DOPAS

DOPAS
Training Workshop 2015

Plugs as a Part of the Demonstration Programmes in Nordic Countries

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16th September 2015

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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

Radioactive Waste Management DOPAS VTT GRS EURATOM Galson Sciences Ltd DBE TEC DBE TECHNOLOGY GmbH ANDRA

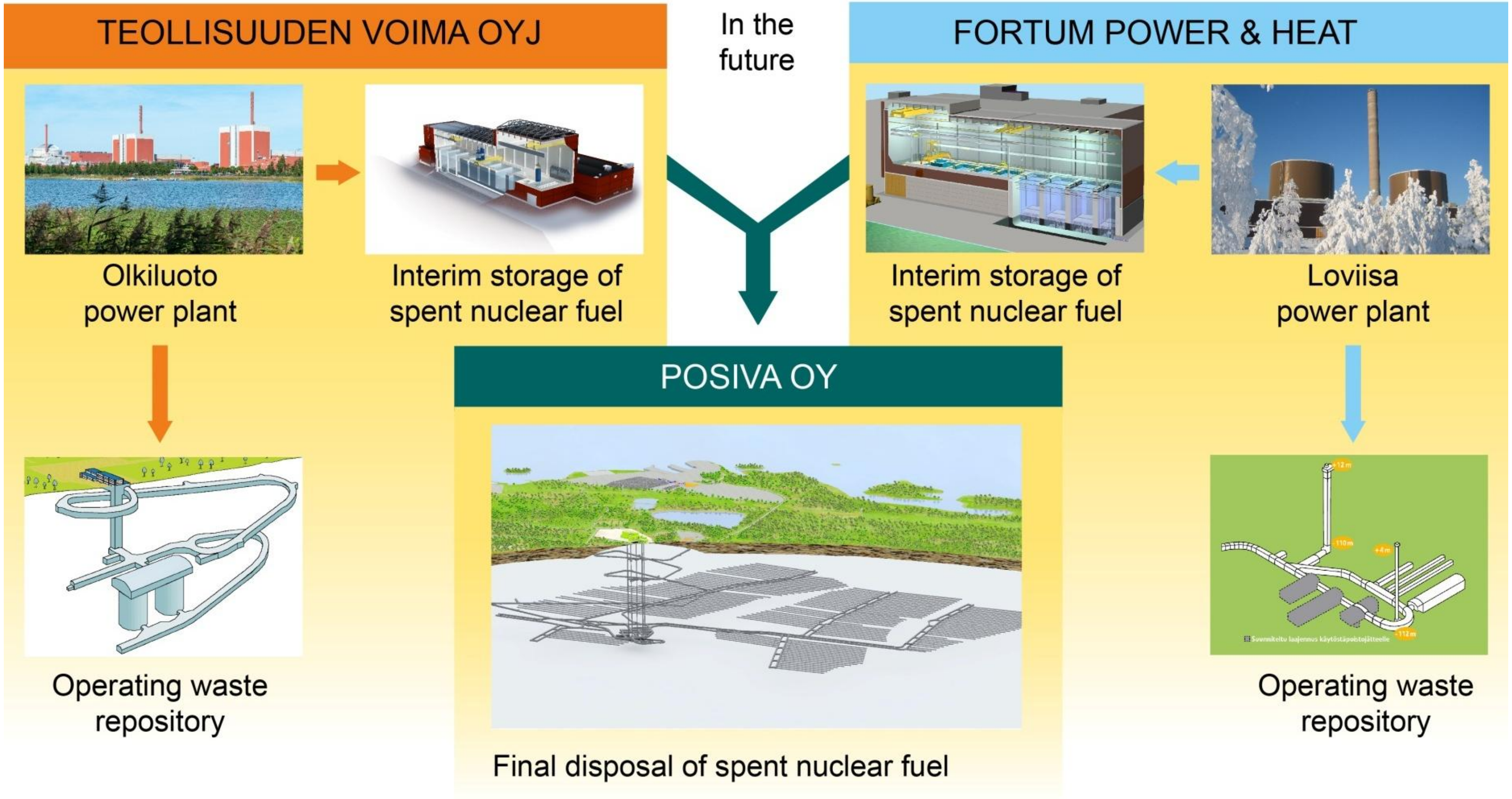
Outline of the Lecture

- **Nuclear Waste Management in Finland**
- **Nuclear Waste Management Programme**
- **Concept Development Programme**
- **Safety Functions of the Closure of Deposition Tunnels**
- **Requirements for the Deposition Tunnel End Plug**
- **Previous Full-Scale Plug Tests**
- **Current Plug Designs; Two different designs**
- **Experimental Design**
- **Forthcoming Development Work and Roadmap to Operation**

Nuclear Waste Management in Finland

- **According to the Nuclear Energy Act, all nuclear waste generated in Finland must be handled, stored and permanently disposed of in Finland**
- **Nuclear waste is not allowed to be exported or imported**
- **As producers of nuclear waste, Teollisuuden Voima Oyj (TVO) and Fortum Power and Heat Oy (Fortum) are responsible for implementing the management of nuclear waste**
- **The disposal of spent fuel from Olkiluoto and Loviisa nuclear power plants is implemented by Posiva Oy established by TVO and Fortum in 1995**

Nuclear Waste Management in Finland



Nuclear Waste Management Programme

- **The Ministry of Employment and the Economy (abbreviated as TEM in Finnish) decides on the principles to be followed in nuclear waste management in Finland**
- **The legislation provides that the parties with the nuclear waste management obligation must provide the ministry with regular reports on how they have planned to implement the measures included in nuclear waste management and their preparations**
- **Up to 2008, these reports were submitted to the ministry annually**
- **Since 2009, the reports have been submitted at three-year intervals, and it must describe in detail the measures for the next three-year period and also present an outline of the plans for the subsequent three-year period (3+3)**
- **TVO and Fortum as producers of nuclear waste are responsible for producing the report, but they have given the task to Posiva**

