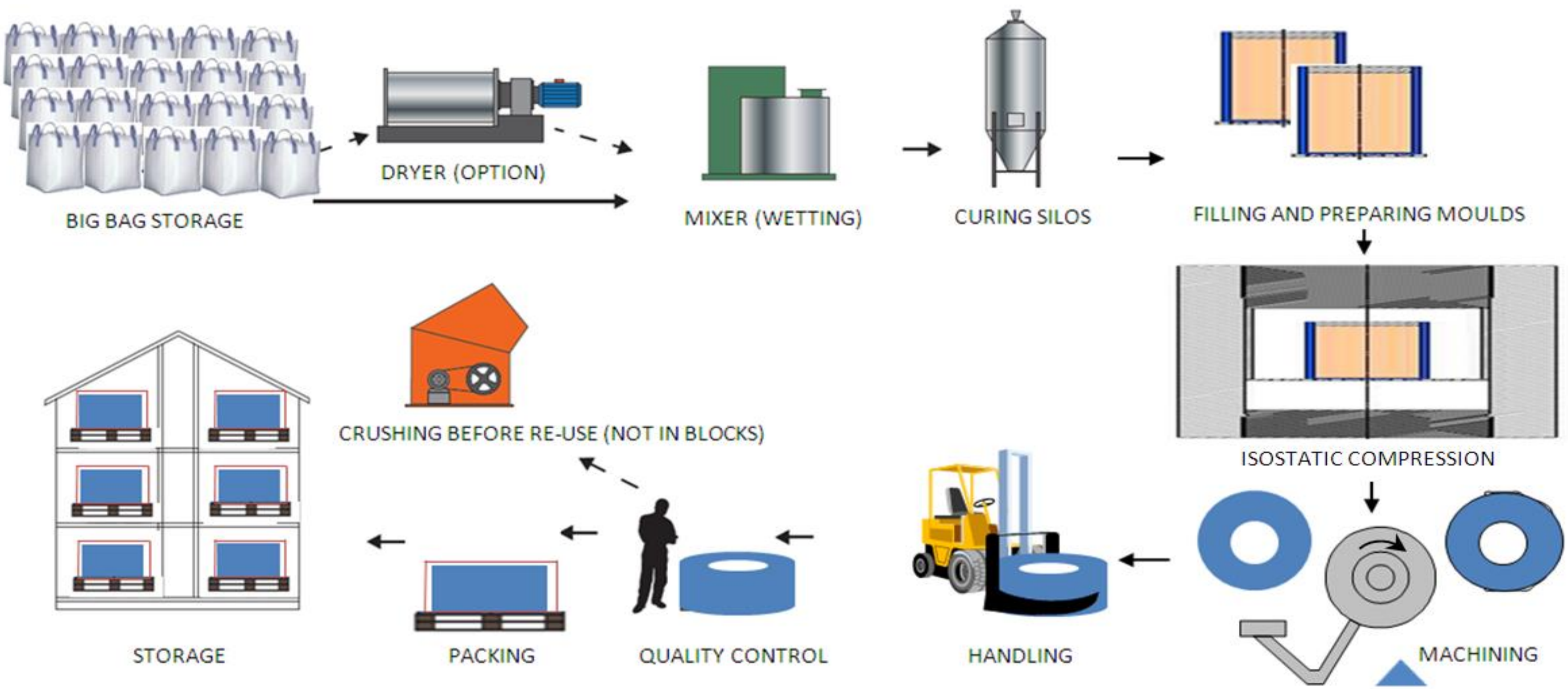
Buffer component manufacturing

- Manufacturing technologies for bentonite blocks, rings and pellets
  - uniaxial compression
  - isostatic compression
  - roller compaction and extrusion of pellets

- Optimal component properties are achieved at varying material types, water contents, achievable densities and strengths to suit installation and operation



