Reflections on the use of monitoring technologies in geological nuclear waste repositories

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Presentation at GeoRepNet 2/RATE meeting
Nottingham, UK, 23rd & 24th of October 2014

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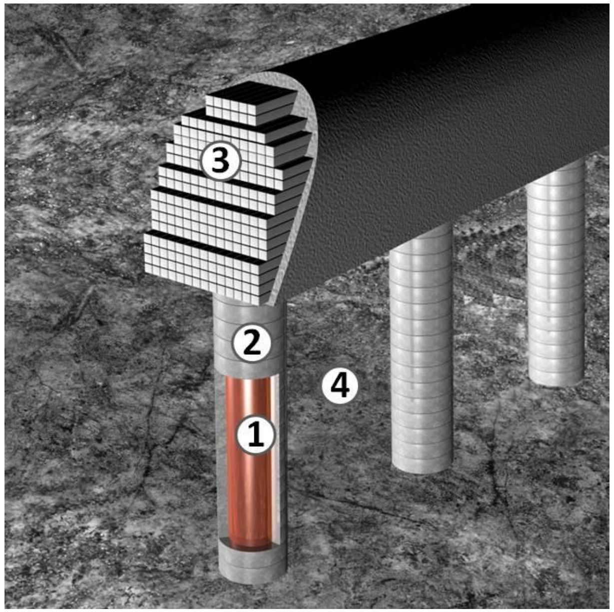
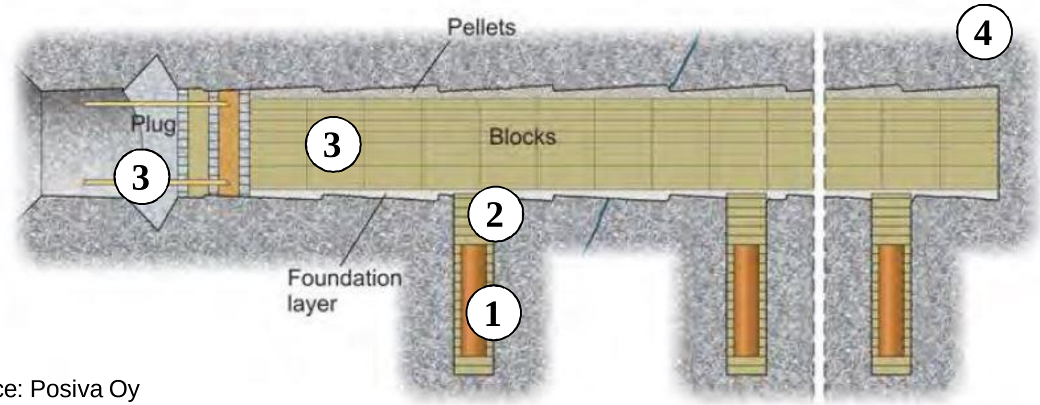
Final disposal of spent fuel in Finland

- Posiva Oy is an expert organisation responsible for the final disposal of spent nuclear fuel in Finland
- The final disposal is based on multiple release barriers, which ensure that the nuclear waste cannot be released into organic nature or become accessible to humans
- Posiva's disposal plans are based on the KBS-3 concept developed by SKB in Sweden



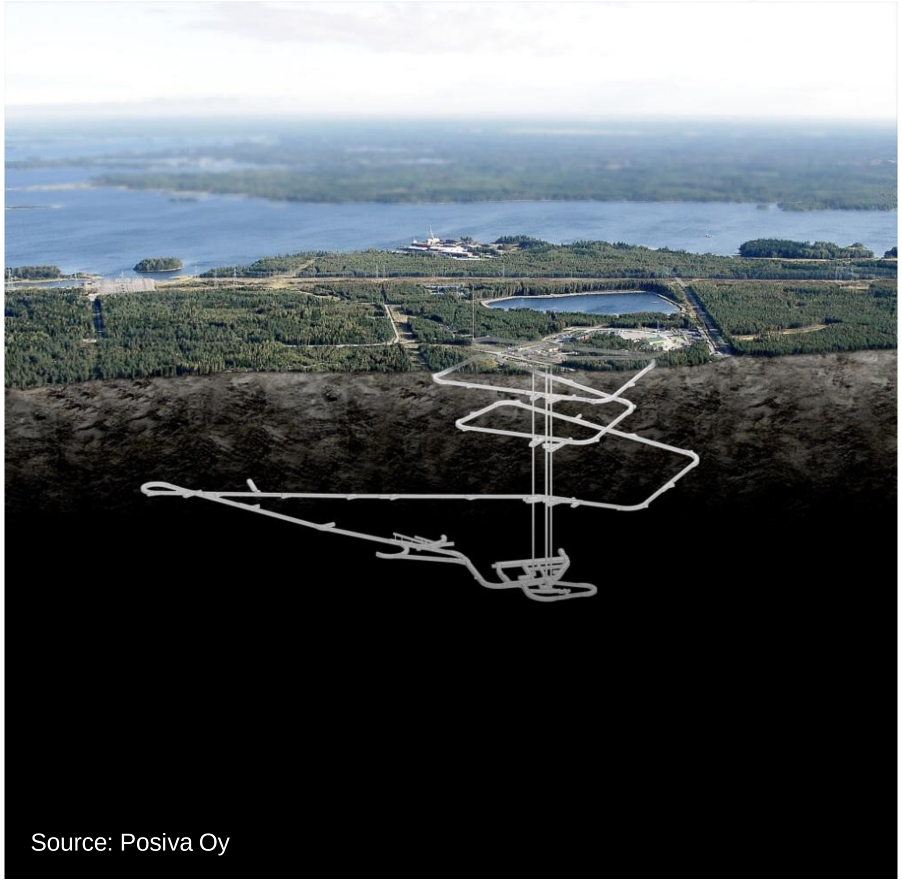
1. Final disposal canister
2. Bentonite buffer
3. Tunnel backfill (+ concrete plug)
4. Bedrock



Source: Posiva Oy

Project site

- The future final repository for spent fuel in Finland is located in the crystalline bedrock of Olkiluoto, an island in the Gulf of Bothnia
- ONKALO is Posiva's underground rock characterization facility. It is being used as an underground research laboratory (URL), but will serve as the future disposal site



Overall Monitoring

- Posiva Oy has established a monitoring program (OMO)
  - ensuring the applicability of the constructed facilities to the final disposal of nuclear waste
  - investigating short and long-term capacities of engineered barrier systems
  - providing confidence and feedback to the safety case
- Monitoring disciplines were identified
  - rock mechanics
  - hydrology
  - hydrogeochemistry
  - surface environment
  - foreign materials
  - engineered barrier systems (EBS)
- Long-term and operational monitoring is intended to be reduced to a minimum due to safety issues

Table 9-1. Potential targets of EBS monitoring.