Nuclear Waste Management Programme

- **In addition to the annual nuclear waste management reports, the parties with the nuclear waste management obligation have been preparing three-year plans for nuclear waste management in Olkiluoto and Loviisa since 2003**
- **The plans (TKS-2003, TKS-2006 and TKS-2009) have included the plans for future research, development and planning work, as well as an assessment of the status of nuclear waste management, in particular with respect to the preparations for final disposal of spent nuclear fuel**
- **Nuclear Waste Management Programme YJH-2012 was the first overall plan to combine the reporting, containing**
  - **low and intermediate waste repositories**
  - **interim storage of spent nuclear fuel**
  - **final disposal of spent nuclear fuel**
  - **planning of decommissioning**

Nuclear Waste Management Programme

YJH-2012

Nuclear Waste Management
at Olkiluoto and Loviisa Power Plants:
Review of Current Status and Future Plans for 2013-2015

Posiva Oy

May 2013

- **YJH-2012 can be found from Posiva's website**
- **http://www.posiva.fi/en/databank/publications/nuclear_waste_management_plans_and_annual_reports_(yjh_reports)**

- **YJH-2015 programme is currently under preparation to describe in detail the measures to be taken from 2016 to 2018 (update: available)**
- **The programme was delivered to TEM by the end of September 2015**

SKB's FUD Programme – Research, Technology and Review

Fud-program 2010

Program för forskning, utveckling och demonstration av metoder för hantering och slutförvaring av kärnavfall

September 2010

Svensk Kärnbränslehantering AB
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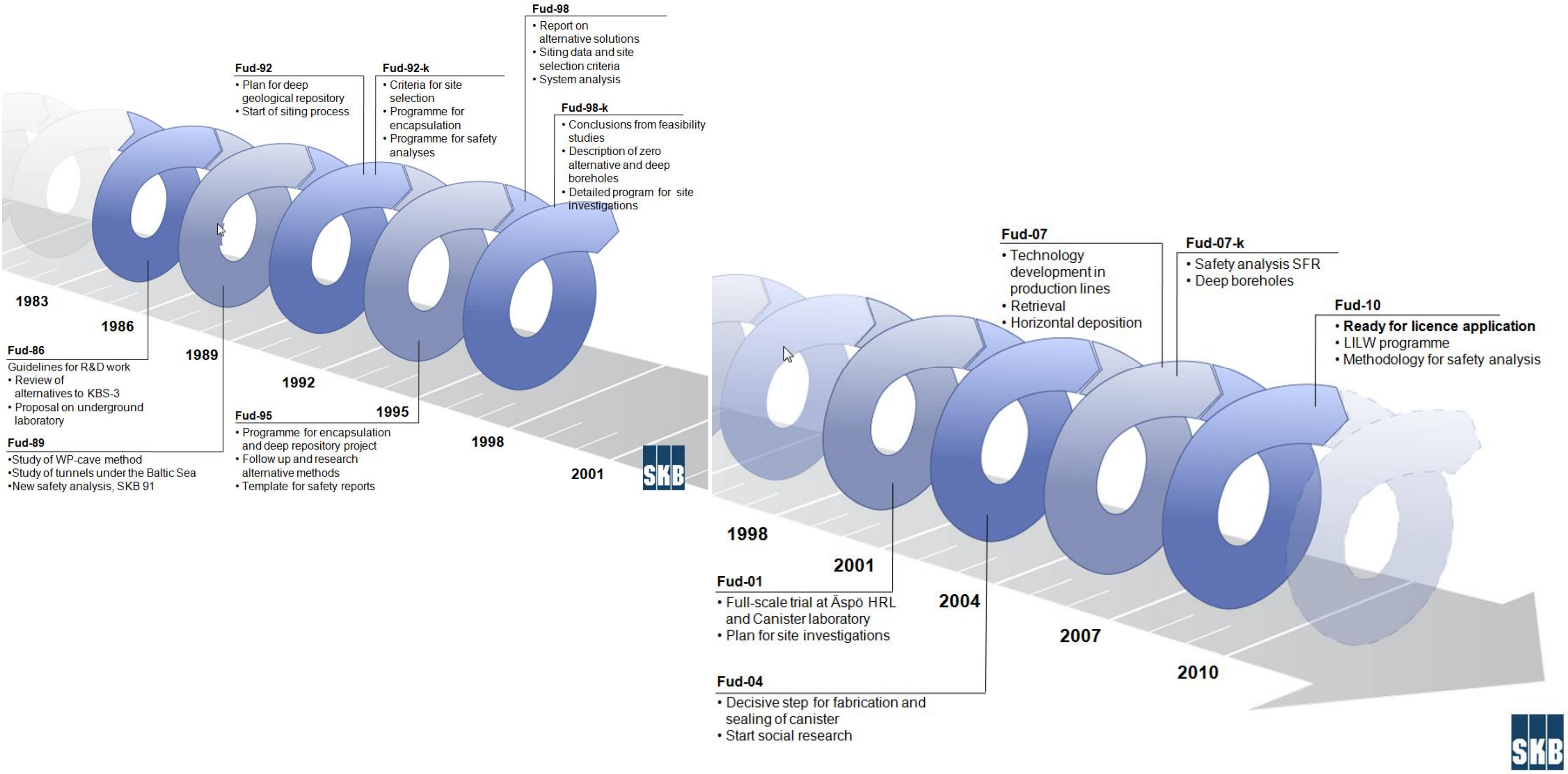
Research cooperation