Buffer and pellet production process and quality control

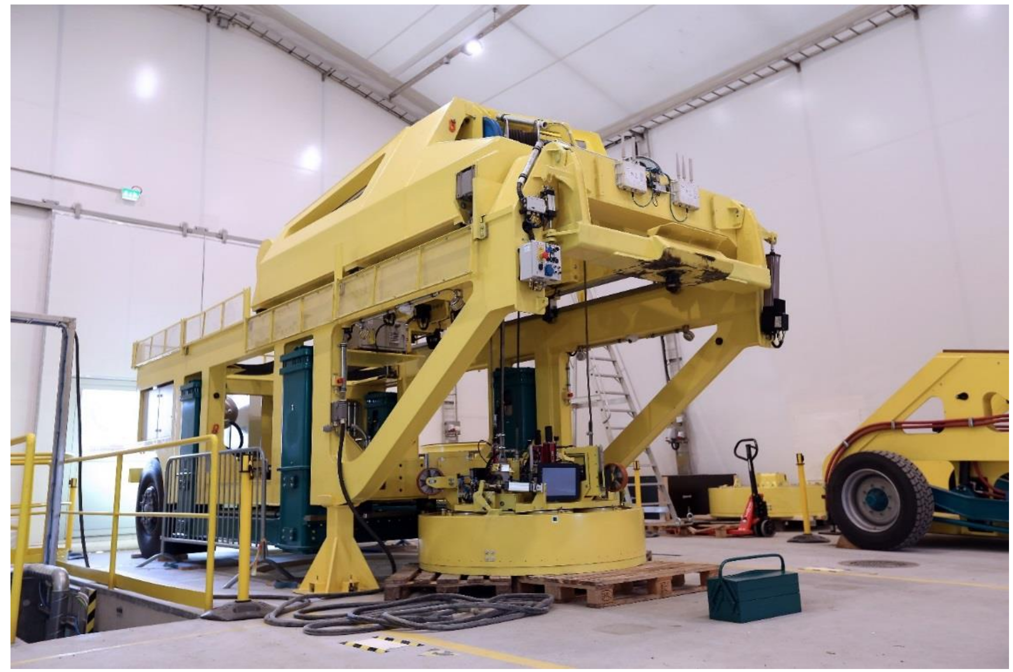


Moisture protection systems and coatings for quality management during emplacement

- Protection of bentonite clay against water leakages and air humidity during installation phase
- Deposition hole liners and temporary thin-film coatings of bentonite components
- Bottom plate of buffer tower with integrated moisture protection liner with support rings, dewatering and alarm system.
- Prototype solutions have been made and demonstrated at full-scale

Buffer emplacement

- Automated and remote emplacement with a robot
- Equipment developed within the EURATOM research project LUCOEX – Large Underground Concept Experiments
  (Grant agreement 269905;
  URL: www.lucoex.eu)



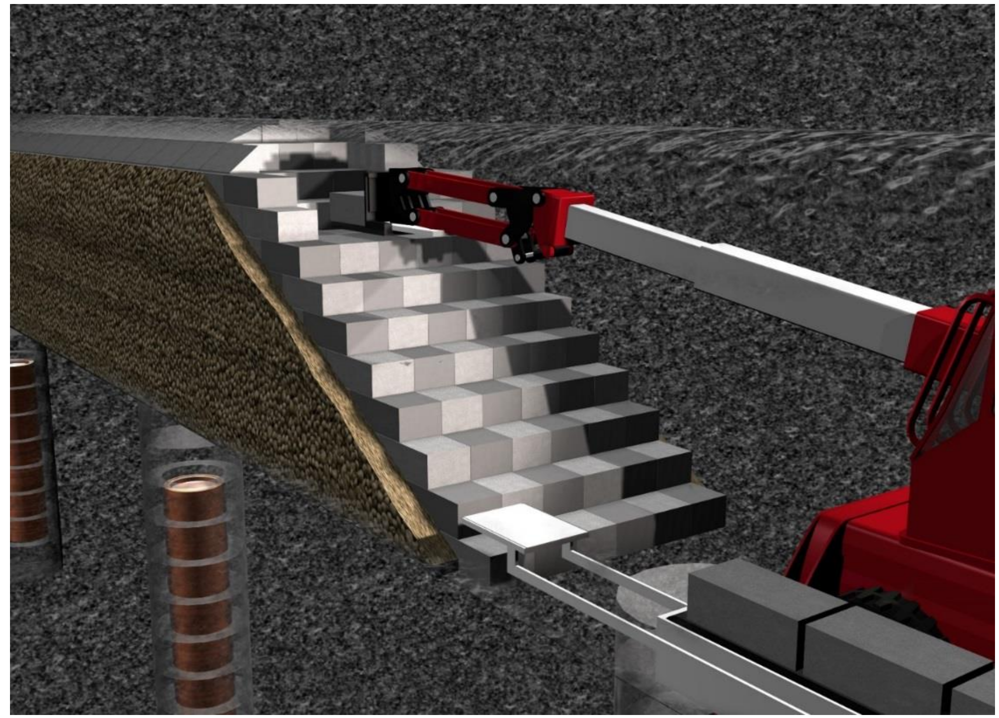
Backfill design – requirement hierarchy

- Reference: Posiva-SKB Report 01 (2017)

Requirement level	Example for backfill
Safety function	Limit advective mass transfer
Performance target	Hydraulic conductivity <1x10^{-10} m/s and swelling pressure > 0.1 MPa
Technical design requirement	Threshold dry density where the backfill material fulfills the performance target in certain site specific conditions.
Design specification	Specifications for the backfill design in order to reach the threshold dry density in the backfilled tunnel. For example, minimum dry density for the backfill blocks.