Objectives						Process	Targets
1: Long-term safety (site)	2: Site characterisation and modelling	3: Environmental impact	4: Feedback for constructors and design	5: EBS performance	6. Compulsory radiological monitoring		
Canister (monitoring possible in a mock-up)							
				X		Radiogenic heat production	Surface temperature
				X		Deformation of the copper overpack	Radial and axial strain
Buffer and backfill							
				X		Heat transfer	Temperature
				X		Water uptake	Moisture in buffer
				X		Swelling	Swelling pressure and pore pressure
				X		Mass redistribution	Buffer displacement and uplift Canister displacement
				X		Chemical changes in pore water	in situ pH (and other possible) measurements
Auxiliary components							
				X		Degradation of plugs and seals	Plug integrity Temperature, moisture, pressure

- Short-term in-situ demonstrations offer suitability tests for sensors and monitoring systems

DOPAS Project

- DOPAS - Full-Scale Demonstration Of Plugs And Seals
- Consortium of 14 Partners from 8 European countries, funded by EC Euratom Collaboration Program, Posiva coordinator
- Duration: 4 years (Sept. 2012 - Aug. 2016)
- Total budget 15.8 M€, with EC contribution 8.7 M€
- Five full-scale experiments, implemented in under- or above-ground conditions
- Information can be used for planning of repositories as well as spent fuel disposal facilities

Source: ANDRA

POSIVA · nagra · ČVUT FSv · NRG · ÚJV · igd·tp safe solutions for radioactive waste · SÚRAO Správa úložišť radioaktivních odpadů Radioactive Waste Repository Authority · B+TECH · SKB Svensk Kärnbränslehantering AB

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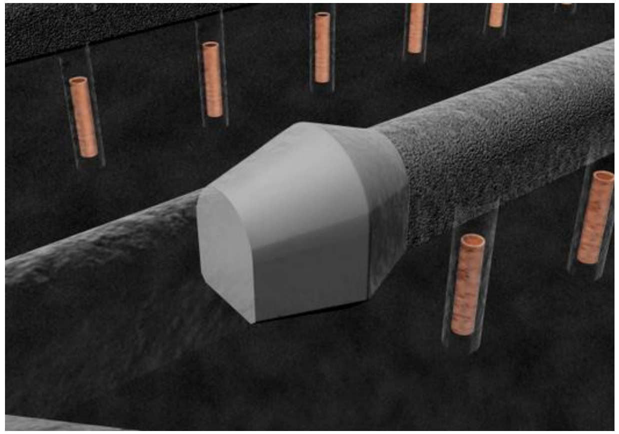
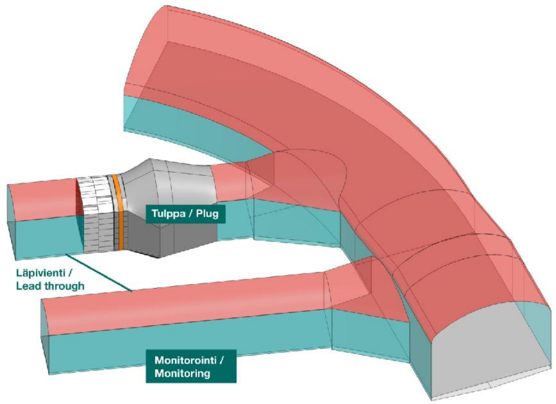
Objectives of DOPAS Experiments

- Establishing requirements on plugs and seals in different European countries based on a common view on the influences from national and general factors respectively
- Establishing a design basis for five different types of studied plugs and seals
- Developing designs for such plugs in tunnels and for various shaft seals
- Developing strategies for demonstration of design compliance with design basis
- Assessing performance of plug and seal systems and its implications on the overall safety for the whole reference period (1 Mio years)
- Nordic experiments (DOMPLU & POPLU): Evaluate two design alternatives

POPLU - tunnel end plug in ONKALO

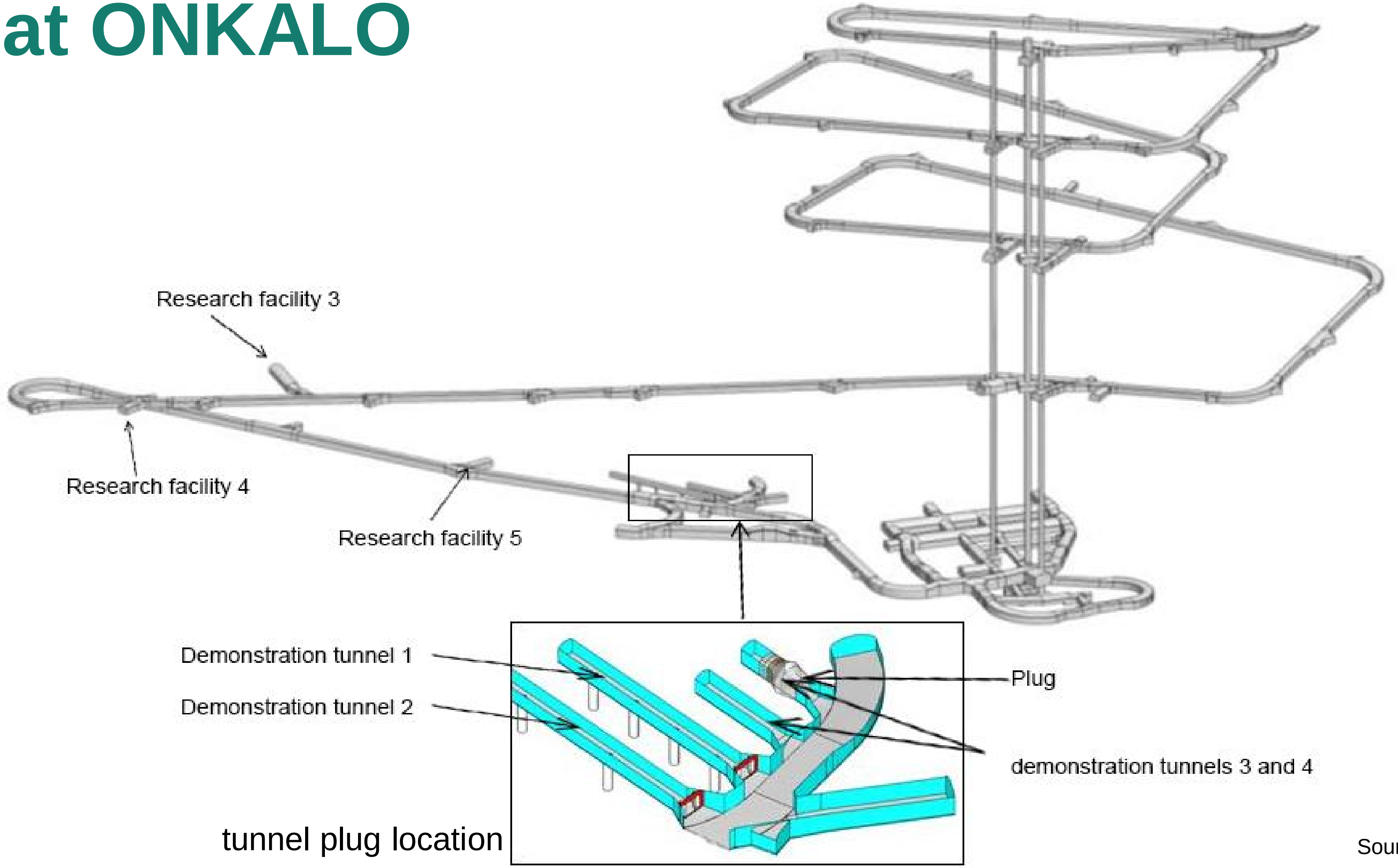
- Posiva Oy demonstrates the first full-scale construction and performance of EBS, with a deposition tunnel end plug (POPLU)
- POPLU is part of the EU-project DOPAS
- The plug demonstration provides the possibility to develop instrumentation and performance monitoring techniques