Technology development and full scale tests

Regularly review

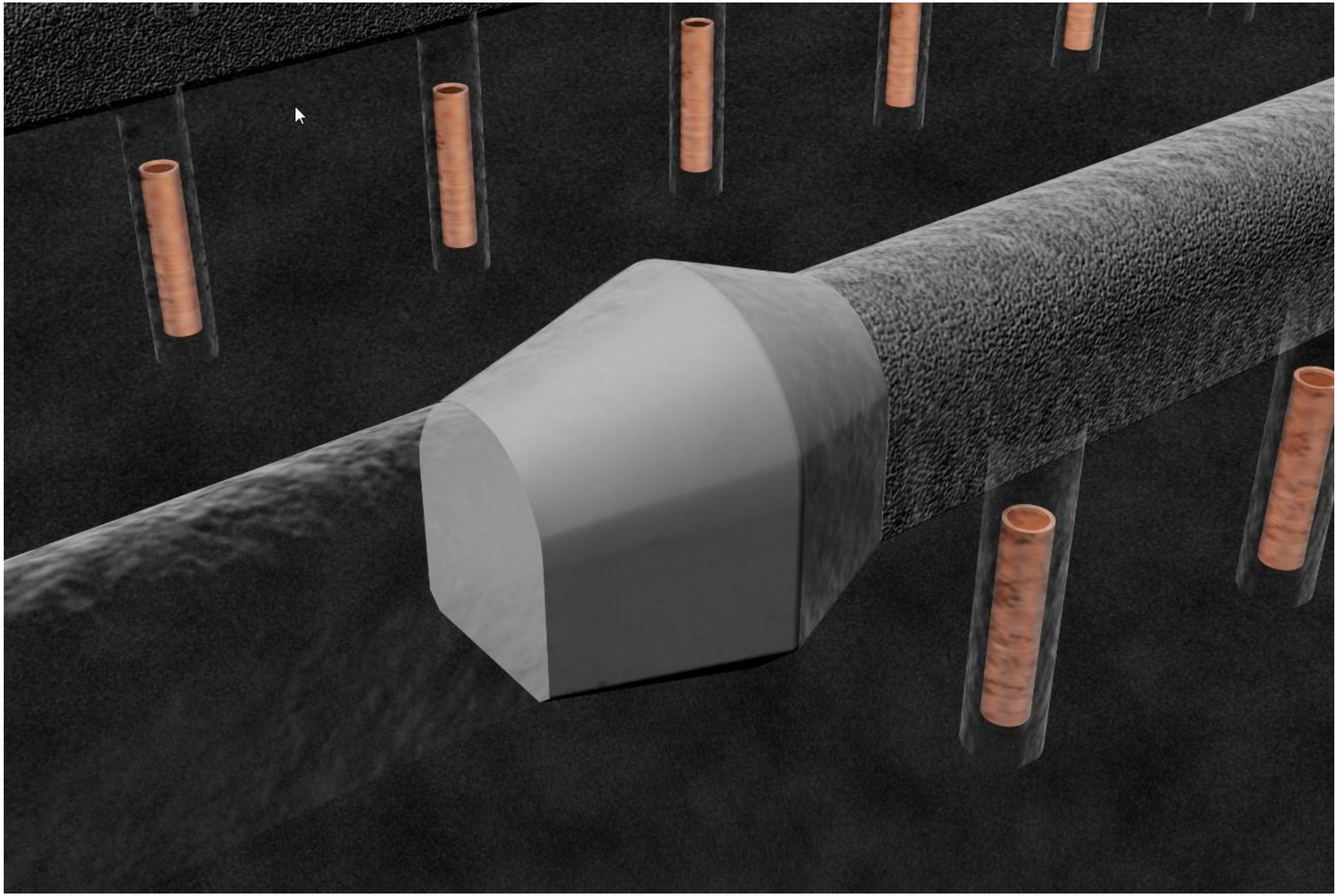
SKB's FUD Programme – Continuous Knowledge Building



Concept Development Programme

- **Based on the request of the Finnish Radiation and Nuclear Safety Authority (STUK), Posiva has collected the plans to solve open issues relating to the final disposal concept and the descriptions for testing and demonstration of the functionality of the disposal concept to Final Disposal Concept Development Programme**
- **The programme lists the requirements placed on each factor involved in the final disposal process, such as spent fuel, disposal canister, buffer, deposition tunnel backfill and end plug, and rock facilities**
- **The programme also presents plans for implementing full-scale testing in the underground rock characterisation facility ONKALO**
- **The programme describes the issues that are still open as well as the tests to be performed in order to solve them**
  - **Research, development and testing of the engineered barrier system**
  - **Deposition tunnel backfill and end plug**
  - **POPLU – full-scale deposition tunnel end plug test**

Role of the Deposition Tunnel End Plug



Role of the Deposition Tunnel End Plug and Safety Functions

- The long-term safety principles set out for the KBS-3 method are based on the use of a multi-barrier disposal system consisting of engineered barriers and host rock
- The roles of the barriers in establishing the required long-term safety of the repository constitute the safety functions of the barriers
- The closing structures of the deposition tunnels consist of backfill and end plugs with the following safety functions
  - Contribute to favourable and predictable mechanical, geochemical and hydrogeological conditions for the buffer and canisters,
  - Limit and retard radionuclide releases in the possible event of canister failure, and
  - Contribute to the mechanical stability of the rock adjacent to the deposition tunnels
- The safety functions are implemented in the proposed design through a set of technical design requirements, based on performance targets defined for the engineered barriers that they should meet in the long-term to provide the safety level needed

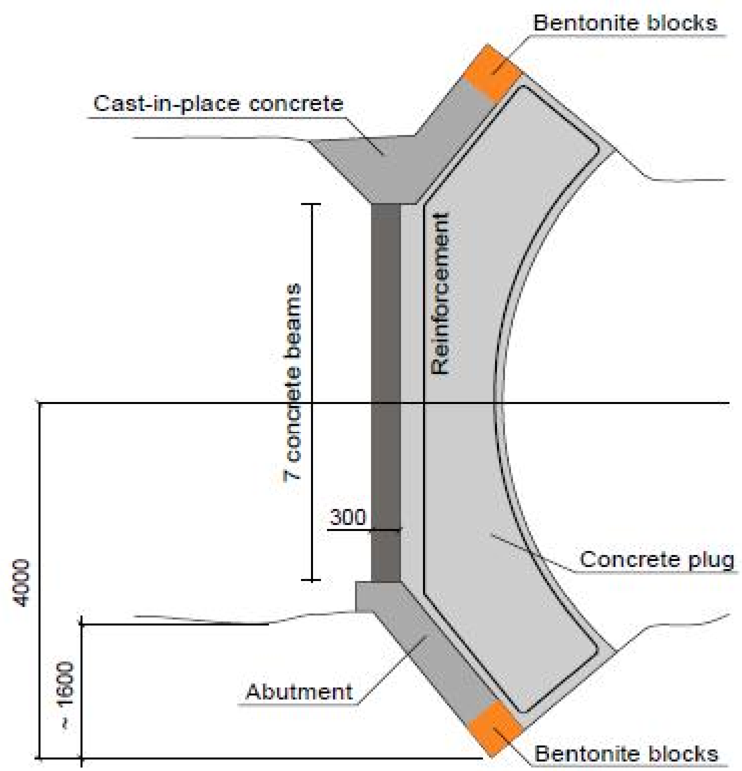
Requirements for the Deposition Tunnel End Plug