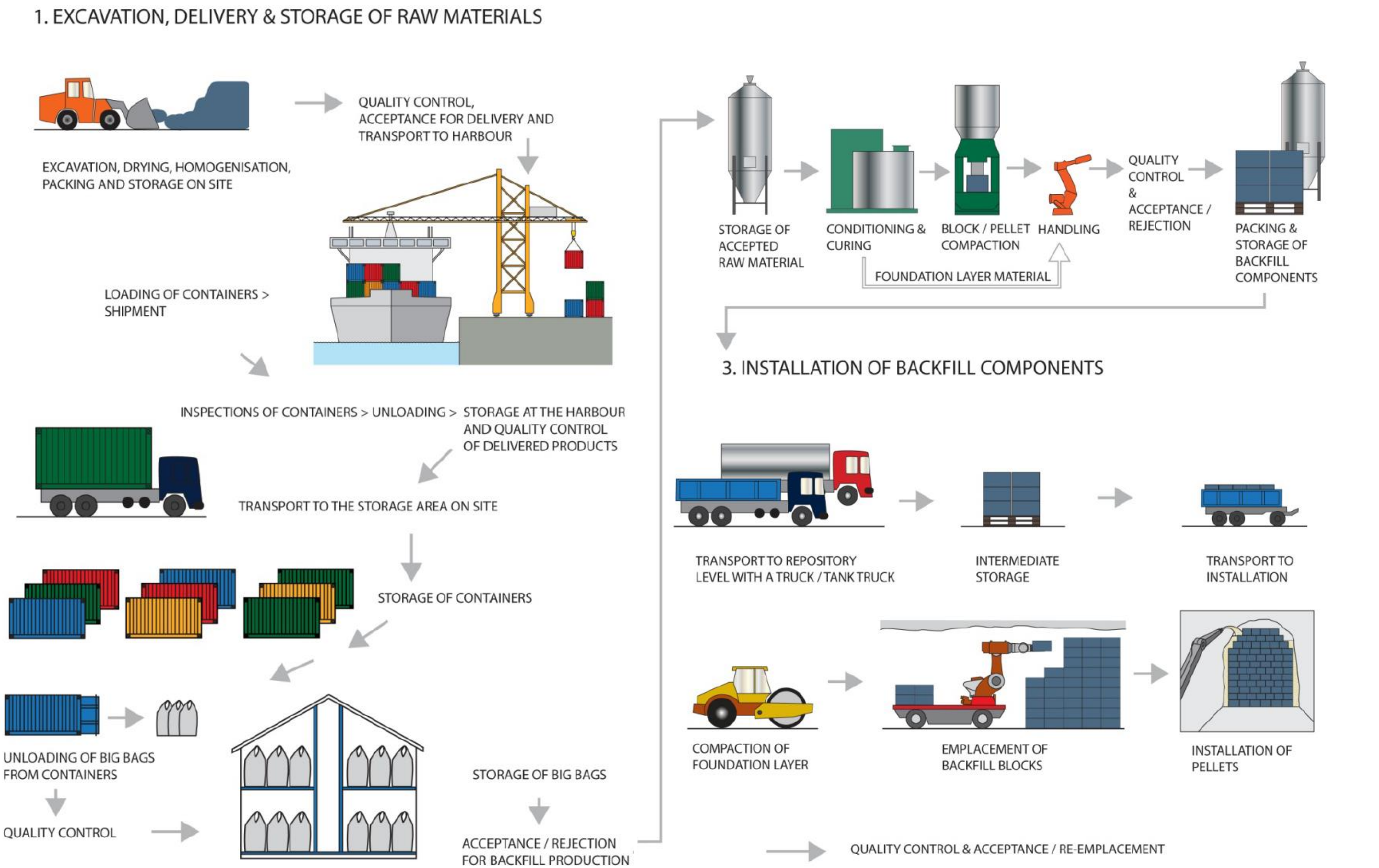
Backfill design and production

- Backfill concept is based on ”block concept” with pre-compacted backfill blocks and bentonite pellets (Reference POSIVA 2012-18)
- Backfill blocks provide high average dry density for the backfill
- Automated and remote emplacement with a robot
- Full-scale test in 2018 in ONKALO