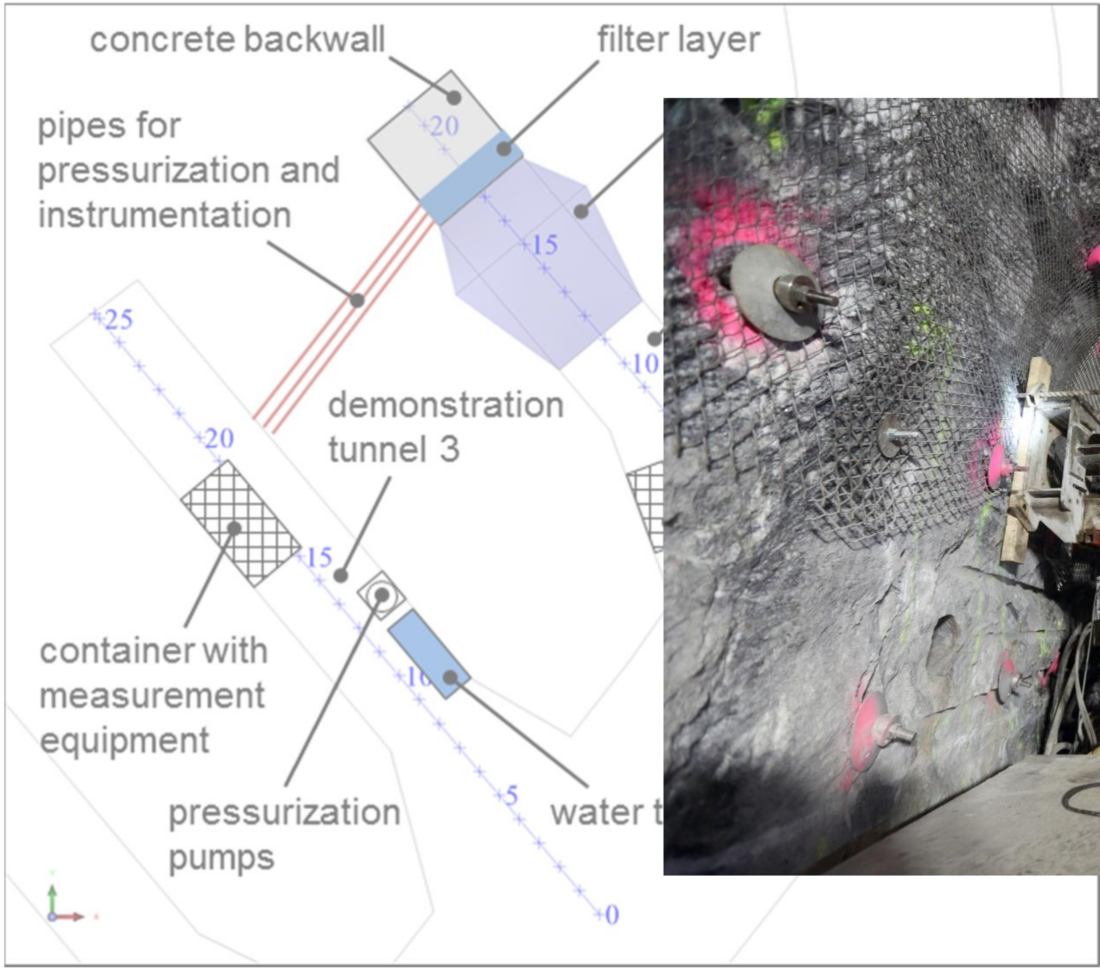
Source: DOPAS (© Posiva)

POPLU demonstration area at ONKALO



Source: Posiva Oy

Demonstration site



with concrete plug

Drilling of lead-through pipes

Source: Posiva Oy

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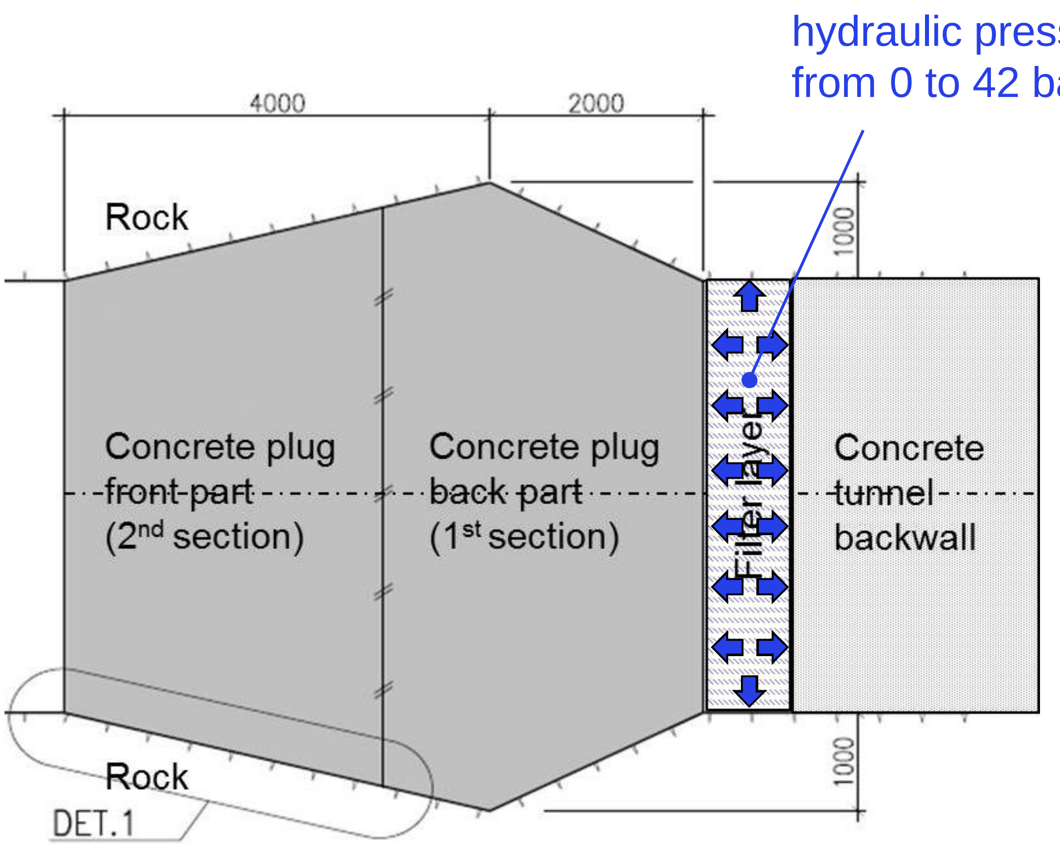
Tunnel end plug