- **The technical design requirements of the engineered barriers are expressions of performance targets in a form that can be tested or otherwise proven at the stage of implementation through observations and measurements**
- **Design specifications are detailed specifications determined for the design based on the performance targets and design requirements**
- **The design specifications for the deposition tunnel end plug reflect the design of the plug that aims to provide sufficient structural stiffness and water tightness to ensure that the system performs as intended**
- **In the Concept Development Programme the fulfilment of the requirements set for the deposition tunnel end plug is discussed and the plan to show the fulfilment through development and testing is given**
  - Þ **POPLU and DOMPLU deposition tunnel end plug tests**

Previous Full-Scale Plug Tests

- **The need for a plug at the entrance of a deposition tunnel was recognised at an early stage of the KBS-method**
- **Different plug designs have been tested in previous full-scale experiments**
  - **Stripa mine tunnel plugging experiment in the 1980s**
  - **Backfill and Plug Test in 1999 - 2005 at Äspö HRL**
  - **Prototype Repository from 2001 onwards at Äspö HRL**
  - **Compartment plug test for the horizontal emplacement concept in 2005 at Äspö HRL and Grimsel**
  - **Tunnel Seal Experiment (TSX) in 1998 - 2004 at AECL's URL**
  - **Enhanced Sealing Project (ESP) from 2009 onwards at AECL's URL**

Backfill and Plug Test



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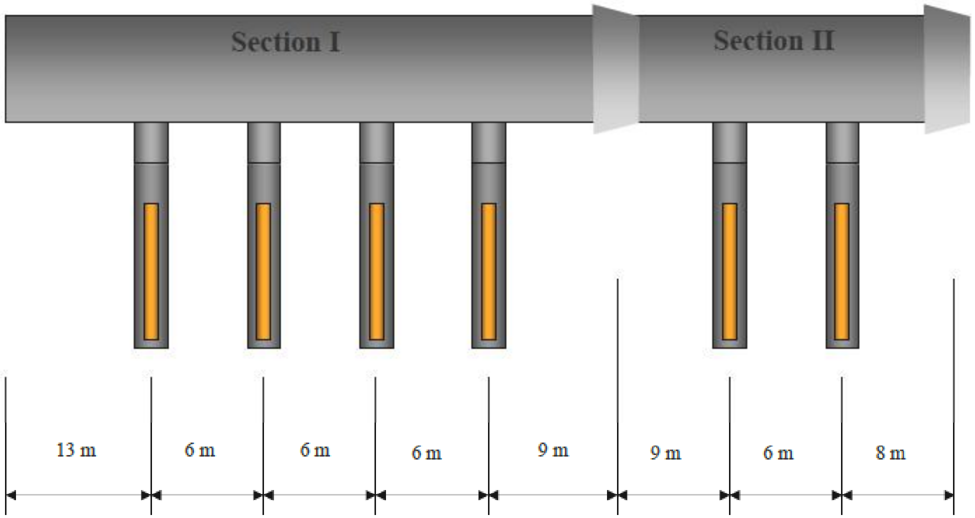
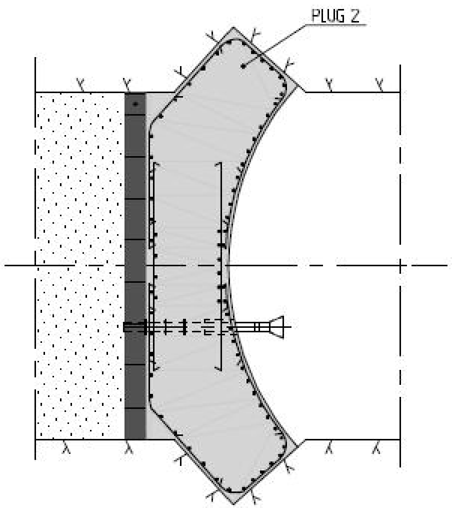
- **An O-ring made of bentonite blocks was introduced into the plug design after the Stripa Experiment**
- **The O-ring did not perform as intended, as leakage of water was found to be quite high**
- **The test was made as a preparation for the Prototype Repository (Euratom project)**