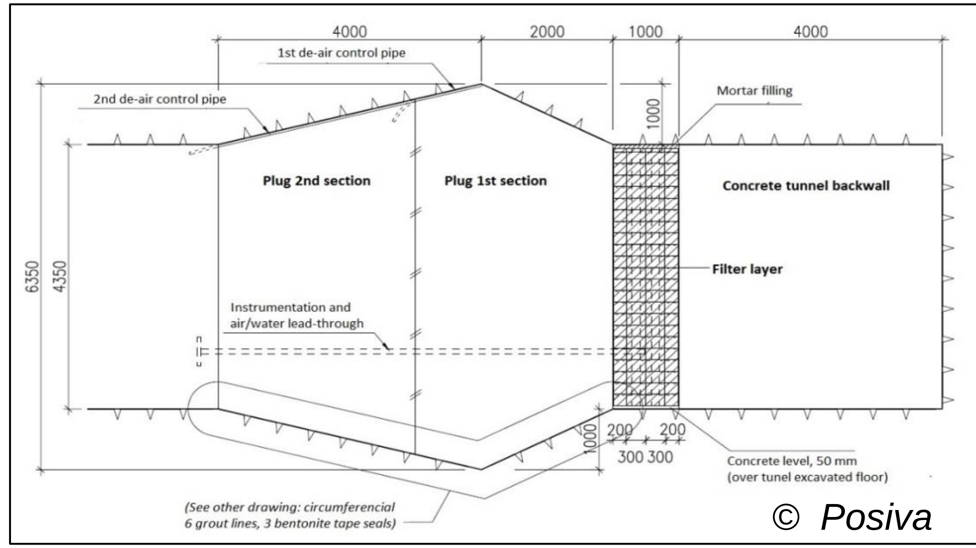
Source: Posiva Oy

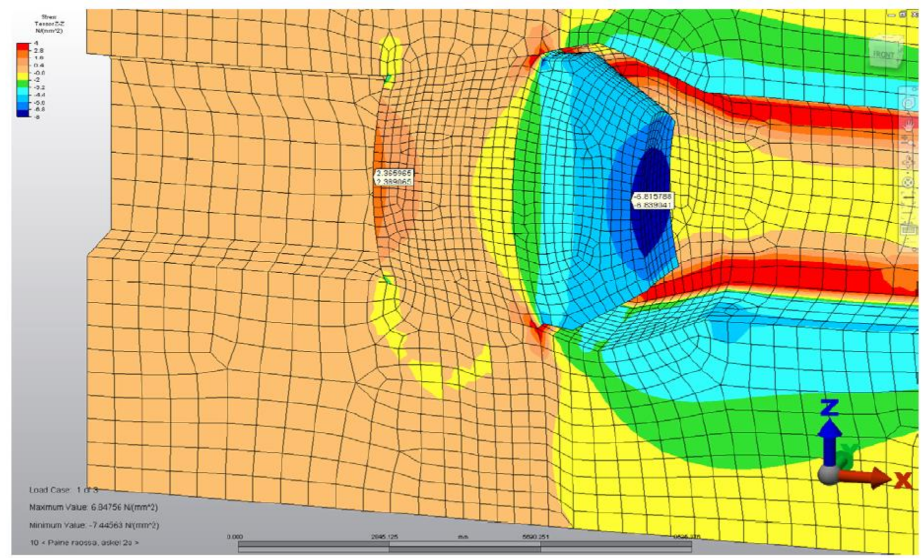
Backfill production process and quality control



Concrete plugs and seals

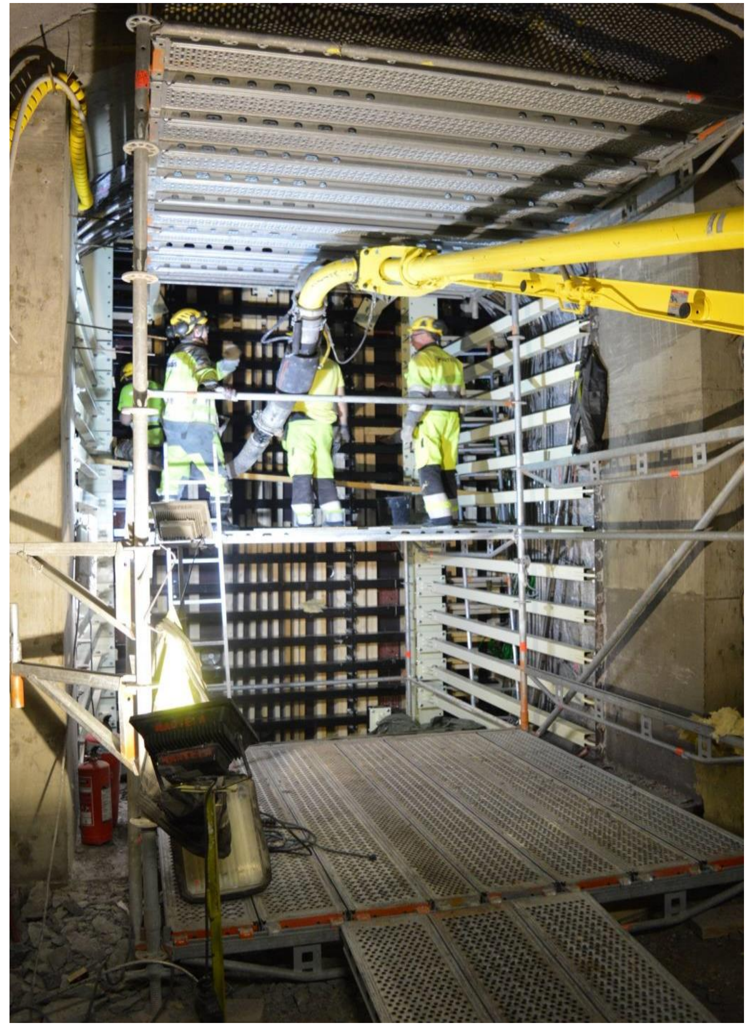
- Plug
  - assures hydraulic isolation for operation phase (100 years)
  - keeps backfill in-place
  - withstands swelling and hydrostatic pressure
- Concrete
  - low heat, minimal shrinkage, highly flowable (like self-compacting concrete)
  - local materials (including long-term safety, not jeopardizing site)
  - target pH leachate < 11 (Ca:Si ratios)
  - high durability in saline groundwater
- Rock
  - no continuous or water conducting fractures
  - minimal EDZ





Posiva’s Wedge Plug design (left) & water pressure simulations in FEM modeling (right)