Vertical section of Posiva's wedge plug
(dimensions in mm)

- structural design: wedge plug
- reinforced low pH concrete, casted in two parts (back & front)
- height 4.35 to 6.35 meters
  width 3.30 to 5.50 meters
  length 6.00 meters
- filter layer out of highly permeable concrete blocks
- concrete tunnel backwall
- concrete-rock interface sealed with injection grout and circumferential bentonite belts

POPLU monitoring requirements

- A monitoring system for a full-scale demonstration is installed to the deposition tunnel end plug
- Sensors measure continuously displacements, strains, humidity, total and pore pressure and temperature
- A pressurization system allows for applying a hydrostatic water pressure up to about 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

Requirements for instrumentation equipment in POPLU

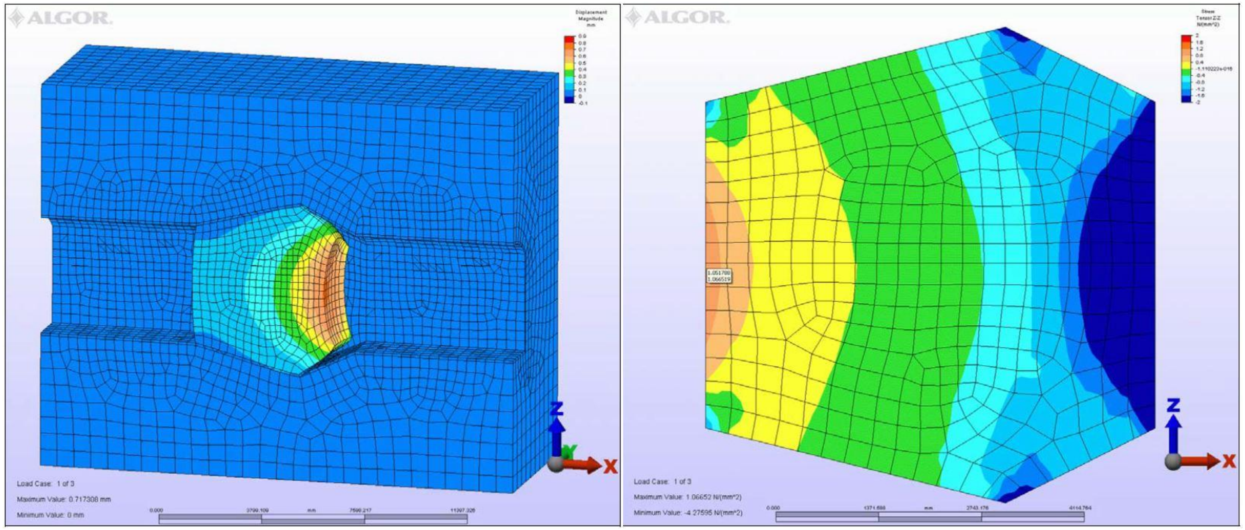
All sensors and wires should be durable and robust to permanently operate without maintenance in a demanding environment:

- Corrosive environment for sensors and wires
  - inside tunnels RH close to 100 %, constant temperature 12 °C
  - inside concrete max temperature during hydration approx. 50 °C
  - pH < 12 due to low pH concrete (blend of cement, silica fume and fly ash)
  - presence of chloride and sulfate ions in groundwater
- Water pressure up to 4.2 MPa (42 bar) (earlier 10 MPa, 100 bar)
- Test duration expected about 5 years

Plug sensors

Sensors inside and around the concrete plug are selected to measure during

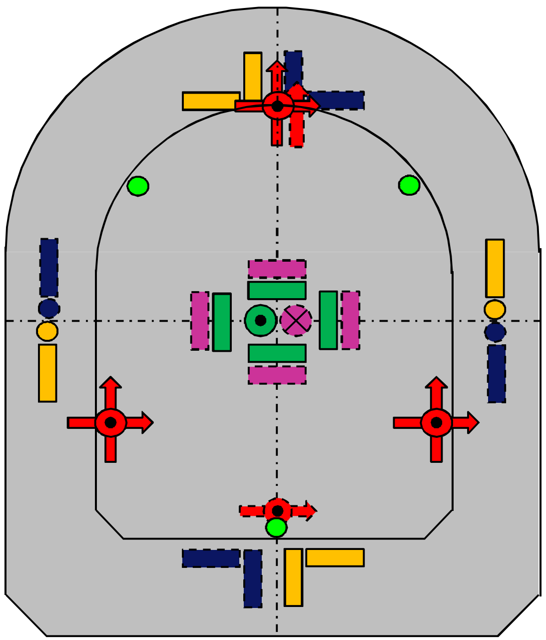
- concrete casting and grouting (pressure, displacement)
- hydration process (temperature, relative humidity, pressure)
- pressurization phase (displacements, strain, pressure, relative humidity, temperature)