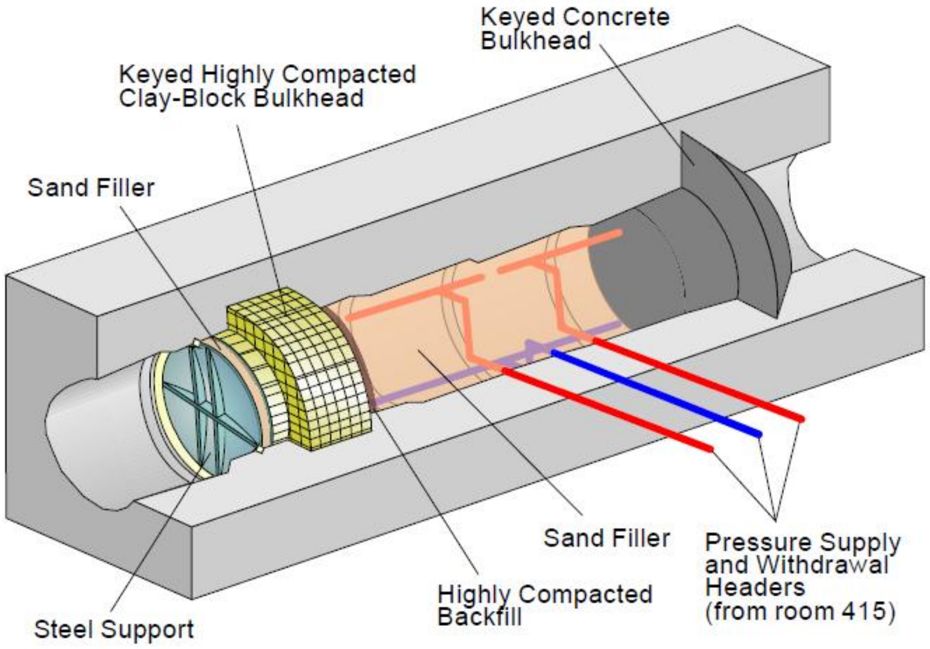
Prototype Repository





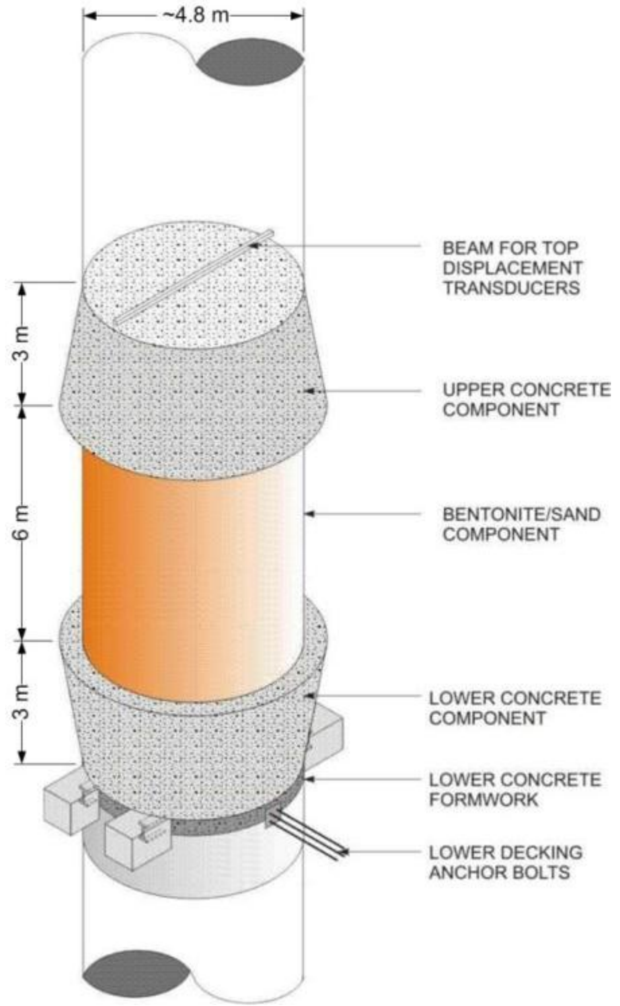
- **The Prototype Repository incorporated two plugs**
- **Unlike the previous experiments, both concrete plugs were cast with self-compacting concrete (SCC)**
- **Plug 2 was comprehensively instrumented to investigate its mechanical response to the pressure load**
- **Both plugs were contact grouted through pre-installed grouting tubes**

Tunnel Seal Experiment (TSX)



- **The concrete bulkhead was made of unreinforced low-heat high-performance concrete (LHHPC)**
- **The experiment also included a bulkhead composed of highly compacted sand-bentonite blocks**
- **The clay bulkhead provided an effective barrier to water transport and demonstrated the ability to close off existing flow paths and to self-seal**
- **The TSX also highlighted the importance of keeping joints and interfaces to a minimum and the effectiveness of contact grouting to reduce seepage between the concrete bulkhead and rock**

Enhanced Sealing Project (ESP)



- **The ESP consists of an instrumented, full-scale shaft seal, designed to permanently seal the access shaft to Atomic Energy of Canada Limited's (AECL's) URL**
- **The project was undertaken as part of the permanent closure of AECL's URL**
- **The seal consists of two concrete segments that sandwich a bentonite-clay-based unit limiting the mixing of deeper saline groundwater with shallower less-saline groundwater on a hydraulically active fracture zone**
- **The monitoring results are indicative of a system where the clay is effectively isolating the regions above and below the fracture feature**

Current End Plug Reference Design

- **The previous full-scale experiments have contributed into the development of the reference deposition tunnel end plug design**
- **The experiments have for example shown that the requirement of water tightness in combination with a concrete plug subjected to high pressure is a challenge**
- **The current reference design is the same for SKB and Posiva, and was developed based on a concept where the plug is divided into separate layers; filter, bentonite seal and low-pH reinforced concrete dome, each layer separated with delimiters**
- **The purpose of the bentonite seal is to aid in the water tightness of the plug by sealing water leakage paths through small cracks in the concrete plug or between the concrete and the rock surface**

Posiva's Current Reference: Dome plug (Posiva 2012-18) (= SKB Reference design, TR-10-16)