Concrete production and quality control

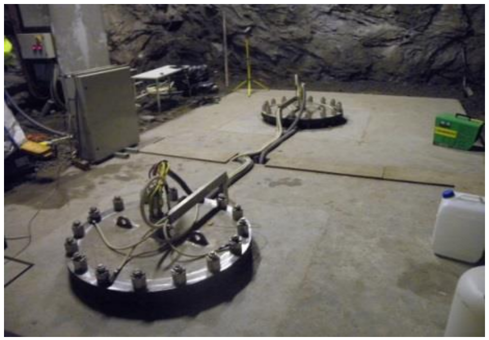


In-situ Demonstrations of EBS concepts and Monitoring of EBS performance

In-situ demonstrations of EBS concepts

- Demonstration tests in nuclear repository conditions are performed from small to full-scale
- The objective is
  - to obtain information about early phase processes in bentonite
  - to compare construction to design
  - to instrument experiments for data collection to be used in analysis and model development
  - to offer suitability tests for sensors, monitoring systems and other technical equipment
- In-situ tests provide information on the real-time interaction between buffer and backfill and other EBS components
- The outcomes of demonstration tests provide feedback to the design, safety requirements and operation of the repository

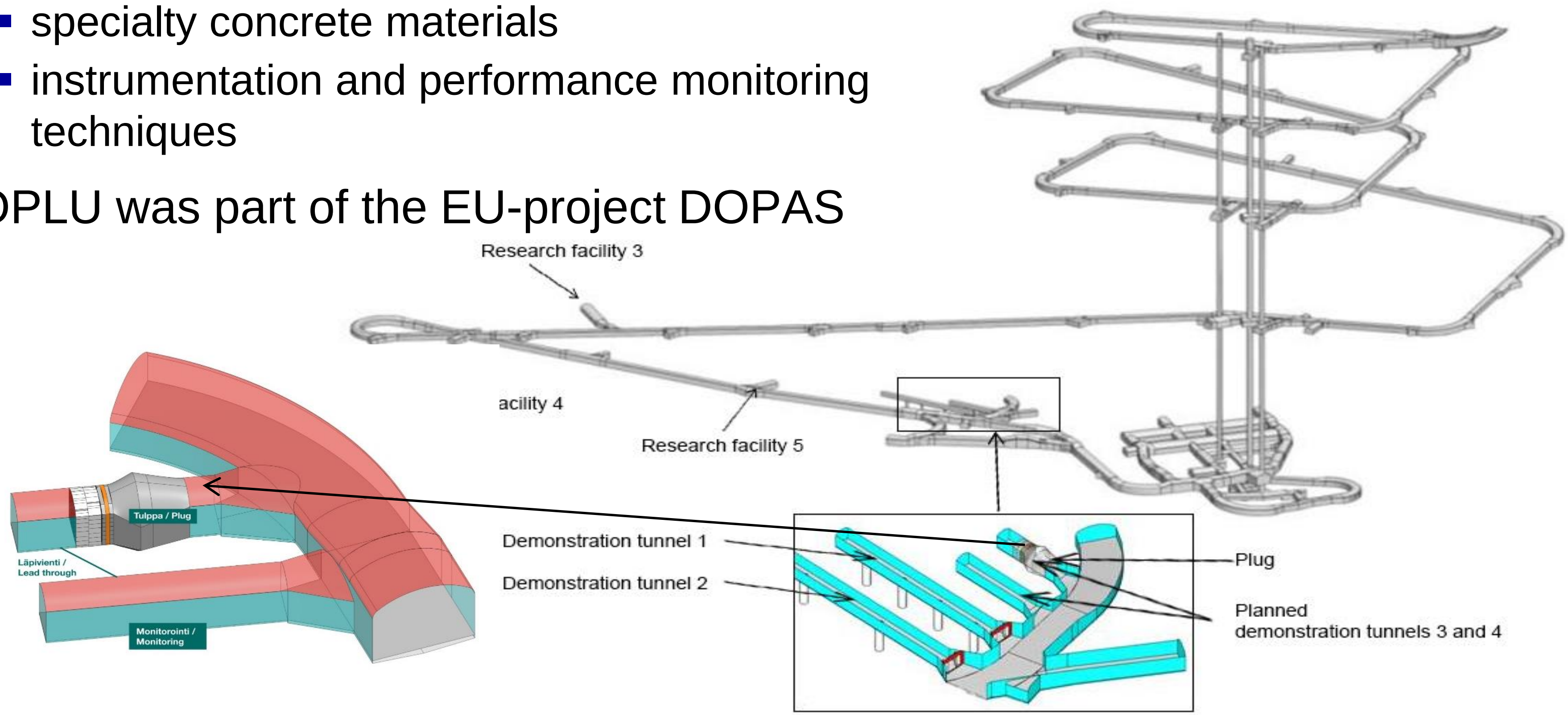
In-situ demonstrations of EBS concepts



POPLU project – tunnel end plug in ONKALO

- Posiva Oy together with VTT demonstrated the first full-scale construction and performance of EBS, with a deposition tunnel end plug (POPLU)
- The plug demonstration needed to develop
  - specialty concrete materials
  - instrumentation and performance monitoring techniques
- POPLU was part of the EU-project DOPAS