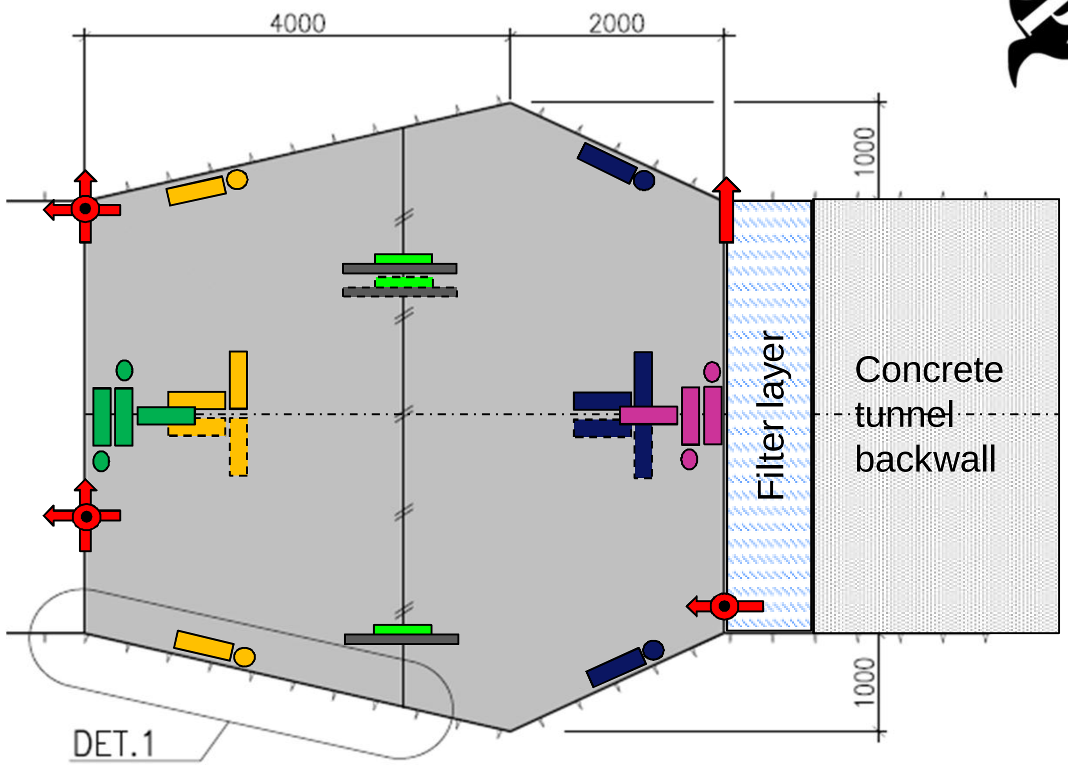


Displacements (left) and principal stresses (right) in vertical direction due to hydraulic pressure on the back face of the plug

Source: Finnmap Consulting Oy

Displacement sensors and strain gauges



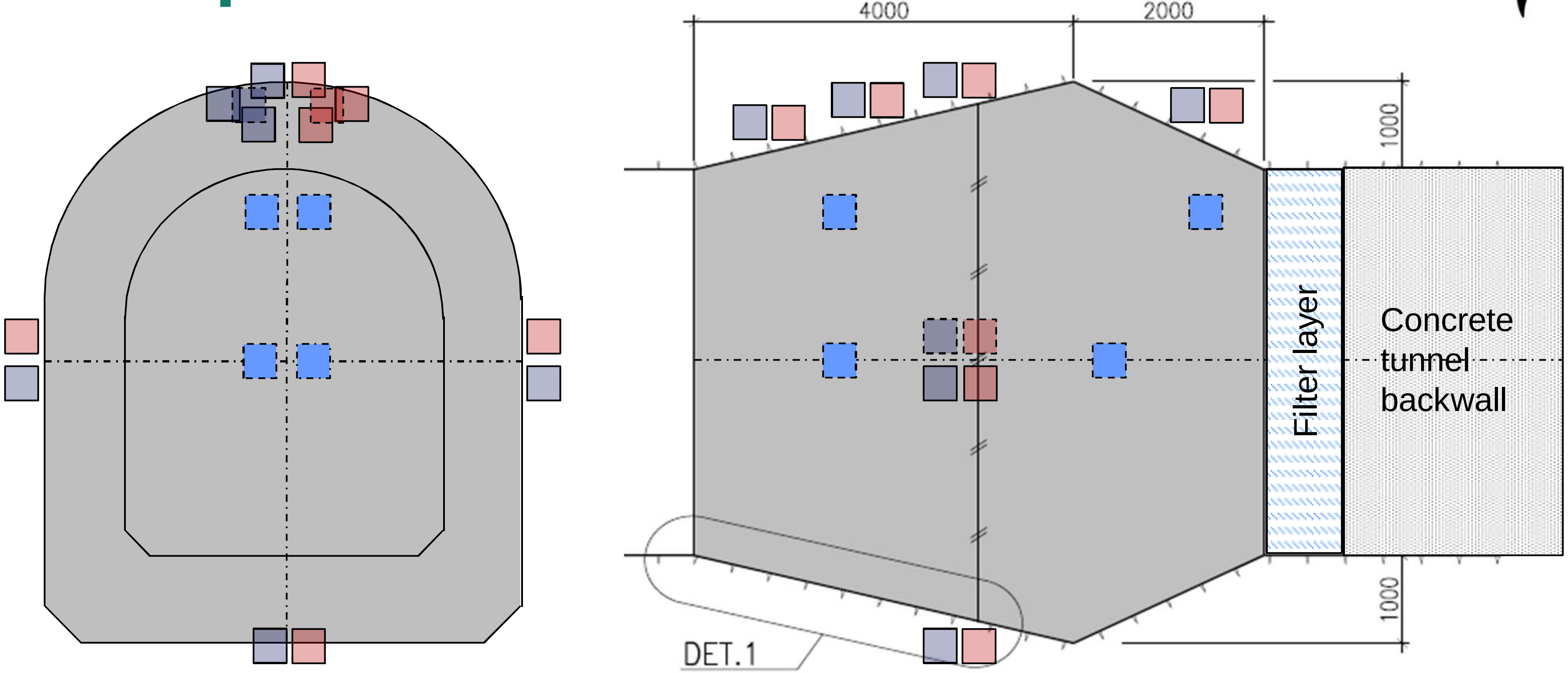


Strain gauges:
- vertical rebars, include temperature measurements (2 pc.)
- vertical rebars (6 pc.)
- inclined rebars, include temperature measurements (4 pc.)
- horizontal rebars (14 pc.)

Strain gauges connection rebars, include temperature measurement (3 pc.)

Displacement sensors (12 pc.)