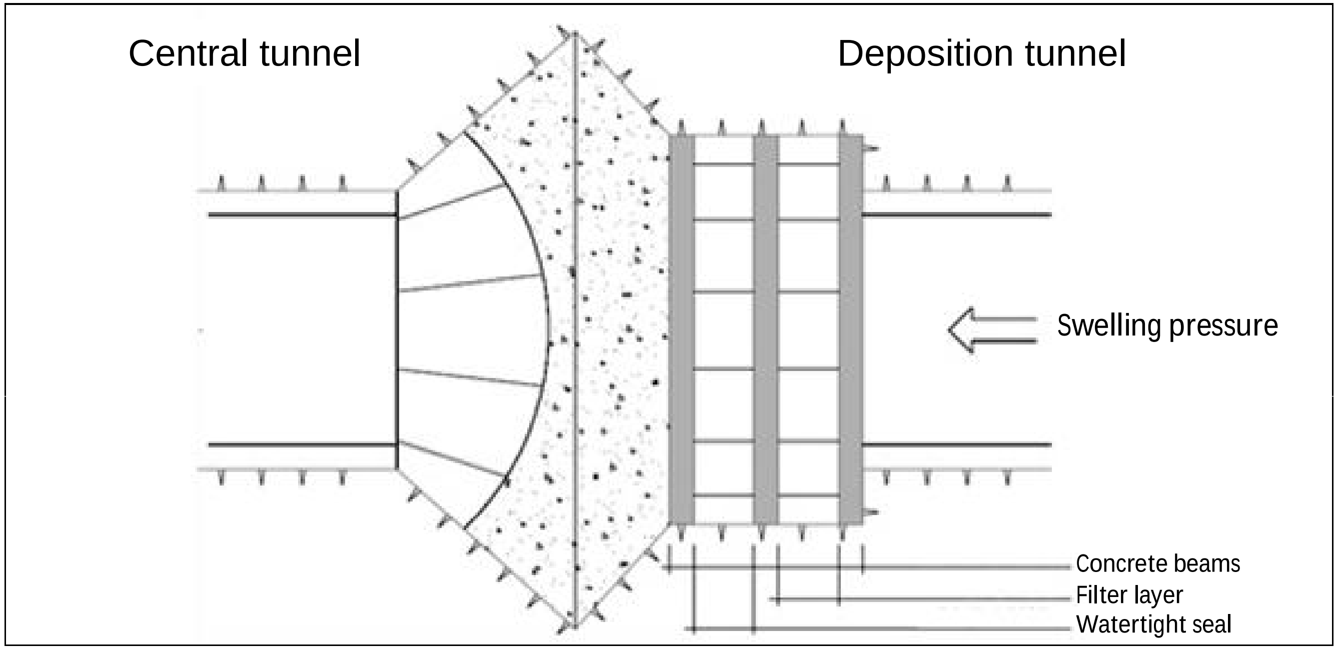


Figure 1. Posiva's dome plug, top view, as current reference design. [Posiva 2012a]

- **Filter: 750 mm crushed rock or permeable blocks, installed density ≥ 1900 kg/m^3**
- **Seal: 750 mm compacted MX-80, dry density ~1400 kg/m^3**
- **Delimiters: 300 mm wide (x 3) of concrete beams**

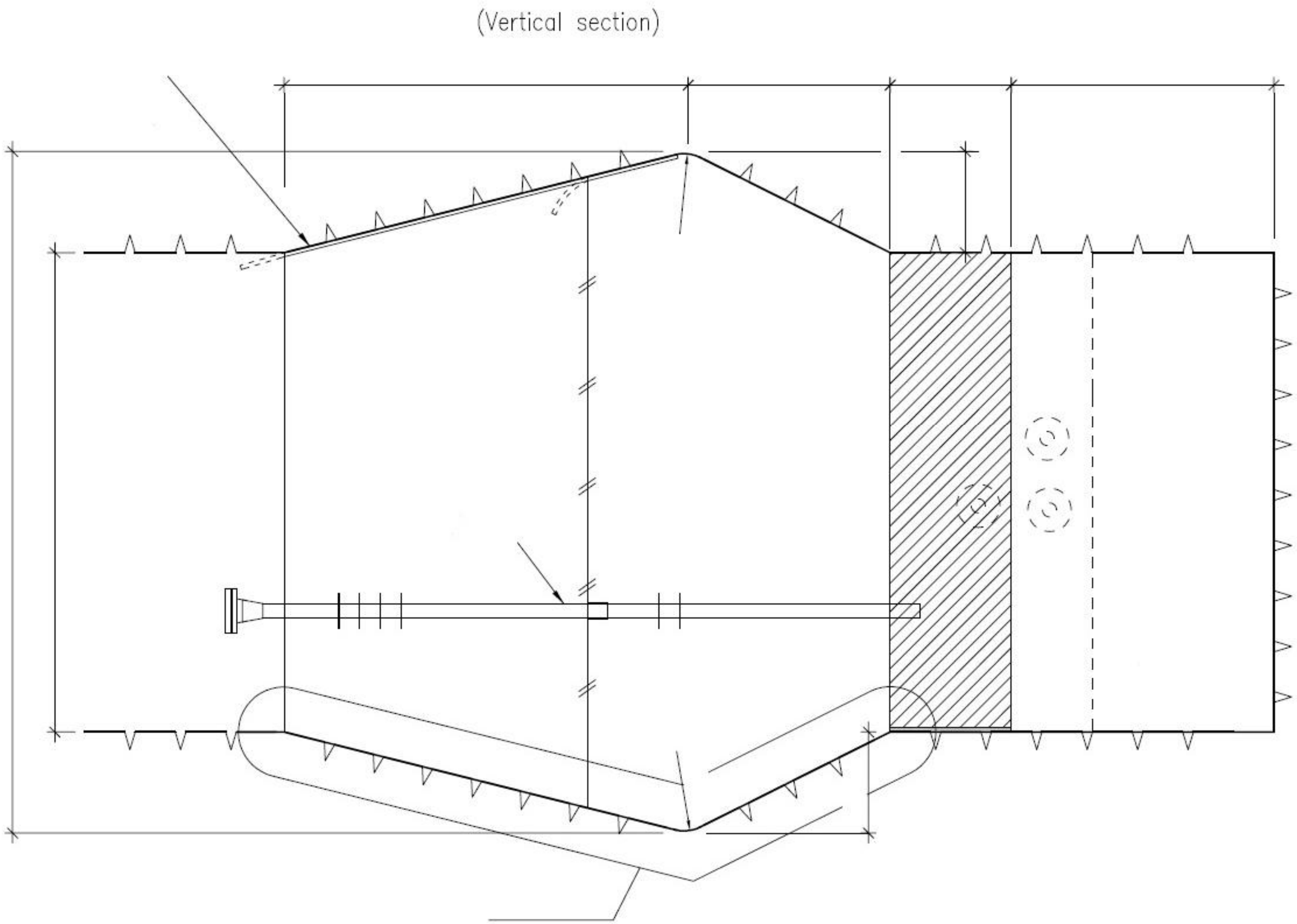
Current End Plug Experiment Designs

- The design of the plugs constructed and tested in the POPLU and DOMPLU experiments differ from the reference design
- The plug design used in the DOMPLU experiment is similar to the reference design with some modifications
  - use of unreinforced concrete instead of reinforced concrete for the concrete dome
  - two of the concrete delimiters have been replaced with other materials
  - the thickness of the watertight seal is 500 mm
  - the installed dry density of the filter is 1400 kg/m^3
- The modifications intent to test the performance of new materials planned to potentially be introduced as the reference design in the future, or to facilitate experiment implementation

Current End Plug Experiment Designs

- **The POPLU design is based on a different concept to that of the reference design**
  - **POPLU is a wedge-shaped low-pH reinforced concrete structure**
- **The idea is to demonstrate the performance of a simpler plug design that can potentially be used in a drier tunnel without high water inflows; such as the conditions in ONKALO**
- **By providing evidence that a simpler concrete structure with less components will perform as required, the plugging process could become more straightforward to implement**
- **After POPLU and DOMPLU experiments, there may be two options for the deposition tunnel end plug available during the implementation stage and possibly the wedge design might replace the dome design as Posiva's reference design**