Source: DOPAS (© Posiva)

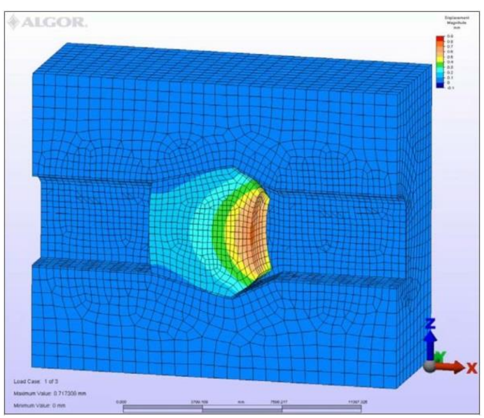


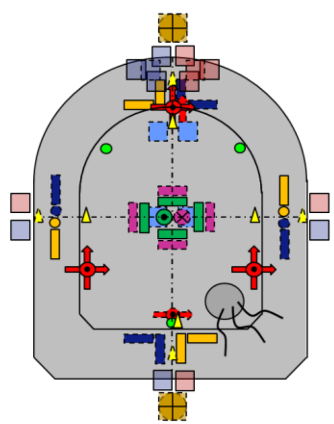
Background: EU-DOPAS Project Facts

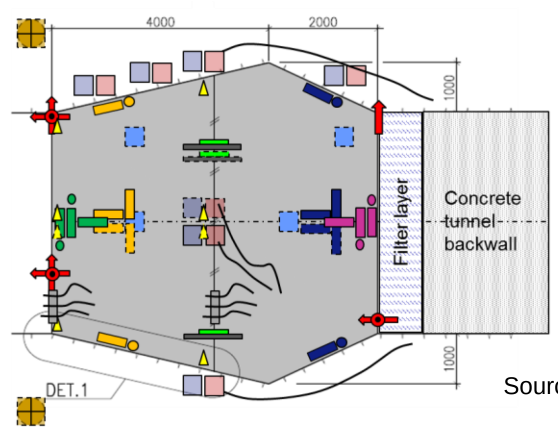
- Consortium of 14 Partners from 8 European countries, funded by EU FP7 Collaboration Program, Posiva Oy coordinator
- Duration: 4 years (September 2012 - August 2016)
- Total budget 15.8 M€, with EU contribution 8.7 M€
- Five sets of full-scale experiments, implemented in both under- or above-ground repository conditions
- See details at www.posiva.fi/en/dopas

POPLU monitoring system

- A monitoring system for a full-scale demonstration based on 131 sensors was installed to the deposition tunnel end plug within the POPLU project
- A pressurization system allows for applying a hydrostatic water pressure up to 10 MPa (100 bar) in a filter layer behind the plug
- A leakage measurement system quantifies any seepage at the plug and in the nearby surrounding at the front face at the plug
- Sensors inside and around the concrete plug were selected to measure continuously during
  - concrete casting and grouting (pressure, displacement)
  - hydration process (temperature, RH, pressure)
  - pressurization phase (displacements, strain, pressure, RH, temperature)

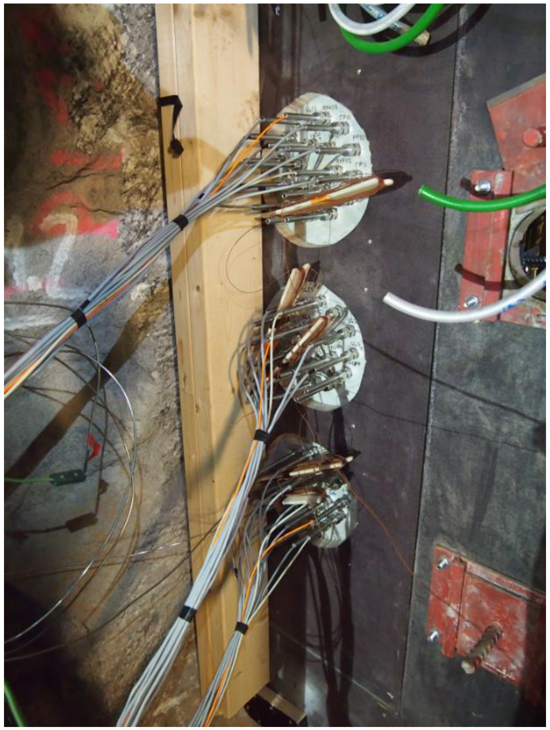


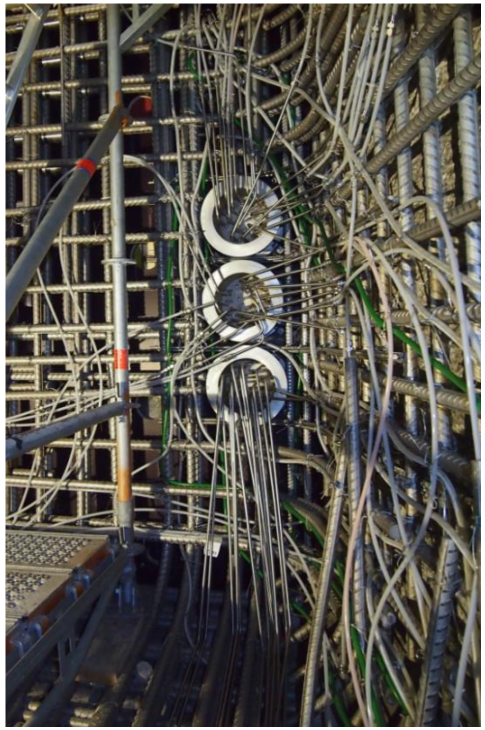




Source: DOPAS (© Posiva)