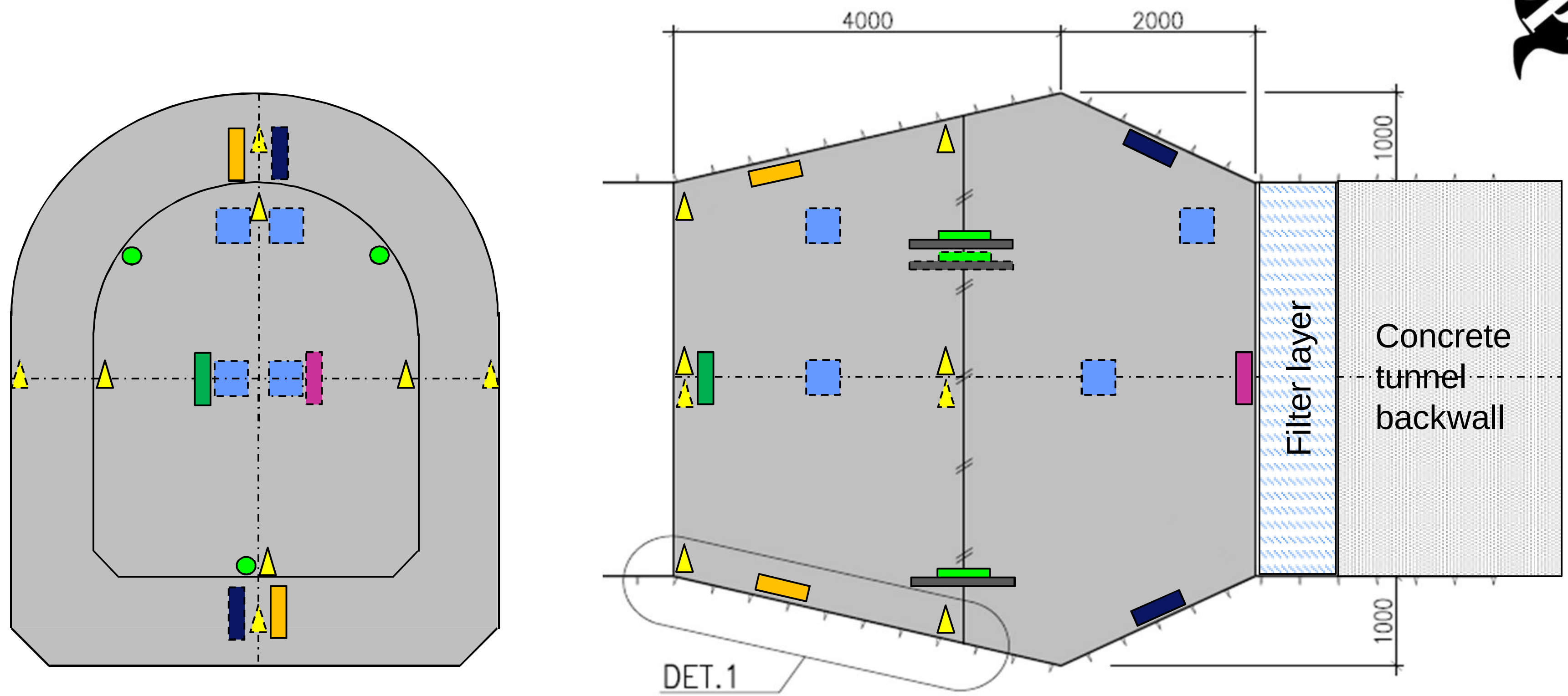
Relative humidity sensors, pore and total pressure sensors



Relative humidity sensors, concrete (4 pc.)
(include temperature measurements)

Pore pressure and total pressure sensors
in gap (7 pc. + 7 pc.)

Temperature sensors



Temperature sensors (8 pc.)

Relative humidity sensors, concrete (4 pc.)
(include temperature measurements)

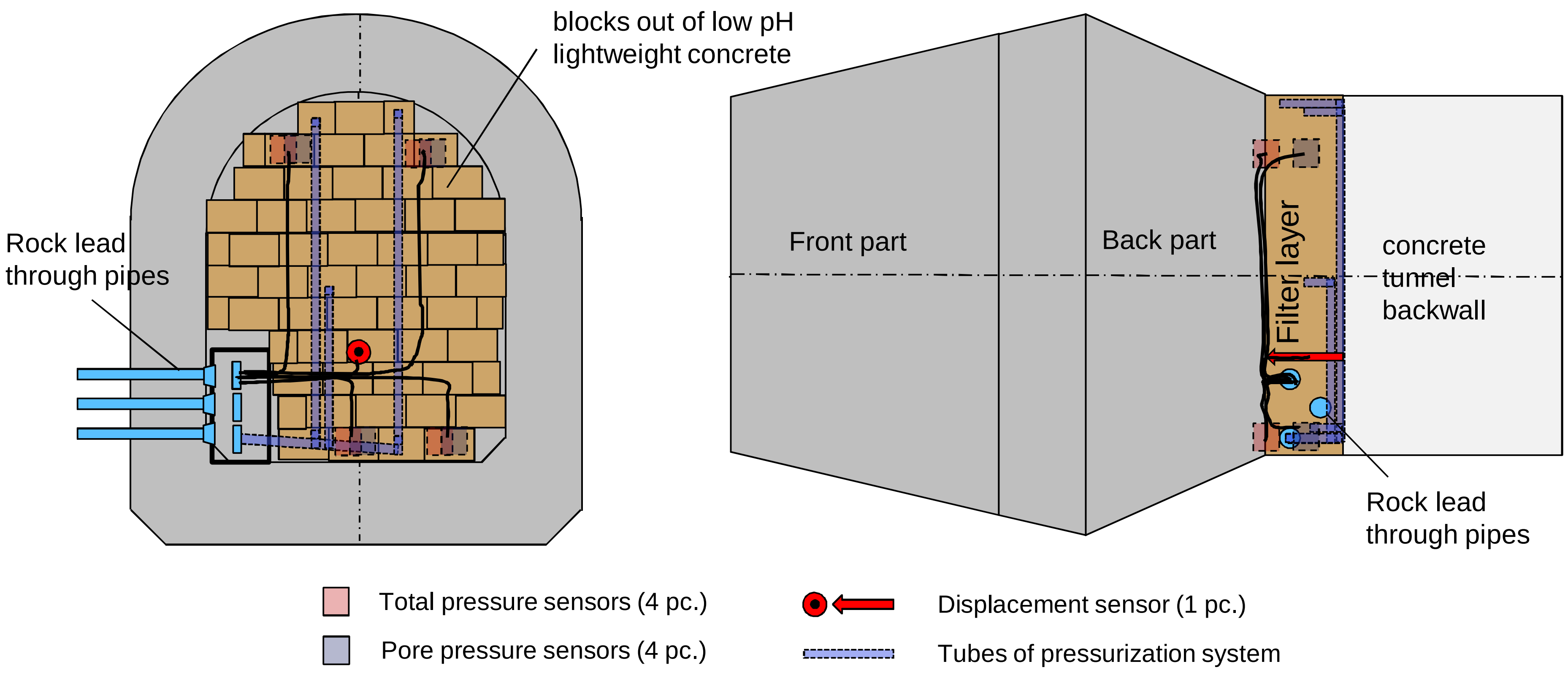
Strain gauges:
- vertical rebars, include temperature measurements (2 pc.)
- inclined rebars, include temperature measurements (4 pc.)

Strain gauges connection rebars, include temperature measurement (3 pc.)

Filter layer sensors

Sensors behind the plug inside the filter layer are selected to provide information about

- water distribution inside layer
- magnitude of pressure
- potential movements (displacements) of the plug due to pressure changes



Pressurizing system

will supply high water pressure to investigate the sealing performance of the wedge plug