Posiva Wedge Design

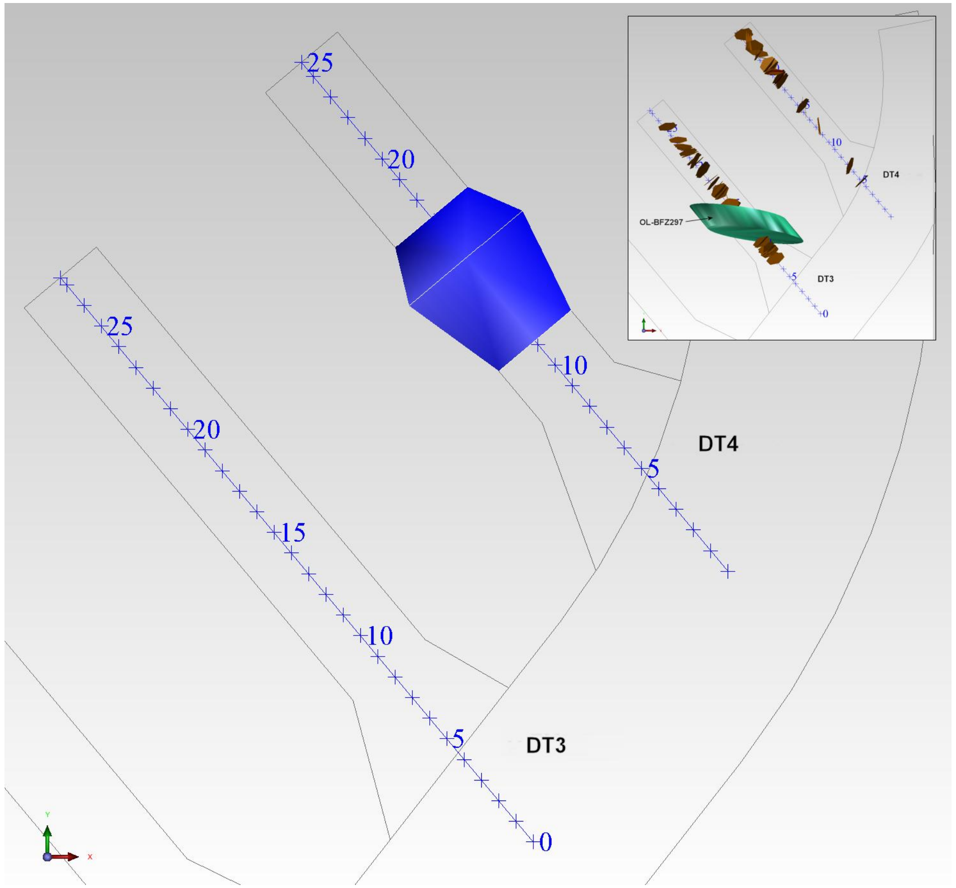


Full-Scale End Plug Experiments

- **If the developed plug design deviates from the previously tested plugs, the new concept must be tested in order to verify that it works in realistic conditions**
- **Performing the test in full-scale gives input on the construction feasibility of the design**
- **A full-scale test will also give valuable input on the water tightness of the plug in real or simulated water inflow conditions**
- **The experiences from full-scale experiments are very valuable to the design of future full-scale tests**

  Þ **e.g. Full-Scale In-Situ System Test (FISST)**

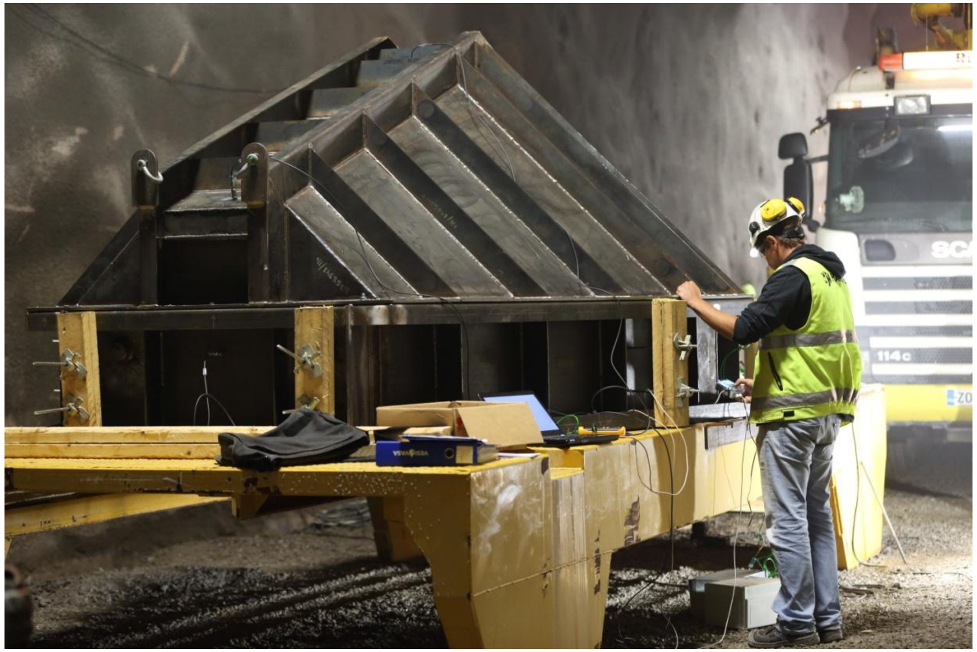
Experimental Design



- **Finding a suitable location for the experiment in crystalline rock requires the identification of suitable bedrock volumes to host the experiment**
  - **the criteria to select the bedrock volume is set so that it promotes the fulfilment of the requirements set for the experiment**
- **For POPLU, the Rock Suitability Classification (RSC) -system developed by Posiva was applied**
  - **it was used to verify the suitability of the plug demonstration tunnel locations and to select the location for the plug within the tunnels**
- **Also, the stability of the new demonstration tunnels was verified based on the objectives of the POPLU experiment (10 MPa)**

Experimental Design

- When performing experiments at the future repository there are more things to be considered compared to the URL
- These items include for example
  - regulatory authority control
  - safety classifications
  - possible method tests
  - quality control practices
  - approval cycles by the authority
  - foreign materials control