POPLU Sensor installation



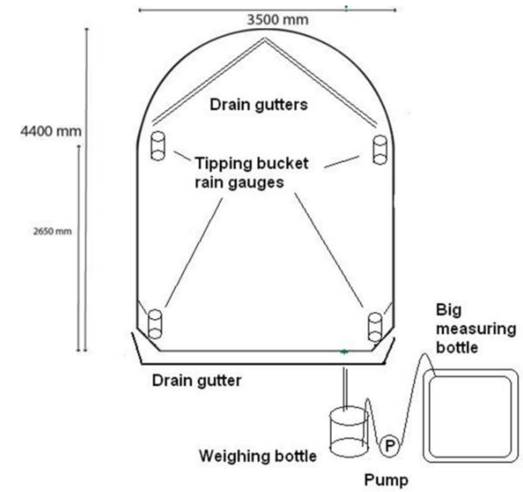


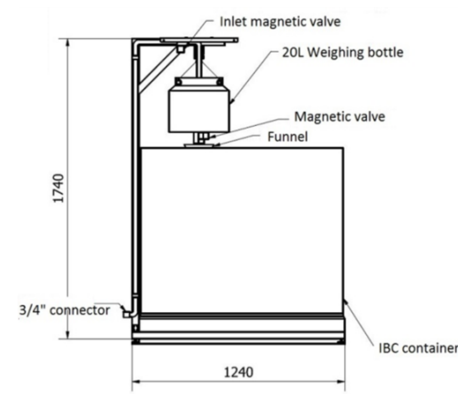
Three cable flanges, which carry in total 51 sensor wires, photographed from inside (left) and outside (right) plug section 2

PVDF and stainless steel tubes, directing the pressure sensor cables to the cable flanges towards the filter layer (right side) and plug section 2 (left side)