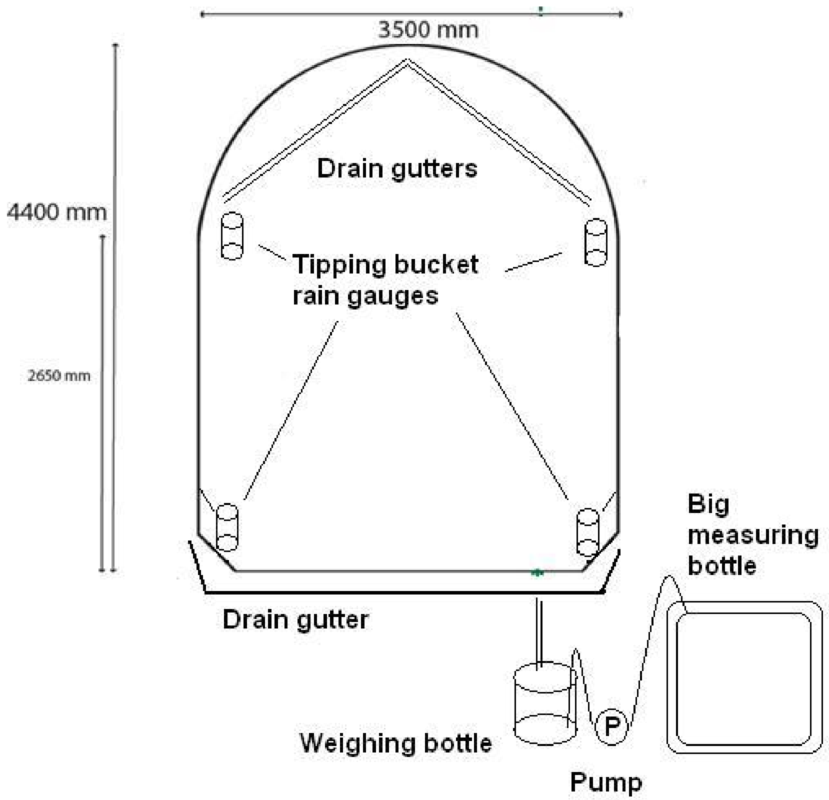
Its design is based on a high redundancy:

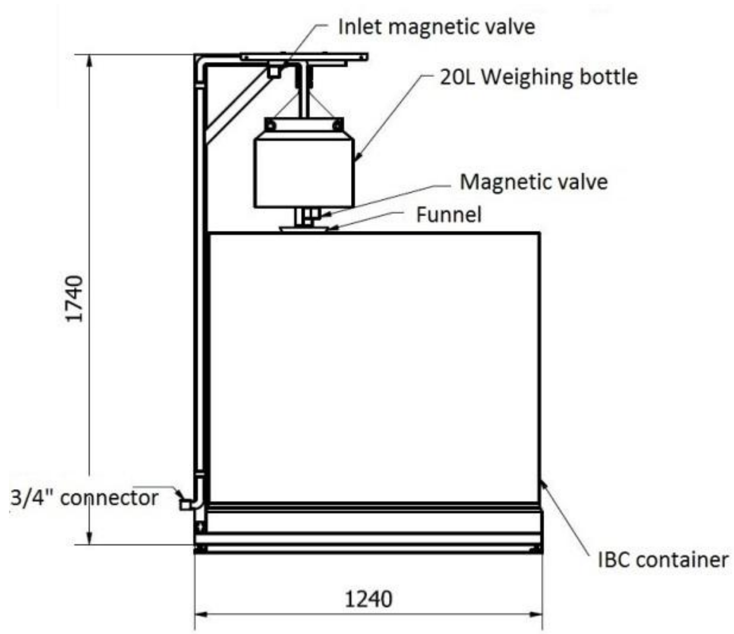
- two high pressure piston pumps
- two unloader valves
- two electrical motors with gearing box
- thyristors with automation and control units
- water tank

Source: VTT

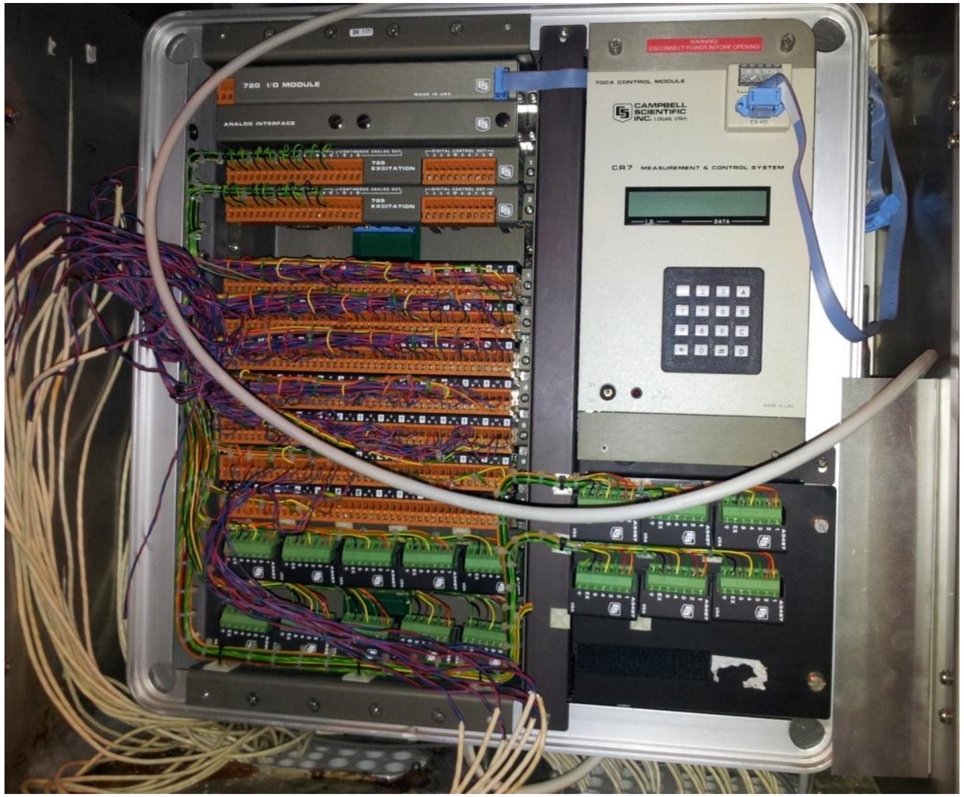
Water leakage measurement system

to measure seepage coming through concrete plug or through the gap between plug and rock