- It is of course beneficial to note all the above items when performing experiments at the URL to gain experience and maximum benefit from the experiment for the future
- It is highly important to decide in the planning phase of the experiment what are the items considered in the experiment e.g. approval cycles by the authority must be noted in the schedule

Experimental Design

- **Foreign materials control is an important aspect of the experimental design especially at the future repository such as ONKALO**
  - **Even if the materials used in the test components will be later removed from the site prior to repository operation, they have the potential to leave traces to the surrounding groundwater and bedrock environment**
  - **These traces could have an impact the to long-term performance and safety of the whole repository**
  - **It is thus very important to use materials that have been evaluated and allowed to use by the foreign materials approval**
  - **Any new materials introduced to the experiment must have the foreign materials approval before use in the experiment**

Experimental Design

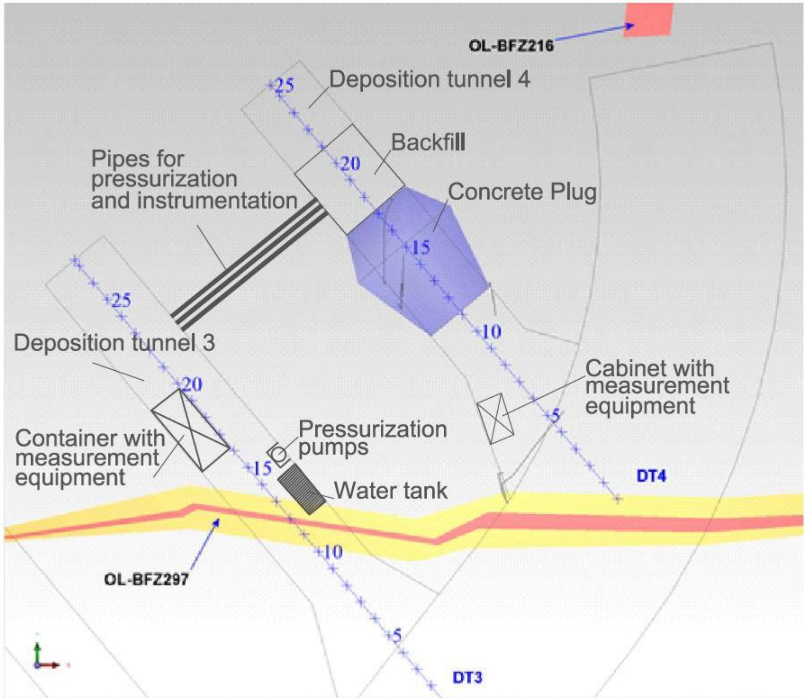
- **When the objective of the experiment is to develop components to repository operation, it must be evaluated that the components do not have harmful effects to the other components in the concept**
  - **High calcium content affects adversely to the swelling properties of bentonite**

    => low-pH concrete and contact grout
  - **Organics promote radionuclide transport when released**

    => use of e.g. plastics is strictly limited
- **When performing experiments at an URL it is also important to use the same materials as e.g. in real operational-phase plugs, to see that the initial state of the plug will be achieved with approved materials**
- **In the planning phase of the experiment the approval time and possible iteration rounds of new materials and the costs related to that must be noted, e.g. testing of concrete materials is time consuming**

Experimental Design

- **Monitoring of the experiment is useful for observing the behaviour and performance of the experiment**
- **Monitoring can however disturb the system so that the initial state of the component is not achieved**
- **It must be planned in the experimental design how and in what extent the monitoring of the experiment is done**



- **In the POPLU experiment e.g. following are needed for monitoring**
  - **81 sensors**
  - **monitoring tunnel**
  - **tunnel-to-tunnel lead-throughs**
  - **plug lead-throughs**
- **An example of the challenges in end plug monitoring is how to separate the three different types of leakage**
  - **through the concrete plug**
  - **in the contact between the concrete plug and the rock**
  - **passing the plug through the rock**

Forthcoming Development Work and Roadmap to Operation

- **POPLU and DOMPLU test results and experiences provide input for the plug development work**
- **Feedback by STUK to the reference design presented in the Construction Licence Application is taken note in the update of the Concept Development Programme and thus implemented in the development work**
- **Any modifications or iterations to the end plug design will be tested in the Full-Scale In-Situ System test (FISST)**
- **New evaluation round of the design is made after FISST and possible changes to the design are tested in the Joint Operating Test (JOT)**
- **The end plug design used in JOT is the design that has been approved for the actual repository operations**
- **The conclusions of JOT are needed for the Operating Licence**

SKB: Continued Development

- A new RD&D plan (FUD 2016)
- Buffer & backfill; Continued system tests e.g. manufacturing of clay components, verification of installation processes, handling of groundwater inflow during installation, quality management etc.
- Plugs; Opening and retrieval of DOMPLU in 2017
- Integrated system test at Äspö Hard Rock Laboratory 2018-2019; Excavation of 100 m tunnel, drilling of deposition holes, plug slot excavation, deposition of two full-scale dummy canisters, installation of buffer and backfill, plugging of the deposition tunnel

SKB: Continued Development

- **Governmental decision for the Swedish Spent Fuel Repository at Forsmark is expected in 2018. License conditions will be given in late 2019. (Note that the application was submitted in 2011!)**
- **Start of repository construction (ramp) in mid 2020**
- **Fully integrated system tests at the deposition area around 2027-2028**
- **Final functional testing from 2029**
- **Trial operation starts around 2031**

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Posiva's publications can be found at http://www.posiva.fi/en/databank

SKB's publications can be found at http://www.skb.com/publications

Abbreviations

TVO	**Teollisuuden Voima Oyj**
TEM	**Työ- ja elinkeinoministeriö,** **Ministry of Employment and the Economy in Finland**
STUK	**Säteilyturvakeskus,** **Radiation and Nuclear Safety Authority in Finland**
POPLU	**Full-scale deposition tunnel end plug test at ONKALO**
DOMPLU	**Full-scale deposition tunnel end plug test at Äspö HRL**
HRL	**Hard Rock Laboratory**
URL	**Underground Research Laboratory**
AECL	**Atomic Energy of Canada Limited**
FISST	**Posiva's Full-Scale In-Situ System test**
JOT	**Posiva's Joint Operating Test**

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