POPLU Leakage measurement system

Leakage measurement system at front face of plug during pressurization test

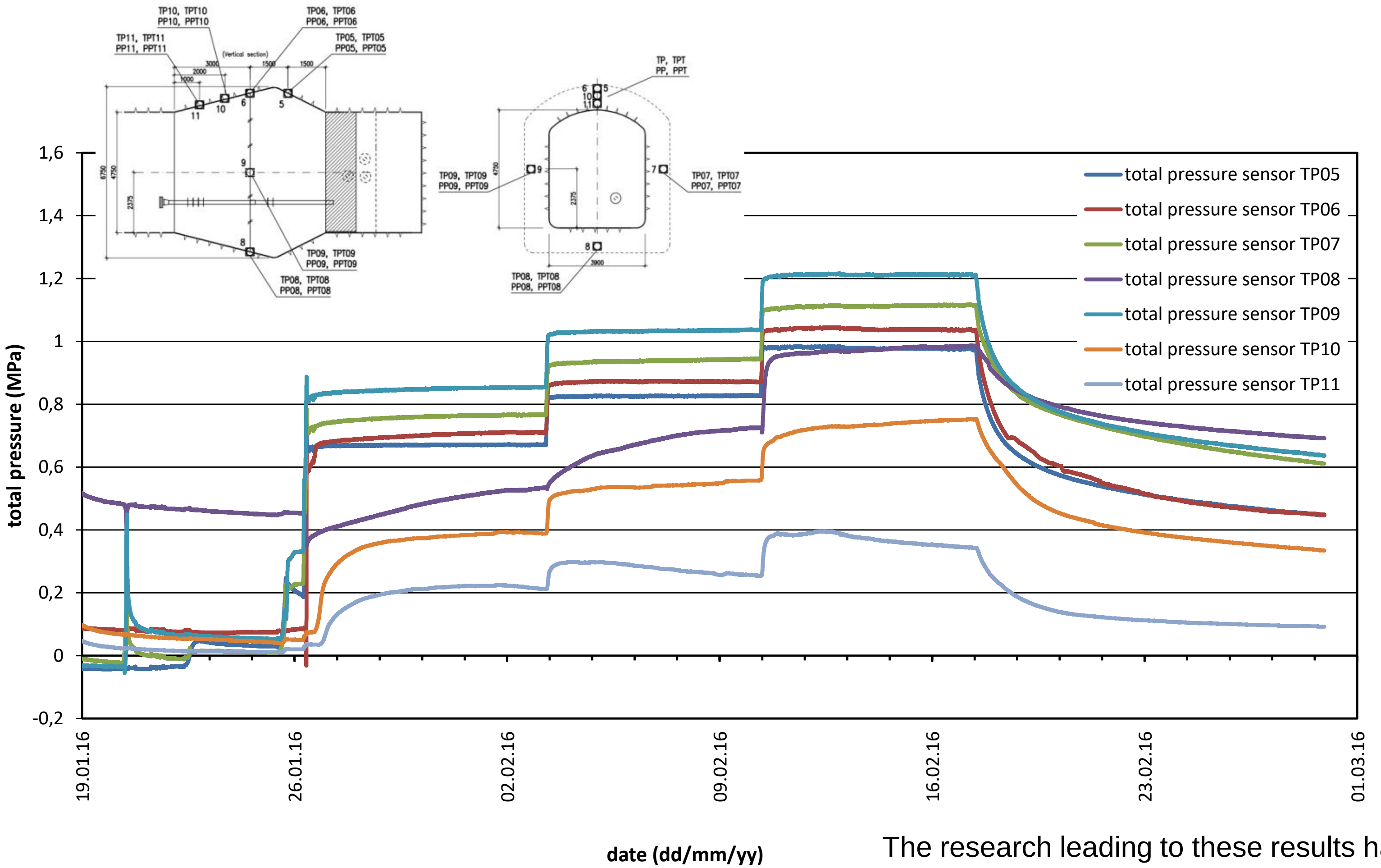




Schematic illustration of the design of the leakage measurement system. © VTT

POPLU instrumentation performance

- Example: Total pressure in plug area during initial phase of pressurization



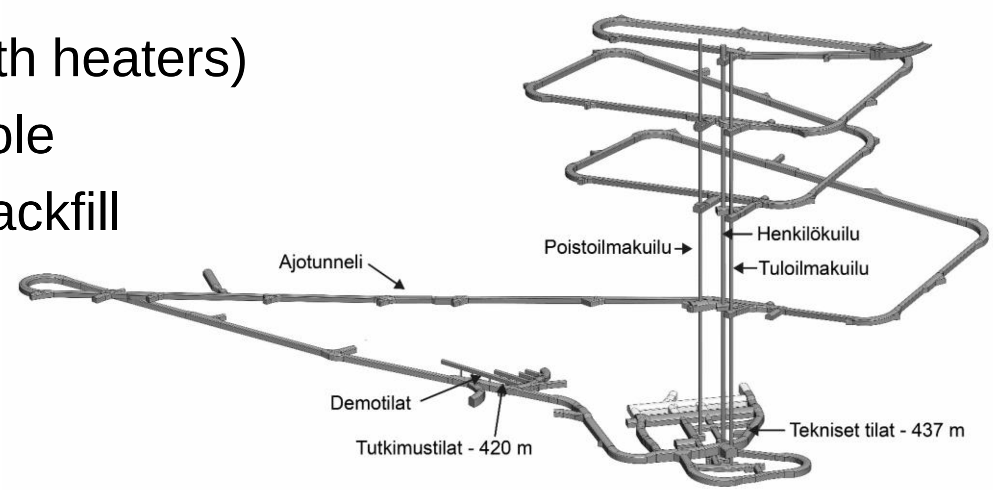
Response of total pressure sensors in plug area after start of pressurisation (pressure level in filter at 1.4 MPa)

The research leading to these results has received funding from the European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2007-2013, under Grant Agreement No. 323273 for the DOPAS project.

Posiva's new demonstration FISST

- Full Scale In-Situ System Test will be implemented in ONKALO^{TM} demonstration area -420m below surface
- Part of the stepwise propagation from component specific tests towards the joint operation demo
- Design, installation and early evolution of EBS system in crystalline host rock:
  - 2 deposition holes
  - 2 copper-cast iron canisters (with heaters)
  - buffer bentonite in deposition hole
  - 50 meter of deposition tunnel backfill
  - deposition tunnel plug
- Installation starts 2018

Source: Posiva Oy



Conclusions

R&D&I as joint effort

- Examples of recent VTT research financed by the EURATOM programme
  - MIND: Microbes In Nuclear waste Disposal (2015-2019) http://www.mind15.eu/
  - CEBAMA – Cement-based materials, properties, evolution, barrier functions (2015-2019), *http://www.cebama.eu/*
  - BEACON – Bentonite Mechanical Evolution (2017-2021), http://www.beacon-h2020.eu/
  - MODERN2020 – Development and Demonstration of monitoring strategies and technologies for geological disposal (2015-2019), *http://www.modern2020.eu/*
  - CAST: Carbon-14 Source Term (2013-2018), https://www.projectcast.eu/
  - DOPAS – Full-scale demonstration of plugs and seals (2012-2016), *http://www.posiva.fi/en/dopas*

Conclusions

- The Finnish final disposal of nuclear spent fuel is based on a system of multi-barriers, both natural and engineered
- Design, development, manufacturing and monitoring of the barriers is a successful approach which is based on scientific research, decision making, regulatory and implementer needs
- Technologies for a successful disposal exist and can often be transferred from other industries, like mining and construction. However, they need to be adapted and modified due to the long time scale and the high safety requirements
- Nuclear waste management in Finland is built on trust and transparency, which is a continuous process of communication between all stakeholders

Thank You!

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