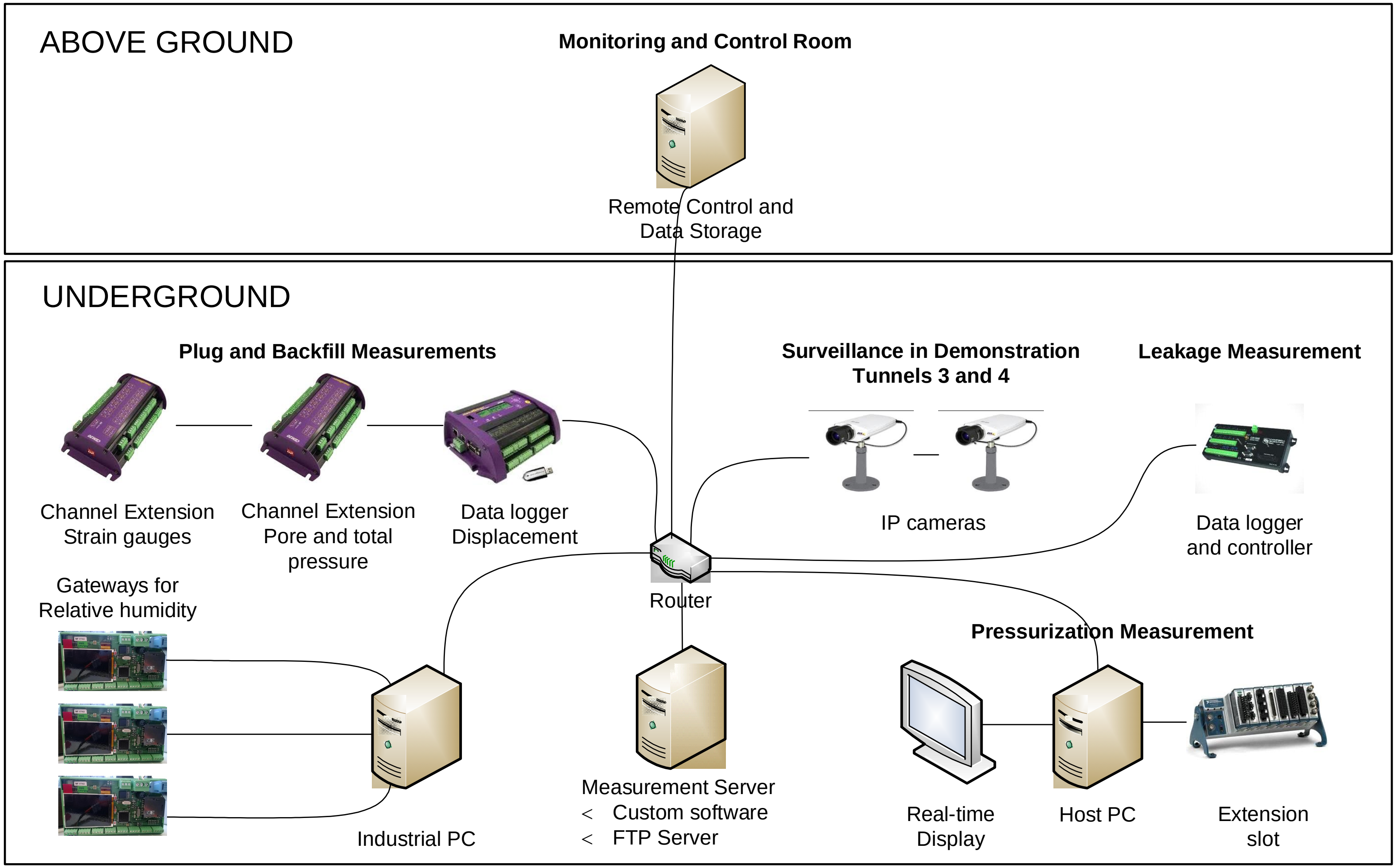


Wiring of plug and filter layer sensors



Source: SKB

Data collection equipment



Future outlooks - wireless systems

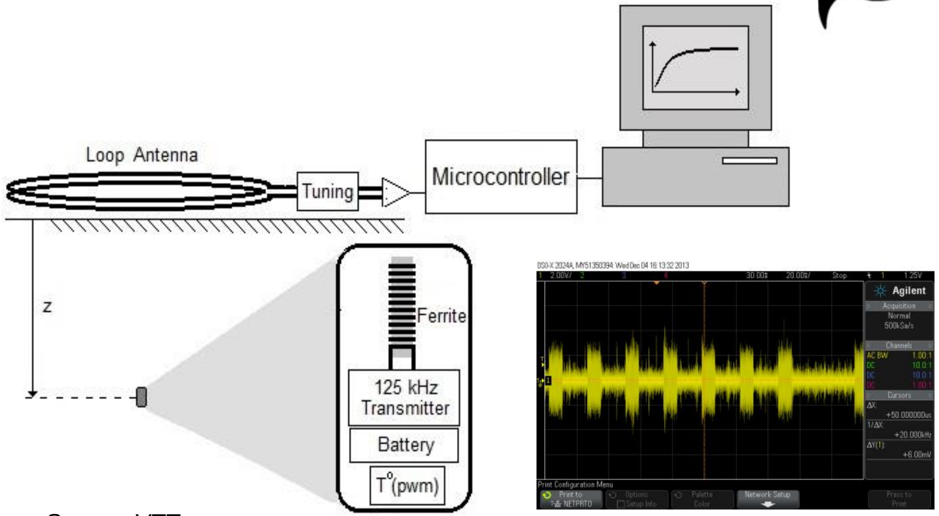
- Concern
  - Classical wired sensors are widely used, but cables could affect the behaviour of the engineered barriers and carry a risk for leakage
- Goal
  - Use of wireless systems with self-sufficient energy supply for monitoring
- Challenge
  - Conditions for signal transmission are extremely demanding
  - Systems need to be tailored and designed for application
  - Development of long-lasting energy harvesting systems is needed
- Solution
  - Integration of wireless systems into the repository design

Principle of wireless transmission through dense media

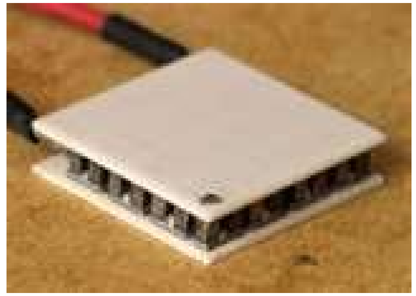
- Challenge
  - Signal attenuation increases with distance and presence of conductive materials like water, concrete, rock, bentonite, etc.
  - Attenuation increases rapidly with increasing signal frequency
  - Large dependency of energy use on transmission distance
- Solution
  - Low-frequency electromagnetic fields in range from 3 Hz to 135 kHz make medium/long-range wireless transmission through dense materials possible
  - Wireless data transfer is based on magnetic coupling in the near field since magnetic wave attenuation is less strong
  - Large loop antennas are used for signal receiving

Design of wireless system for harsh environments

- Solution by VTT
  - Magnetic coupling between transmitter and receiver antennas (near field)
  - Ferrite antenna
  - 125 kHz band used in RFID – readily available components
  - Connection of specific sensors for e.g. temperature or pressure measurements
  - Waterproof casing
  - Energy transmission or harvesting



Source: VTT



Source: www.marlow.com

Conclusions

- Final disposal of spent nuclear fuel in geological repositories of Finland and Sweden is based on the use of multiple release barriers
- Monitoring of the repository
  - helps to evaluate the behaviour of components of the repository system
  - builds confidence in construction, operation and the long-term safety
  - provides information for decision making
- A monitoring system has been developed to observed and evaluate performance and safety of the tunnel end plug (POPLU)
- The POPLU project helps to identify the trigger values for evaluating EBS performance, especially water tightness
- Results obtained by instrumentation and monitoring of the demonstration are essential for design development and performance verification of safe plugs and seals

Thank You to the Audience and the DOPAS Consortium!

http://www.posiva.fi/dopas

The research leading to these results has received funding from the European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2011-2013, under Grant Agreement No. 323273 for the DOPAS project.